Working Memory and Learning

A 3-Year Longitudinal Study of Children Growing Up In a Multilingual Environment

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Fir meng Elteren

All that is valuable in human society depends upon the opportunity for development accorded to the individual.

- ALBERT EINSTEIN -

Abstract

This thesis presents the findings of a 3-wave, latent variable longitudinal study, exploring variations and the development of working memory in young children and its contributions to learning in the key domains of language, literacy, and mathematics. A sample of 119 Luxembourgish children, learning German and French as secondary languages, were followed from kindergarten to second grade and completed multiple assessments of working memory, short-term memory, phonological awareness, fluid intelligence, vocabulary, language comprehension, foreign language knowledge, reading, spelling, and mathematics.

Results indicate that relations between the measures were best characterized by a model consisting of two related but separable constructs - corresponding to short-term storage and a central executive - that were highly stable across the years. Whereas verbal short-term memory was more specifically linked to early language development and vocabulary in particular, the central executive appeared to support learning in a wide range of domains, including language comprehension, literacy, and mathematics.

The findings reinforce previous evidence indicating that verbal short-term memory is one of the main contributors to vocabulary development by supporting the formation of stable phonological representations of new words in long-term memory. Furthermore, the findings fit well with the position that the central executive makes general rather then specific contributions to learning - possibly in terms of an attentional control system that actively maintains crucial information and regulates controlling processes during complex cognitive activities. In conclusion, the findings indicate that different components of the working memory system can be reliably assessed in children as young as 5; that individual differences in these abilities are highly stable over time; and that working memory assessments are predictive of future learning in key academic domains. This reinforces the value of early screening of working memory abilities to identify children who are at a present and future educational risk.

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Author's declaration

I hereby declare that this thesis is the result of my own work. Material from the published or unpublished work of others is credited to the author in question in the text. The development of one of my measures (*TECOSY*) was completed in collaboration with Prof. Romain Martin from the University of Luxembourg.

The research referred to in this thesis has been presented at interdepartmental seminars of the department of Psychology of the University of York and at the following conferences:

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CHAPTER ONE

Introduction

Learning is one of the most important mental functions of humans, leading to the development of new skills, knowledge, and understanding. Although learning is a lifelong process, the most intense period of learning occurs during childhood. One of the major milestones in children's cognitive development is the understanding and production of spoken language that appears to occur naturally for most children. More structured learning takes place later on in life when the children enter school. The major goal of primary education, in most parts of the world, is to achieve basic literacy and numeracy amongst all pupils. In contrast to early civilisations in which schooling was reserved for an elite of people enjoying superior social or economic status, access to education in the modern society has increased dramatically over the past several decades and has been described as a fundamental human right since 1948 (United Nations, 1948). Success in school is often associated with success in society by providing people with the means to fully participate in their communities. Education has therefore a direct impact on the economic future and social well-being of all individuals.

Given the importance of education and learning on individuals and society as a whole, the crucial question to ask is therefore: How does learning occur? And more particularly: How do young children learn? These questions have been studied intensively for many years and have led to the conclusion that learning is not determined by a single underlying ability but that it is due to a confluence of factors. Access to formal education as well as a stimulating home or social environment provide children with the opportunity for learning to take place. In other words, it allows them to build up skills that are based on experience, also referred to as *crystallized knowledge*. In addition to environmental factors, learning is also constrained by basic cognitive abilities or *fluid cognition*. Two children growing up in a similar learning environment might differ considerably in their academic progress as a result of differences in their biologically based capacities to learn.

Environmental and cognitive factors interact in various ways and are consequently difficult to separate. It is, however, of great practical utility to be able to distinguish these factors as much as possible in order to identify a child's true "learning potential" and be able to provide appropriate remediation support in the case of educational difficulties.

One particular area of fluid cognition that has received major attention in recent years is *working memory*. Working memory (WM) can be seen as a mental workplace in which information can be stored while complex cognitive activities are carried out. Increasing evidence suggests that WM capacities play a key role in supporting children's learning over the school years and beyond this into adulthood (Gathercole, Lamont, & Alloway, 2006). Furthermore, assessments of WM have been found to be relatively independent of external factors such as socio-economic status (Engel, Santos, & Gathercole, 2008) or ethnic background (Campbell, Dollaghan, Needleman, & Janosky, 1997). Taken together, tests of WM appear to measure cognitive processes that are not explicitly taught but that underlie the acquisition of many important scholastic abilities. These measures might therefore provide a promising tool to separate between environmental and intrinsic factors that affect a child's learning progress.

Even though WM research has led to a better understanding of the cognitive underpinnings of learning, a number of questions remain unresolved: Is WM causally related to learning? - and - Why do WM tasks predict complex cognitive behaviour? are only some of the issues that are at the forefront of current research efforts. Individual difference research, involving large scaled, structural equation modelling studies, has addressed a certain number of these questions by shifting research conclusions from the level of observed variables to the theoretical constructs of interest. The work presented in this thesis is adopting this "macroanalytic" approach of studying individual differences at the level of latent variables (Engle & Kane, 2004). Its central goal is to advance understanding of WM variation in childhood and its consequences on learning.

The research presented in this thesis investigates the intrinsic factors that can affect learning. The main focus will be on WM in childhood, its development over time and, most importantly, its relationship with learning in the key domains of language, literacy, and arithmetic. The remaining of this chapter will provide an in-depth literature review on the relevant research findings in the area. As Pickering (2006) states: "The concept of working memory is both, reassuringly simple and frustratingly complex" (Pickering, 2006, p. xvi). The first part of this literature review will therefore focus on different WM models in the field, the structure of WM in childhood, and its distinction from short-term memory (STM). In a second part the relationship between WM/ STM and related cognitive abilities - phonological awareness and fluid intelligence - will be considered. The chapter will end with a discussion of pertinent research findings relating WM to learning.

1.1. Working memory: A theoretical framework

According to Baddeley (1997) human memory is defined as: "a system for storing and retrieving information that is… acquired through the senses" (Baddeley, 1997, p. 9). This definition seems to suggest that memory is a unitary system whose main function lies in bringing past information back to mind. An extensive amount of research in the area of cognitive neuropsychology, brain imaging, as well as childhood memory have, however, shown that despite the singularity of the term "memory", there is not one single memory store underpinning all mnemonic experiences but rather many separate systems that can function relatively independently of one another. These memory systems are distinctive both on the functional as well as the anatomical level, with different brain areas responsible for mediating the performance on different memory tasks (Nelson, 1995). In recent years, a number of different memory systems have been identified ranging from autobiographical memory to WM and differing from each other in terms of storage capacity as well as the type of information that is maintained. The following section is going to focus on the distinction between some of these memory systems, namely STM, long-term memory, and WM.

1.1.1. Short-term and long-term memory

One of the earliest distinctions between memory systems emerged in the 19th century with a separation between "primary" memory, with a limited capacity, and "secondary" memory corresponding to the large amount of information stored for a lifetime (James, 1890). The terms primary and secondary memory were later replaced by short and long-term memory[1]. STM refers to information that is temporarily held accessible in mind. Most researchers agree that it has a limited capacity, either in terms of units (or chunks) of information that can be retained (Cowan, 2000; Miller, 1956) or in terms of the lengths of time that an item can remain active (Baddeley, 1986). Long-term memory in contrast, is thought to have a wider capacity than STM and can hold vast amounts of information over hours, days, and even years. Although defenders of a unified memory theory remain (see Cowan, 2005 for a review), compelling experimental and neuropsychological evidence suggests that STM and long-term memory are separate: Some brain damaged patients present severe disruptions in the capacity to form lasting memories but manifest preserved performance on STM tasks (Baddeley & Warrington, 1970); others present the opposite pattern of deficits (Basso, Spinnler, Vallar, & Zanobio, 1982; Vallar & Shallice, 1990). The identification of these brain disorders, that selectively impair either short-term or long-term storage, together with considerable evidence from studies of normal subjects (Glanzer & Cunitz, 1966; Postman & Phillips, 1965) favour a dichotomous view of memory.

In their influential "two-store model" Atkinson and Shiffrin (1968) propose a distinction of a temporary short-term store and a more permanent long-term store (Figure 1.1.). A basic assumption of this model is that storage of information in the long-term store is determined by the amount of time information resides in the short-term store. Information in STM quickly fades unless it is refreshed through subvocal repetition, referred to as *rehearsal*. STM can therefore be seen as a workplace for long-term learning. Importantly, according to this model, an item has to pass through STM to be transferred into the long-term store and vice versa has to pass through STM in order to get out of long-term memory.

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[1] the terms primary and secondary memory have re-emerged in some contemporary memory theories (e.g., Unsworth & Engle, 2006).

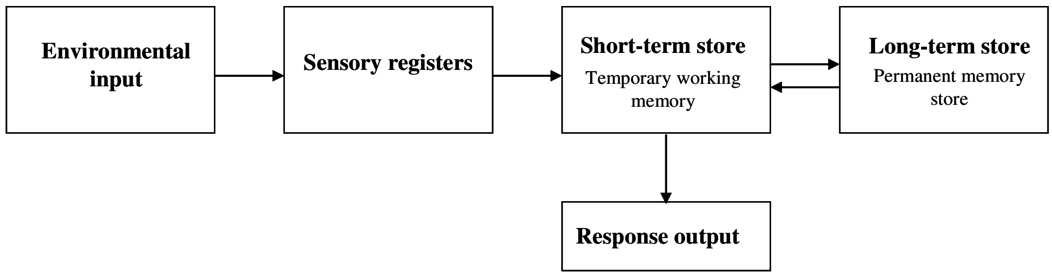

FIGURE 1.1. The flow of information through the memory system, based on Atkinson & Shiffrin (1968)

Although Atkinson and Shiffrin's model could account for a vast amount of observed results, it also ran into a number of problems: According to the model, patients presenting STM deficits should also manifest impairments in long-term learning. The existence of patients with normal long-term learning but impaired STM capacity (Shallice & Warrington, 1970) appeared to contradict this hypothesis. Another point that proved to be poorly supported by the model is the assumption that long-term learning is a function of the amount of time information is maintained in the short-term store (Bekerian & Baddeley, 1980; Nickerson & Adams, 1979).

1.1.2. Working memory

In the light of considerable evidence from developmental, experimental, and neuropsychological studies, the concept of a unitary short-term storage system was reformulated in terms of *working memory*. Working memory (WM) has been defined as: "a system for the temporary holding and manipulation of information during the performance of a range of cognitive tasks such as comprehension, learning, and reasoning" (Baddeley, 1986, p. 34). One of the most influential specifications of WM is provided by Baddeley and Hitch's (1974) multi-component model (revised subsequently by Baddeley, 2000).

Multi-component working memory model

According to this structural approach, WM consists of a limited capacity attentional control system, referred to as the *central executive*, that is supplemented by two passive storage buffers - the *phonological loop* and the *visuo-spatial sketchpad* -

holding information automatically and effortlessly (Baddeley & Hitch, 1974; Baddeley & Logie, 1999). In a more recent update of this model, the *episodic buffer* was added as a fourth component (Baddeley, 2000). The structure of the current WM model is represented in Figure 1.2.

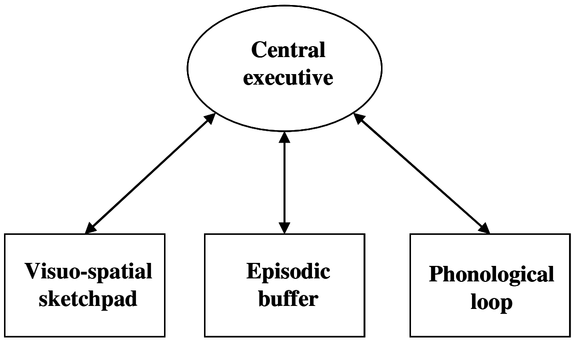

FIGURE 1.2. Simplified representation of the WM model, based on Baddeley, 2000.

The model assumes that verbal material is held in a rapidly decaying phonological form in the phonological loop that comprises two components: A passive phonological store that can hold speech based information for up to two seconds (Baddeley, 1986; Hulme & Mackenzie, 1992); and an articulatory control process that prevents decay in the store by reactivating the fading phonological representations via subvocal rehearsal (Baddeley, 1986). This subvocal rehearsal process is thought to operate in real time and is therefore equivalent to overt speech rate. Disrupting its proper functioning, by introducing an interference task for example, markedly impairs phonological loop functioning (Baddeley, 1990). Two properties of the phonological loop are particularly relevant for the present context: First, the number of verbal items that it can retain depends on the time taken to articulate them; and second, encoding in the loop is phonologically based (see Baddeley, 1997 for a review).

The second short-term storage system featured by the model is the visuo-spatial sketchpad. The current model of this subcomponent is less well advanced than the phonological loop model described above. The visuo-spatial sketchpad is thought to be responsible for the limited short-term storage of visual and spatial information. Like the phonological loop, it is suggested to consist of a passive temporary visual store and a more active spatial rehearsal process (Della Sala, Gray, Baddeley, Allemano, & Wilson, 1999). Importantly, research evidence has shown that tasks supposed to tap the visuo-spatial sketchpad also depend heavily upon the central executive (Alloway, Gathercole, & Pickering, 2006; Gathercole & Pickering, 2000a).

In contrast to the phonological loop and the visuo-spatial sketchpad, the central executive does not involve any storage. Many roles have been ascribed to this WM component including focusing, dividing, and switching attention, as well as linking WM with long-term memory (Baddeley, 1996). Whether or not it is a unitary system or is composed of different subcomponents, is open to debate (Baddeley, 2006; Miyake et al., 2000). The central executive is considered by many to be the core of WM (Baddeley, 2003; Torgesen, 1996), mainly because of its suggested role of controlling the other subsystems in a domain free manner.

The final component - the episodic buffer - is the most recent subcomponent of the model (Baddeley, 2000). It was added to the original model as a response to increasing evidence showing that STM span performance depends on information from long-term memory (Hulme & Mackenzie, 1992). The main difference to the three-component model (Baddeley & Hitch, 1974) is that functions previously ascribed to the central executive are now assigned to the episodic buffer. As such, the episodic buffer can be considers as a fractionation of the central executive (Baddeley, 2006). Like the phonological loop and visuo-spatial sketchpad (but in contrast to the central executive), it encompasses a storage function. One of its main roles is to integrate inputs from within WM and long-term memory, to form unitary multimodal representations. The detailed structure of the episodic buffer and methods of assessing its capacity have yet to be identified.

The basic tripartite WM model (Baddeley & Hitch, 1974) has had a major impact on WM research over the last three decades and remains one of the leading models in the field (Neath, Brown, Poirier, & Fortin, 2005). Alternative models have, however, been developing in recent years providing a slightly different view on the WM system.

Alternative models of working memory

Whereas the multi-component model bears a strong structural focus by separating WM into distinct components with different features, alternative WM theories emphasis functions and processes over structure. Other leading models in the field have conceptualized WM in terms of a subset of activated long-term memory units (Cowan, 2001; Engle, Kane, & Tuholski, 1999; Kane, Conway, Hambrick, & Engle, 2008; Unsworth & Engle, 2006).

In his influential theory, Cowan (1995) distinguishes between a subset of long-term memory that is temporally activated above some threshold and a subset of this activated memory that is in the *focus of attention* or conscious awareness (Figure 1.3.).

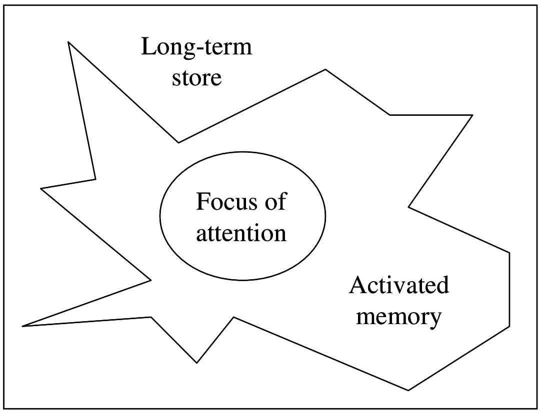

FIGURE 1.3. Simplified diagram of the relationship between memory faculties, based on Cowan (1995)

The focus of attention is controlled, in part at least, by the central executive (Cowan, 1997). It is though to be constrained in storage capacity, with a suggested limit of three to five separate units (or chunks) in normal adults. The capacity of the attentional focus corresponds to the *scope of attention* (Cowan, Fristoe, Elliott, Brunner, & Saults, 2006). One important feature of this model is that attention can be used for both the control and the storage of information. According to Cowan, tasks that make it difficult to apply attention in order to improve the encoding and maintenance of information should mainly reflect the scope of attention; i.e. the number of objects that can be held in the focus of attention at one time (Cowan et al., 2006).

A similar view has been proposed by Engle and colleagues (Engle, Kane et al., 1999; Engle, Tuholski, Laughlin, & Conway, 1999; Kane et al., 2008). In their model, they differentiate between WM as a broader system and WM capacity, which corresponds to just one element of the system - *controlled attention*. WM capacity (or controlled attention) is described as: "the attentional processes that allow for goal directed behaviour by maintaining relevant information in an active, easily accessible state outside of conscious focus, or to retrieve that information from inactive memory, under conditions of interference, distraction, or conflict" (Kane et al., 2008, p. 23).

Working memory: A working definition

Despite differences, most theories agree that WM comprises mechanisms devoted to the storage of information and mechanisms for cognitive control (controlled attention or the central executive, in the respective models). WM is thus best described as a system for holding and manipulating information over brief periods of time, in the course of ongoing cognitive activities. Its main function can be defined as the maintenance of memory representations in the face of concurrent processing, distraction, and/or attention shifts (Baddeley & Hitch, 1974; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Engle, Tuholski et al., 1999). In simple words: WM can be seen as *memory at work* in the service of complex cognition (Kane et al., 2008).

1.1.3. Working memory and short-term memory

As outlined above, the relationship between STM and WM is differently described by various theorists, but it is generally acknowledged that the two concepts are distinct (Baddeley & Hitch, 1974; Conway et al., 2002; Cowan, 1995; Engle, Tuholski et al., 1999; Just & Carpenter, 1992). According to the dominant position in the field, STM is conceived as a passive holding device (or set of devices), and WM is the combination of that holding device along with attentional processes that control it (Baddeley & Logie, 1999; Engle, Kane et al., 1999).

Engle and colleagues (Engle, Kane et al., 1999; Engle, Tuholski et al., 1999) have specified the relationship between WM and STM via the following formula:

Working memory = short-term memory + controlled attention
(Engle, Tuholski et al., 1999, p. 313)

In the Baddeley and Hitch model (1974), STM is consistent with the two slave systems, phonological loop and visuo-spatial sketchpad. Within this model, the storage demands of WM tasks are suggested to depend on their appropriate subsystems (i.e. phonological loop or visuo-spatial sketchpad), whereas processing as well as the ability to coordinate the processing and storage operations is principally supported by the central executive (Baddeley & Logie, 1999; Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002).

It is worth pointing out that in both theoretical accounts (Baddeley & Logie, 1999; Engle et al., 1999a, 1999b) STM appears as a sub-system of WM. According to these positions the main difference between STM and WM lies in the assumption that the latter involves attention or the central executive. What distinguishes WM from STM therefore seems to be only indirectly about memory.

Measuring WM and STM: Complex and simple span tasks

WM is usually evaluated by complex memory span tasks that involve the simultaneous storage and processing of information (Daneman & Carpenter, 1980). An example of such a task is counting span, in which participants are asked to count target items in successive arrays and to recall the number of items of the arrays in the right sequence (Case, Kurland, & Goldberg, 1982). A wide variety of complex span measures have now been developed (Kyllonen & Christal, 1990; Turner & Engle, 1989). What most of these tasks have in common is their dual task requirement in which the to-be-remembered items are interleaved with some form of distracter task, such as solving mathematical operation, reading sentences, or counting.

These complex span measures stand in contrast to simple span tasks that generally require just the preservation of sequential order information with no explicit concurrent processing task (Hutton & Towse, 2001). A classic example of a verbal STM span task is digit recall, involving the immediately recall of short list of digits.

Figure 1.4. presents an example of a simple and a complex span task (digit span and counting recall) with the same to-be-remembered stimuli.

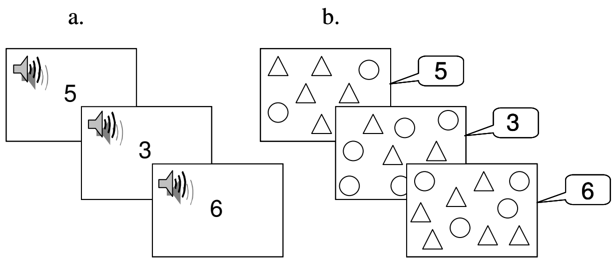

FIGURE 1.4. Examples of (a) a simple span task (auditory digit span), in which serially presented material has to be recalled, and (b) a working-memory span task (counting recall), in which the subject has to count the triangles at the same time as remembering the number of triangles counted on each array for later recall.

Although complex and simple span tasks have been extensively used and studied in recent years (Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Colom, Shih, Flores-Mendoza, & Quiroga, 2006; Conway et al., 2002; Unsworth & Engle, 2006), it is still far from clear what they really measure (Baddeley, 2006). The main difficulty in attempting to tease apart the factors that contribute to performance on these measures lies in the problem of collinearity. As Engle and colleagues point out, no one task is a pure measure of either STM or WM. Instead all immediate memory tasks are complex and determined by many factors (Conway et al., 2002; Conway, Jarrold, Kane, Miyake, & Towse, 2008; Engle, Tuholski et al., 1999). Even a seemingly simple task, such as digit recall that is assumed to place heavy demands on verbal STM, might involve some contribution from the central executive; especially as the length of the to-be-remembered sequences increases (Baddeley, 2006; Unsworth & Engle, 2006). Considering STM tasks as reflecting only temporary storage with no executive involvement therefore seems overly simplistic. In the same way, complex span tasks involve simple storage in addition to their processing requirements (La Pointe & Engle, 1990). Simple and complex span measure therefore most likely involve both storage and executive attention but to different degrees: Complex span tasks might primarily reflect executive attention and secondary storage and rehearsal processes, whereas it might be the opposite for simple span measures, reflecting storage and rehearsal skills primarily and executive attention processes only secondarily (Kane et al., 2004).

Latent variable analysis offers a promising solution to the above described task purity problem. A latent variable consists of the variance that several tasks have in common, thus provides a "purer" index of the hypothesized underlying construct of interest. This statistical technique has been applied in a range of studies on adults (Conway et al., 2002; Engle, et al., 1999b; Kane, et al., 2004), showing that complex span measures share substantial variance with simple span tasks, but that these tasks also reflect some unique variance. According to the theoretical framework presented above (i.e. WM = STM + controlled attention), the shared variance should conceptually reflect the short-term storage component, and the residual variance should correspond to controlled attention or the central executive.

Although many latent variable studies have concluded that simple and complex span tasks load on distinct factors, interpreted as STM and WM respectively (Alloway et al., 2006; Alloway, Gathercole, Willis, & Adams, 2004; Conway et al., 2002; Engle, Tuholski et al., 1999; Kane et al., 2004), the question of whether or not STM and WM task tap distinctive theoretical constructs has re-emerged in recent years. In their study, Colom and colleagues (2006) assessed 403 adults on a vast array of simple and complex span measures. Their results showed that simple and complex span tasks shared largely overlapping underlying capacity limitations, leading the authors to conclude that all memory span tasks essentially tap the same construct (see also Colom, Abad, Quiroga, Shih, & Flores-Mendoza, 2008 for similar findings). Furthermore, in their recent re-analysis of five key latent variable studies (Bayliss, Jarrold, Gunn, & Baddeley, 2003; Conway et al., 2002; Engle, Tuholski et al., 1999; Kane et al., 2004; Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001), Colom and colleagues failed to find empirical support for the view that simple span tasks are distinguished from complex span tasks (Colom, Rebollo, Abad, & Shih, 2006). The re-analysis of the Kane et al. (2004) dataset for example, revealed a correlation of .99 between the supposed WM and STM constructs. The authors acknowledge, however, that although simple and complex span task share most of their variance, specific sources of variance are also present (Colom et al., 2006).

Working memory and short-term memory in children

STM and WM abilities have been shown to increase markedly over the childhood years (Case et al., 1982; Cowan, 1997; Gathercole, 1999; Towse, Hitch, & Hutton, 1998). Different explanations for this boost in memory performance have been put forward. Increases in verbal STM have been attributed to changes in: basic perceptual analytic abilities (Bowey, 1996; Metsala, 1999); the construction and maintenance of memory traces in phonological storage (Gathercole & Baddeley, 1993); retention of order information (Brown, Vousden, McCormack, & Hulme, 1999); subvocal rehearsal (Gathercole & Hitch, 1993); retrieval processes (Cowan et al., 1998); the reconstruction of memory traces (Roodenrys, Hulme, & Brown, 1993) - only to name a few.

Possible sources for developmental changes in WM involve more efficient processing (Daneman & Carpenter, 1980; Fry & Hale, 2000); increased attentional capacity or a more effective control of attention (Engle, Tuholski et al., 1999; Swanson, 1999); and improved task switching abilities (Barrouillet & Camos, 2001; Towse et al., 1998). In a recent study, Bayliss and colleagues have found that developmental improvements in complex span task were driven by processing speed and basic storage abilities, suggesting that both factors contribute significantly to the development of WM performance (Bayliss, Jarrold, Baddeley, Gunn et al., 2005; see also Bayliss et al., 2003). Importantly, these studies also identified a separate component of complex span tasks that was independent of storage and processing capacity; what this component represents is not yet clear. The authors speculate that this factor might reflect the executive costs of coordinating the processing and the storage aspects of the task (Bayliss et al., 2003; Jarrold & Bayliss, 2008). This hypothesis is in line with a recent study by Swanson (2008), having identified controlled attention in addition to STM as an important contributors to WM span performance in 6- to 9-year-olds. In summary, developmental changes in STM and WM performance seem to be multiply determined, reflecting complex changes in various processes, many of which might occur in parallel.

One area that potentially underlies developmental change in WM and has received increased interest in the literature is subvocal rehearsal. As outlined previously, rehearsal is suggested to prevent decay by reactivating fading traces in STM (Baddeley, 1986). Exactly when children start to make use of subvocal rehearsal processes has been widely debated (for a review see Gathercole & Hitch, 1993). Initially it was proposed that rehearsal does not emerge until about 7 years of age (Flavell, Beach, & Chinsky, 1966). This view has, however, been challenged by studies showing that children as young as 4 appear to subvocally rehearse auditory presented items in memory span tests (Hitch & Halliday, 1983; Hulme, Thomson, Muir, & Lawrence, 1984) - yet again this position has been called into question by others (Gathercole, Adams, & Hitch, 1994; Gathercole & Hitch, 1993). Given the seemingly contradictive evidence in the area, it appears more likely that rehearsal in children is not an all-or-nothing process. This position has now been embraced by many researchers, and the overall consensus seems to be that children engage in some rudimentary form of rehearsal before 7 years of age that might, however, be less efficient (Hulme et al., 1984) or qualitatively different from that in adults (Gathercole, et al., 1994; Gathercole & Hitch, 1993).

Most importantly for the present context is that, given the above presented evidence, rehearsal strategies are likely to be less automatized and subsequently more effortful in young children then in adults. STM task, that are thought to involve this strategy, might therefore be more attention demanding for children than for adults and consequently call in resources of the central executive (Engle, Tuholski et al., 1999). Rehearsal is, however, not the only strategy that is thought to contribute to accurate recall in STM tasks. Other cognitive processes, such as grouping skills (i.e. chunking) and coding strategies, have been suggested to support STM performance and, as for rehearsal, have been found to be less routinized in children (Cowan, 1995). This has lead to the proposal that STM and WM tasks should be more closely associated in children then in adults, with both type of measures mainly reflecting the ability to control attention (Engle et al., 1999b) or the scope of attention as suggested by Cowan (Cowan et al., 2005). Some evidence exists in favour of this position: In their study on 8- and 11- year-olds, Hutton and Towse (2001) found via a principal components analysis that WM and STM tasks loaded on the same factor. Furthermore, relations between WM and STM with reading, number skill, and fluid intelligence were found to be of a similar magnitude. Theses results were, however, based on observed rather than latent variables.

In contrast to research on adults, only a handful of studies have addressed relationships between STM and WM at the level of latent variables in young children. The few studies that exist generally conclude that measures of STM and WM tap distinct but associated underlying constructs (Alloway et al., 2006; Alloway et al., 2004; Gathercole & Pickering, 2000a; Gathercole, Pickering, Ambridge, & Wearing, 2004; Kail & Hall, 2001; Swanson, 2008). In a recent study investigating the organization of WM in children from 6 to 15 years of age, Gathercole et al. (2004) found that a model in which complex and simple span measures loaded onto different factors fitted the data significantly better than a model in which both type of tasks were linked to a common construct. Importantly, this model was found to be highly stable across this developmental period (for similar findings see Alloway et al., 2006; Swanson, 2008,). Another study showed that WM and STM can be separated in children as young as 4 years of age (Alloway et al., 2004).

Interestingly, the magnitude of the correlations between measures of verbal STM and WM increased from .58 for the 4- to 6-year-olds (Alloway et al., 2004) to .73 for the 6-to 7-year-old group and .92 for the 10- to 12-year-olds (Gathercole et al., 2004). Corresponding high correlations between verbal STM and WM were found in a population of 11- and 14-year-olds (Jarvis & Gathercole, 2003), suggesting that the underlying two-factor structure is less distinct in older than in younger children. This seems to contradict the position of Engle and colleagues (Engle et al., 1999b, see also Cowan et al., 2005) and the findings of Hutton and Towse (2001) that assessments of STM and WM should reflect more common variance in young children then in adults. Gathercole et al. (2004) propose that developmental increases in processing efficiency might lie at the root of the observed strong links between measures of STM and WM in older children. According to this account, the processing demands of the complex span tasks used in the above presented studies (Alloway et al., 2004; Jarvis & Gathercole, 2003) might not have been sufficiently demanding enough, thereby rendering these tasks more similar to STM measures. Furthermore, the authors argue that strong links between STM and WM might have been observed because: “the central executive’s identification was based on tasks that are constrained by phonological loop capacity” (Gathercole et al, 2004, p.188). It is, however, worth pointing out that although STM and WM were highly related in these studies, they were not equivalent constructs.

1.1.4. Working memory, short-term memory, and long-term memory

Although most theories view WM and STM as functionally distinct from long-term memory (Baddeley, 1986; Cowan, 2008), it has become increasingly clear that both are deeply connected with long-term knowledge (Baddeley & Logie, 1999; Bjorklund & Douglas, 1997).

Influences of long-term memory on working memory and short-term memory

Substantial evidence has accumulated showing that short-term and working memory span tasks are influenced by people's knowledge base for the to-be-remembered material - in other words by their long-term memory (Dempster, 1978; Gathercole, 1995b). Miller (1956) has discussed long-term memory implications in STM performance in terms of *chunking*, by which items are bound together on the basis of established knowledge. It is for example harder to recall a list of unrelated letters (e.g. BSG-TRN-PKL) than a list of letters that can form meaningful chunks (e.g. ABC-IBM-DNA). In the latter case long-term memory can aid task performance.

Another important demonstration of long-term memory contributions to STM task performance is provided by the *lexicality effect* - the greater difficulty of remembering nonwords as compared to real words in a serial recall task (Hulme, Maughan, & Brown, 1991). Hulme and colleagues (1991) propose a *redintegration* process to explain this finding. According to this account stored knowledge of the phonological form of words supports the retrieval of partially decaying words in STM. Since no long-term lexical representations for nonwords exist, they can not be redintegrated and their accurate recall is therefore diminished (Hulme et al., 1991; Roodenrys et al., 1993). In a series of experiments, Gathercole and colleagues (Gathercole, 1995b; Gathercole, Frankish, Pickering, & Peaker, 1999; Gathercole, Willis, Emslie, & Baddeley, 1992) demonstrated that the redintegration process does not just operate at the lexical level, as originally believed, but also at the sublexical level. In a key study, they designed two sets of English sounding nonwords (Gathercole et al., 1991), judged as high versus low wordlike by native English speakers. Their findings showed that performance was significantly better for the repetition of the high worldlike nonwords (see also Gathercole, 1995). Implicit knowledge of the phonotactic frequencies - i.e. knowledge of frequent sound combinations within a language - might be used to automatically reconstruct the decaying memory traces in verbal STM at retrieval and thereby enhance performance in STM tasks involving high wordlike nonwords. An alternative explanation is that knowledge of phonological rules within a language allows one to group individual phonemes within a nonword into larger multiphonemic chunks. Larger amounts of material can therefore be stored in STM because more items are incorporated into each individual chunk (Cowan, 1996).

In summary, findings on the lexicality and the wordlikeness effect have established that long-term lexical and sublexical knowledge about the sound structure of a language make a significant contribution to STM performance for both familiar lexical stimuli and familiar sound combinations in nonwords. Importantly for the present context, these findings clearly demonstrate that caution needs to be taken when interpreting the performance on WM and STM tasks, especially in children for whom the general knowledge base in many areas is often poorly developed. Low scores on these tasks might therefore reflect, in part at least, weak support from long-term memory (Gathercole & Pickering, 2000).

Influences of working memory and short-term memory on long-term memory

It is not only long-term memory that influences STM and WM performance, but most importantly WM also affects long-term memory. In a seminal study, Hebb (1961) has shown that the repetition of a sequence of digits on every third trial markedly improved the serial recall of that particular digit sequence compared to non-repeated sequences. Over multiple exposures, the temporal retention of a sequence of digits therefore seemed to have created a representation of the digit sequence in long-term memory or, in other words, long-term learning had occurred. Although the exact nature of the Hebb effect remains a topic of debate (Couture & Tremblay, 2006; Mosse & Jarrold, 2008), the study clearly demonstrated a relationship between short-term recall and long-term learning.

Over the last years a substantial amount of evidence has accumulated exploring the contributions of WM to long-term learning. Researchers widely agree that WM plays an important role in the process of creating durable codes or representations in long-term memory (discussed in more detail in section, 1.3., p. 48). The impact of WM might be particularly important during the initial stages of learning, before stable organizational structures or schemas are in place. Once an individual has acquired substantial knowledge, long-term representational structures have been created and encoding of new conceptual information might therefore only involve rearranging and adding the new information to already existing schemas in long-term memory (Dehn, 2008).

Taken together, WM, STM, and long-term memory appear to have reciprocal influences on each other that are generally difficult to separate. The different memory systems seem to operate in a highly interactive fashion with long-term knowledge being used to enhance STM and WM performance, and WM and STM facilitating the building and retrieval of long-term structures.

1.2. Working memory, short-term memory and related cognitive processes

WM and STM have been closely linked to many cognitive processes including attention, processing speed, executive functioning, fluid reasoning, and phonological awareness (Alloway et al., 2004; Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Colom et al., 2008; Conway et al., 2002; de Jong & van der Leij, 1999; Engle, Tuholski et al., 1999; Swanson, 2008). Some of these processes are so intertwined with WM that it is often difficult to separate them from it. Different reasons for theses close links can be proposed: First it is possible that some cognitive processes directly affect working memory efficiency. Fast processing speed might, for example, enhance WM performance. Another possibility is that WM capacity constrains related cognitive functions that in themselves might not necessarily involve the retention of information. Finally, the relationship could be mediated by a third factor that affects both WM and the cognitive process in question. Unfortunately, it is often difficult to distinguish between these alternative accounts regarding the nature of the relationship between WM and associated cognitive skills. Most likely the influences are reciprocal: WM might contribute to related cognitive functioning and in turn various cognitive processes might support WM performance.

In the following sections two specific cognitive processes and their relationship with WM and STM are going to be reviewed - phonological awareness and fluid intelligence. Both factors have been found to make significant contributions to learning and are therefore directly relevant to the discussion at hand.

1.2.1. Fluid intelligence

Fluid intelligence has been defined by Cattell (1971) as: “an expression of the level of complexity of relationships which an individual can perceive and act upon when he does not have recourse to answers to such complex issues already sorted in memory” (Cattell, 1971, p. 99). In other words, fluid intelligence can be thought of as the ability to reason under novel conditions and stands in contrast to performance based on learned knowledge and skills or *crystallized intelligence* (Haavisto & Lehto, 2005; Horn & Cattell, 1967). Fluid intelligence is generally assessed by tasks that are nonverbal and relatively culture free. These tests are thought to reflect a person’s intellectual potential and therefore measure a more general dimension of intelligence than is tapped by tasks of crystallized intelligence (Luo & Petrill, 1999).

Working memory and fluid intelligence in adults

Many studies have shown that in adults, fluid intelligence and WM are highly related (Colom, Flores-Mendoza, & Rebollo, 2003; Conway et al., 2002; Cowan et al., 2005; Engle, Tuholski et al., 1999; Kane et al., 2004). Some even suggest that WM and fluid intelligence are unitary constructs. Although some evidence for this isomorphism exists (Buehner, Krumm, & Pick, 2005; Colom, Escorial, Shih, & Privado, 2007; Kyllonen & Christal, 1990), the general consensus is that WM and fluid intelligence are not identical factors despite their extremely close relationship (see Ackerman, Beier, & Boyle, 2005 for a review).

In a key latent variable study, Engle and colleagues (1999b) have found that WM, verbal STM, and fluid intelligence were highly related but separate constructs. Most importantly, the study showed that when the variance common to the STM and the WM latent variables was removed, the WM residual factor was related to fluid intelligence, whereas STM was not. The authors interpreted these findings as suggesting that controlled attention (reflected by the WM residual) is responsible for the relationship between WM and fluid intelligence. Similar results were obtained in two independent latent variable studies by Conway et al. (2002) and Kane et al. (2004), showing that WM, but not verbal STM, predicted individual differences in fluid intelligence. These findings provide further support to the position that the executive demands rather then the storage component of WM span tasks are the source of the link with fluid intelligence.

Although the findings of these latent variable studies seemed robust, they have recently been called into question: Colom and colleagues (Colom, Rebollo et al., 2006) have shown that when subjecting the three data sets (Conway et al., 2002; Engle et al., 1999b; Kane et al. 2004) to the same latent model, with all of the measures loading on the STM factor but only the complex span measures loading onto WM, individual differences in fluid intelligence were predicted by both STM and WM. Furthermore, they found that in two out of the three studies in question (Engle et al., 1999b; Kane et al., 2003), STM was actually a better predictor of fluid abilities than WM. They confirmed these findings in several other studies (Colom et al., 2008; Colom, Abad, Rebollo, & Shih, 2005; Colom, Flores-Mendoza, Quiroga, & Privado, 2005) leading them to conclude that STM storage largely accounts for the relationship between WM and fluid intelligence.

Working memory and fluid intelligence in children

In contrast to adults, not many studies have focused on the relationship between WM and fluid intelligence in children (see Fry & Hale, 2000 for a review). The few studies that exist generally agree that WM and fluid intelligence are strongly related but distinct constructs (Alloway et al., 2004; Fry & Hale, 1996). Most of these studies fail, however, to distinguish between STM and controlled attention (or the central executive) and thereby do not address the question of whether WM as a short-term storage system or as an attentional mechanism is making significant contributions to children's fluid intelligence. There is some evidence that the latter position might be more appropriate. In a recent latent variable study on children, ranging from 6 to 9 years, Swanson (2008) found that when controlling for the correlations between WM and STM, the residual variance for the WM factor, but not

STM, predicted fluid intelligence. A similar result was obtained in a study by Bayliss and colleagues (2005) on 6-, 8-, and 10-year-olds. In contrast to the Swanson study, it was found that not only WM but also STM accounted for unique variance in fluid intelligence. In a study on 7- to 9-year-olds the WM residual was, however, not associated with fluid intelligence (Bayliss et al., 2003).

Measures of general fluid intelligence are widely accepted as good predictors of learning ability (see Kline, 1990 for a review). As fluid intelligence tasks are also highly related to measures of WM, the possibility arises that fluid intelligence is the key factor underlying the relationship between WM and learning. Alternatively, it might be that both abilities are linked to learning because of their shared controlled attention requirements, as suggested by Engle et al. (1999b). It is therefore important to explore whether WM and fluid intelligence are dissociable, and foremost to determine if both abilities can be distinguished in terms of their contributions to learning. Some evidence in the literature suggests that this might be the case. In their study, Gathercole, Alloway, Willis, and Adams (2006) have shown that specific links between WM and scholastic attainment persisted even after fluid intelligence had been taken into account (see also Swanson & Sachse-Lee, 2001). Luo, Thompson, and Detterman (2006) found that fluid ability measures did not add much more to scholastic achievement beyond processing speed and working memory. The authors propose that tests of fluid intelligence might be indirect measures of basic cognitive processes, such as WM, that could explain their link with learning. They further argue that the value of fluid intelligence tests in predicting scholastic achievement is doubtful as the cognitive underpinning of these measures are not well understood and consequently are theoretically vague. In conclusion they suggest that: “It seems that the practical value and the theoretical significance of fluid intelligence tests needs to be critically re-examined” (Luo et al., 2006, p. 109).

1.2.2. Phonological awareness

Phonological awareness refers to the ability to recognize and manipulate the sounds of spoken words (Ziegler & Goswami, 2005). It has been argued that phonological awareness operates at a number of different levels with awareness of large phonological units (syllables, onsets, and rimes) arising earlier in development than awareness of smaller segments such as phonemes (de Jong & van der Leij, 1999; Goswami & Bryant, 1990; Wagner & Torgesen, 1987). Assessments of phonological awareness therefore differ considerably in terms of both the size of the phonological units that needs to be manipulated and the degree of explicit metalinguistic awareness that is required to solve the task. Examples of standard phonological awareness tasks include rhyme recognition (Bradley & Bryant, 1983), sound blending (Mann & Liberman, 1984), and Spoonerism tasks (Walton & Brooks, 1995).

Origins of phonological awareness

The exact origins of phonological awareness skills remain a matter of debate. According to one account, phonological awareness emerges as a result of growth in spoken vocabulary (Garlock, Walley, & Metsala, 2001; Metsala, 1999). Because the number of similar sounding words in the mental lexicon increases as vocabulary develops, representing lexical entries in terms of smaller segments of sound, such as syllables or phonemes, might be more efficient than representing the phonological structure of each word in a holistic manner (Metsala & Walley, 1998). Phonological awareness might therefore develop as a result of these “lexical restructuring” processes. Others claim that lexical restructuring occurs as a consequence of the acquisition of literacy, suggesting that phonological awareness emerges as a product of reading instruction rather then as a natural consequence of language acquisition (Morais, Alegria, & Content, 1987; Ziegler & Goswami, 2005). From this perspective, being exposed to written word forms might make an individual aware that spoken words have sounds in common - in other words being introduced into literacy may provide explicit knowledge of the phonological structure of language.

The latter position is based on extensive evidence showing that phonological awareness skills are strongly associated with reading abilities (see Goswami & Bryant, 1990 and Wagner & Torgesen, 1987 for reviews). The lexical restructuration theory can, however, also account for these findings: Because printed symbols represent units of speech, awareness of the sound structure of spoken language might enable, or at least facilitate, the acquisition of beginning reading and spelling skills (Bradley & Bryant, 1983). This position is supported by numerous longitudinal studies in which reading was found to be predicted by phonological awareness skills at a prior point in time (Bradley & Bryant, 1983; Muter, Hulme, Snowling, & Stevenson, 2004; Muter & Snowling, 1998; see Wagner & Torgesen, 1987 for a review). Causal links from phonological awareness skills to reading have, however, not consistently been reported (Morais, Cary, Alegria, & Bertelson, 1979; Read, Zhang, Nie, & Ding, 1986).

Bryant and colleagues (Bryant, Maclean, Bradley, & Crossland, 1990) came closest to resolving the controversy of whether or not phonological awareness is a cause or a consequence of literacy development. According to their account, the relationship between phonological awareness and reading is bidirectional with phonological skills based on large phonological units (e.g. rhyme) preceding reading, whereas phonological awareness of smaller units (phonemes) are thought to develop as a consequence of learning to read (see also De Cara & Goswami, 2003; Wagner, Torgesen, Laughon, Simmons, & Rashotte, 1993; Wagner, Torgesen, & Rashotte, 1994; see also Wagner et al., 1997). Others claim, however, that prereaders' awareness of rhyme is not strongly connected to reading as this more "global" form of perception is argued to have little relevance for establishing the grapheme-phoneme correspondence rules which are a central aspect of learning to read (Morais et al., 1987). A general assumption has been that phonological awareness is specifically associated to reading but not to other areas of scholastic achievement (Bryant et al., 1990). In several studies phonological awareness has, however, been found to be linked to other domains of learning including vocabulary (Bowey, 1996, 2001, 2006; de Jong, Seveke, & van Veen, 2000; Hu & Schuele, 2005; Metsala, 1999; Windfuhr & Snowling, 2001) and arithmetic (Leather & Henry, 1994), casting doubt on the position that the role of phonological awareness is specific for literacy acquisition.

Phonological awareness and phonological memory

One question that has received major interest in recent years and is particularly relevant for the present thesis is whether or not phonological memory and phonological awareness measures tap distinct or the same underlying construct. According to one account, verbal STM tasks and phonological awareness measures are alternative surface manifestations of an underlying phonological processing ability. Support for this position comes from studies showing that both type of tasks account for largely shared variance in vocabulary (Bowey, 1996, 2001, 2006; Metsala, 1999; Wagner & Torgesen, 1987). There is, however, also considerable empirical evidence for a distinction between both. Clinical studies have shown that verbal STM can be selectively impaired in patients while phonological processing abilities are maintained (Vallar & Baddeley, 1989). Furthermore, an extensive number of research has found that measures of verbal STM and phonological awareness share dissociable links with learning (Alloway et al., 2005; Chiappe, Glaeser, & Ferko, 2007; Garlock et al., 2001; Gathercole, Tiffany, Briscoe, Thorn, & the ALSPAC team, 2005). From a theoretical standpoint it makes sense to distinguish between assessments of verbal STM and phonological awareness. The specificity of verbal STM tasks mainly lies in the requirement to immediately encode and retrieve the serial order of phonological sequences (Gupta, Lipinski, Abbs, & Lin, 2005). Phonological awareness tasks, on the other hand, rely more on conscious metalinguistic knowledge of the phonological structure of words than on phonological storage (Boada & Pennington, 2006; Bradley & Bryant, 1983; Windfuhr & Snowling, 2001).

Although empirically, or at least theoretically distinct, it has been suggested that both STM and phonological awareness tasks are determined by the quality of phonological representations (Boada & Pennington, 2006; Gathercole et al., 1992; Service, Maury, & Luotoniemi, 2007) which could explain the observed associations between both constructs. Phonological representations can be defined as the emerging property of the brain to represent linguistic constructs in an increasing fine-grained and robust manner (Boada & Pennington, 2006). Creating a psychological entity (phonemes and words) from a physical stimuli (sound waves propagating in air) is a difficult task given that there are no invariant acoustic or temporal cues in the speech stream that mark these phonological units. Through development the young child learns, however, to derive lexical and phonological representations by discerning, weighting, and integrating various acoustic properties along the temporal and spectral domains (Nittrouer, 1996). Deviations or delays in this developmental process might lead to deficiencies in linguistic tasks that are based on these phonological representations. If phonological representations are poorly defined, access to them in an explicit manner is harder and, as a consequence, performance on phonological awareness tasks might be impaired. In the same way, poor phonological representations might impair performance on verbal STM tasks by preventing efficient lexical-phonological encoding and retrieval to occur (Gathercole & Baddeley, 1990). Poor phonological representations might also affect the use of long-term phonological representations in supporting STM performance (Thomson, Richardson, & Goswami, 2005) which further affects STM recall.

Links between phonological awareness and verbal memory are, however, not restricted to STM alone; strong associations with complex span measures have also been observed (Leather & Henry, 1994). Just like complex span tasks most phonological awareness measure involve simultaneous processing and retention demands by requiring an individual to keep orally presented items in memory while manipulating them. Conventional phonological awareness tasks might therefore place heavy demands on WM capacity (Gathercole, 2006; Leather & Henry, 1994; Wagner & Torgesen, 1987).

The few latent variable studies that exist on this matter provide inconsistent results on the underlying nature of phonological awareness and phonological memory tasks. In a recent study on 4- to 6- year-olds, Alloway and colleagues (Alloway et al., 2004) have shown that verbal WM, verbal STM, and phonological awareness emerged as separate but related factors. Similar findings were reported by Wagner et al. (1997) following children longitudinally from kindergarten to 4th grade (see also de Jong & van der Leij, 1999 for similar findings). These results stand in contrast to earlier studies on 4- to 5-year-olds, demonstrating that a single latent construct accounted for individual differences in verbal memory and phonological awareness tasks (Wagner et al., 1987; Wagner et al., 1993). It is, however, worth pointing out that in these latter studies the latent memory factor was mixing contributions from WM, verbal STM, and articulation rate measures, making it unclear what the latent factor truly represented.

Although some evidence in favour of a single phonological construct underpinning verbal memory and phonological awareness tasks exists (Passolunghi & Siegel, 2001; Wagner et al., 1993), the general consensus appears to be that verbal memory and phonological awareness are distinct with the possibility that both might be supported by phonological representations (Alloway et al., 2004; de Jong & van der Leij, 1999; Jarrold, Thorn, & Stephens, 2009; Wagner et al., 1997). The true nature of the question is thus less related to whether the underlying constructs are separate or not, but focuses more on which measures are appropriate assessments of verbal memory and which reflect phonological awareness. As with all psychological concepts what is observed might not necessarily reflect what one intends to measures, and conclusions vary considerably depending on which measures are used to operationalize a given construct. One particular measure - nonword repetition - has received particular attention, and there exists considerable debate in the field of what this task really measures.

According to some, the ability to repeat nonwords is mainly mediated by phonological awareness (Bowey, 1997, 2006; Metsala, 1999). Support for this position comes from studies showing that under certain conditions nonword repetition is not linked to other measures of verbal STM (Hu & Schuele, 2005). In a recent study, d'Odorico and colleagues (D'Odorico, Assanelli, Franco, & Jacob, 2007) found that late talkers' performance on the nonword repetition task was significantly lower than that of normally developing children, whereas both groups performed similarly on a word span task. The authors speculate that nonword repetition does involve phonological awareness which is absent in the word span task. In the same study, children in the two groups did not differ on assessments of phonological awareness. Group differences on nonword repetition but not on word span and phonological awareness measures seem to suggest that nonword repetition taps some specific skill that is not involved in conventional STM or phonological awareness tasks. These findings fit well with Gathercole's (2006) recent position that there are three areas of skill contributing to memory for nonwords: general cognitive abilities; phonological storage; and an unidentified skill specific to nonword repetition.

In contrast to the few studies indicating no associations between nonword repetition and more traditional measures of temporary verbal storage, a large body of research evidence established reliable links between nonword repetition and other verbal STM tasks across many participant populations (Baddeley & Wilson, 1993; Butterworth, Campbell, & Howard, 1986; Gathercole & Baddeley, 1989; Gathercole et al., 1999; Gathercole et al., 1992; Gupta, 2003; Gupta, MacWhinney, Feldman, & Sacco, 2003). Gupta (2005) showed that primacy and recency effects, that are well established in standard serial recall task, are also present in nonword repetition suggesting that nonword repetition and serial list recall are related tasks that both rely on phonological storage.

In summary, the debate about whether or not phonological memory and phonological awareness tasks are distinct or the same is largely influenced by the type of tasks that are used to operationalise each construct. It is thus important to make sure which underlying factor the observed measures tap in order to provide valuable conclusions in respect to distinctions between phonological awareness, verbal STM and WM, and possible relations with vocabulary, reading, and other scholastic abilities.

1.3. Working memory, short-term storage, and learning

Over the last 20 years an extensive amount of evidence has accumulated suggesting that WM and STM play a key role in supporting learning in many different domains (see Pickering, 2006 for a review). As articulated by Kyllonen (1996): "… Working memory capacity is more highly related to…learning, both short-term and long-term, than is any other cognitive factor" (Kyllonen, 1996, p. 73). In order to get a better understanding of the exact nature of this relationship it is first important to clearly identify to which domains of learning WM and STM are (or are not) related, and second to provide a possible explanation(s) to why these associations are observed. The following sections will focus more particularly on these two issues, with reference to relevant empirical findings and theoretical developments in the domain. The contribution of WM and STM to the acquisition of knowledge and new skills will be addressed in turn, followed by a discussion on their respective implications for learning when considered in combination.

1.3.1. Working memory and learning

Research has shown that individuals vary greatly in their WM skills indexed by task that involve storage and processing, and that these individual differences in WM are a major contributor to individual differences in acquiring new knowledge and skills (Alloway & Gathercole, 2006; Conway et al., 2008; Luo et al., 2006). Variations in WM have consistently been related to higher-level cognitive abilities, including language and reading comprehension (Daneman & Carpenter, 1980; Just & Carpenter, 1992), word decoding (de Jong, 1998; Kail & Hall, 2001; Leather & Henry, 1994), arithmetic and problem solving (Bull & Scerif, 2001; Swanson & Beebe-Frankenberger, 2004), vocabulary learning (Daneman & Green, 1986), and spelling and writing (Alloway et al., 2005; Ormrod & Cochran, 1988).

As intense learning occurs in the childhood years, WM might be particularly important during this developmental period. Consistent with this proposal, progress in the key domains of language, arithmetic, and literacy has been found to be closely linked with children's WM abilities (for reviews see Alloway & Gathercole, 2006; Gathercole, Lamont et al., 2006). Furthermore, poor WM skills have been suggested to lie at the root of many problems encountered by children with specific learning difficulty such as specific reading or arithmetic disabilities (de Jong, 1998; Gathercole, Alloway et al., 2006; Swanson, 1993).

The exact reasons for the close relationship between WM and learning are not yet fully understood. One suggestion is that WM corresponds to a sort of mental workspace that allows an individual to maintain and integrate the products of recently processed information during complex and demanding learning activities (Feldman Barrett, Tugade, & Engle, 2004; Just & Carpenter, 1992; Swanson & Beebe-Frankenberger, 2004). For example in a reading comprehension task, children need to decode words and simultaneously maintain the meaning of the previously decoded text. In a similar way, the resolution of mathematical problems often involves maintaining the outcome of certain operations whilst other calculations are performed. Word decoding is another example of a task that might impose heavy demands on WM, especially in beginning readers for whom grapheme-phoneme conversion rules are not yet automatic. For novice readers, decoding unfamiliar words requires the storage of the sounds of the decoded graphemes whilst decoding the subsequent graphemes. What links WM tasks to many learning activities might be the requirement in both to combine and co-ordinate different task elements (Towse & Houston-Price, 2001).

Engle and colleagues (Engle, Kane et al., 1999; Engle, Tuholski et al., 1999) suggest that the relationship between WM and higher-order cognition is due to the ability to control attention. The completion of complex tasks, such as reading or mathematics, often requires to remember some task elements and to inhibit others. Attention might be used to maintain task-relevant information in an active state and to regulate controlling processes. A related, but slightly different view, has been put forward by Cowan and colleagues, suggesting that individual differences in the scope, rather than the control of attention, are important for individual differences in learning especially in young children (Cowan et al., 2005; Cowan et al., 2006). From this point of view, the predictive power of storage and processing tasks is not the inclusion of a processing element as such but rather the fact that processing prevents rehearsal and grouping of the information to be stored.

In addition to directly constraining specific learning activities, WM has also been suggested to make more general contributions to learning, especially in educational settings. In a recent observational study, Gathercole and colleagues (Alloway & Gathercole, 2006; Gathercole & Alloway, 2008; Gathercole, Lamont et al., 2006) have shown that common classroom activities often impose significant WM loads, particularly in the context of literacy and mathematical lessons. Many learning activities have been found to involve lengthy and complex classroom instructions or difficult task structures, leading to potential WM overload in children with low WM abilities. The authors suggest that WM overload is likely to lead to task failure or abandonment, representing lost learning opportunities which might impair the child's rate of acquiring new knowledge or skills. An important finding in support of the WM overload theory is provided in a study by Pickering and Gathercole (2004), showing that WM skills make general rather than specific contributions to learning (see also Gathercole et al., 2005; St Clair-Thompson & Gathercole, 2006). Furthermore, the study showed that WM deficits appeared to be uniquely linked to learning but not to behavioural or emotional problems in children.

1.3.2. Short-term memory and learning

WM tasks, involving storage and processing, are, however, not the only memory measures that have been linked to the acquisition of knowledge and new skills.

Individual difference in simple span tasks, thought to assess STM, have also been found to make significant contributions to certain aspects of learning (Cantor, Engle, & Hamilton, 1991; Colom, Flores-Mendoza et al., 2005; Hutton & Towse, 2001; Towse & Houston-Price, 2001).

Verbal short-term memory and vocabulary

One particular domain of learning that has been consistently reported to bear close associations with verbal STM is language acquisition. In numerous studies, verbal STM has been found to be associated with individuals' ability to learn the phonological form of words in both native (Avons, Wragg, Cupples, & Lovegrove, 1998; Gathercole et al., 1992; Majerus, Poncelet, Greffe, & Van der Linden, 2006) and non-native languages (Cheung, 1996; Masoura & Gathercole, 2005; Service, 1992). Furthermore, experimental studies of artificial word learning have shown close links between individual differences in verbal STM and the facility to acquire unfamiliar names (Gathercole, Hitch, Service, & Martin, 1997; Jarrold et al., 2009; Mosse & Jarrold, 2008; Papagno, Valentine, & Baddeley, 1991). On the basis of this and other neuropsychological and clinical evidence (Baddeley, Papagno, & Vallar, 1988; Bishop, North, & Donlan, 1996; Gathercole & Baddeley, 1990), the hypothesis has been formulated that verbal STM might have evolved in humans as a "language learning device", in other words - as a system to facilitate the process of learning languages (Baddeley, Gathercole, & Papagno, 1998). More specifically, it has been argued that the quality of the temporary representation of a novel word in STM is critical in the formation of a stable phonological representation in long-term memory (Baddeley et al., 1998; Gathercole, 2006; Gupta, 2003). Without an adequate temporary representation of the phonological sequence of a new word, it seems likely that a robust long-term-memory representation will not be constructed and so the unfamiliar word will not become part of the individual's vocabulary.

The causal role of STM in vocabulary learning is, however, not embraced by everybody and remains a matter of intense debate. An alternative account postulates that the relationship between vocabulary and verbal STM is mediated by an individual's awareness of the phonological patterns and sublexical constraints inherent in the language (Bowey, 1996, 2006; Metsala, 1999; Snowling, Chiat, &

Hulme, 1991). According to the “lexical restructuration” described above (see p. 43), phonological awareness emerges as a result of spoken vocabulary development (Garlock et al., 2001; Metsala, 1999). Association between new word learning and STM might therefore be an indirect consequence of vocabulary growth. Indeed, there is strong evidence showing that knowledge of the language exerts a substantial top down influence on verbal STM performance via redintegrative support (see p. 37).

Unfortunately, it is often difficult to distinguish associated from causal connections on the basis of correlational data and high degree of interrelations between basic skills, such as phonological awareness, verbal STM, and vocabulary, in developmental contexts (Gathercole, 1999; Service, 2006). Some evidence exists in favour of a causal link leading from STM to vocabulary, at least in the very early stages of language acquisition. In a longitudinal study, Gathercole and colleagues (1992) assessed verbal STM and vocabulary knowledge in a large sample of 4-year-olds that were followed up at ages 5, 6, and 8. The data was analysed via a cross-lagged correlational technique in which the strength of the association between STM at time point 1 and vocabulary at time point 2 was compared with the converse link between vocabulary at time point 1 and STM at time point 2. Importantly, the results showed that STM at 4-years made a significantly greater contribution to vocabulary at age 5, than existing vocabulary at 4 did to memory performance at 5. Above age 5, however, the pattern of associations changed, with vocabulary knowledge becoming a stronger predictor of subsequent verbal STM capacities. The authors concluded that verbal STM skills exert a direct causal influence on vocabulary learning in very young children. As children develop, the top down influences of linguistic knowledge on STM performance might, however, become increasingly important, masking the relationship between verbal STM and vocabulary development in older ages (see Cheung, 1996; Jarrold, Baddeley, Hewes, Leeke, & Phillips, 2004 for alternative approaches but similar findings). From this vantage point, assessments of verbal STM might reflect less pure indices of underlying STM skills in older in contrast to younger children (Jarrold et al., 2004).

An alternative explanation is that the nature of vocabulary learning might change with development. As individuals acquire a broader vocabulary within a language, new word learning might rely less on phonological form learning but more on alternative strategies, such as semantic or lexical coding, that have been shown to be less dependent on verbal STM (Duyck, Szmalec, Kemps, & Vandierendonck, 2003; Gathercole et al., 1992; Jarrold et al., 2009). In their study, Papagno, Valentin, and Baddeley (1991) found that disrupting verbal STM functioning impaired Italian speakers' ability to pair novel Russian words with Italian translations. Importantly, no such effect emerged for English native speakers learning Russian in the same way. As the Russian language shares more lexical and possibly semantic features with English than with Italian, the authors argued that English speakers might have learned the novel Russian words via lexical and semantic mediation techniques and thereby circumvented the use of verbal STM.

The question of whether phonological awareness might be mediating the association between verbal STM and new vocabulary learning has been directly addressed in a recent study by Jarrold and colleagues (2009). Their findings clearly showed that in typically developing children learning the phonological form of new words was closer related to verbal STM than to phonological awareness. These results favour an explanation of the relationship that is based on individual differences in STM capacity (see also Jarrold et al., 2004).

Verbal short-term memory and other domains of learning

While the exact nature and the causal direction of the relationship between verbal STM performance and vocabulary is still open to debate, a specific association between both abilities is generally accepted. Whether verbal STM plays a significant role in other aspects of language is less clear.

Some evidence exists linking verbal STM to language comprehension. Recent findings by Papagno, Cechetto, Reati, and Bello (2007) indicate that verbal STM might be necessary for the comprehension of syntactically complex sentences by allowing the sentence to be mentally replayed when comprehension cannot proceed online. Children may rely even more heavily on STM then adults when understanding sentences because their sentence processing mechanisms operate slower (Felser, Marinis, & Clahsen 2003). From this perspective, children might still be trying to process an earlier portion of a sentence as later words are coming in and, as a consequence, need to store these new words in a phonological form in order to process them at a later time (Martin, Lesch, & Bartha, 1999). Although some evidence of a relationship between language comprehension and verbal STM exists (Dufva, Niemi, & Voeten, 2001; Gathercole, Willis, Baddeley, & Emslie, 1994; Montgomery, 1995), others have failed to support this position (Hanten & Martin, 2000; Shankweiler, Smith, & Mann, 1984; Willis & Gathercole, 2001). An alternative suggestion is that verbal STM does not constrain language comprehension directly; instead the link might be mediated by vocabulary knowledge. Since words are the building blocks of language, vocabulary knowledge is critical for many other language processing abilities and is therefore likely to play an important role in language comprehension (Baddeley et al., 1998; Gathercole et al., 1992). In line with this position, some authors suggest that the memory deficits associated with poor comprehension are a concomitant of language impairment rather than a specific cause of comprehension failure (Martin & Lesch, 1996).

As for language comprehension, a similar degree of inconsistency in empirical findings exists for reading development. Verbal STM has been suggested by some to contribute to the development of early reading skills (Alloway et al., 2005; de Jong & Olson, 2004; Gathercole, 1995a); other indications are that this is not the case (Dufva et al., 2001; Gathercole, Alloway et al., 2006; Wagner et al., 1997). In two independent studies, that adopted a latent variable longitudinal approach and controlled for a variety of other plausible causes (de Jong & van der Leij, 1999; Wagner et al., 1994), verbal STM was not found to make specific contributions to reading development once phonological awareness was taken into account. Both studies concluded that individual differences in phonological awareness are more important for reading than individual differences in verbal STM, leading to the suggestion that the role of verbal STM in reading acquisition might be as part of a general phonological processing construct related to literacy development, rather than representing a causal factor per se (see also Wagner et al., 1997).

Visuo-spatial STM and learning

In contrast to verbal STM, less is known about the relationship between visuo-spatial STM and learning. There is some preliminary evidence suggesting that this memory component might play a role in the acquisition of arithmetic skills (Bull, Espy, & Wiebe, 2008). In a study of 6- to 11-year-olds, Gathercole and colleagues (2006) however failed to find a significant associations between both constructs; instead links between verbal STM and mathematical abilities emerged (see also Holmes & Adams, 2006). On the whole, there is little evidence in the research literature suggesting that visuo-spatial STM makes unique contributions to scholastic learning (Gathercole & Pickering, 2000b; Luo et al., 2006).

1.3.3. Central executive versus short-term storage

The preceding review has demonstrated that both WM and STM make significant contributions to learning. As has been shown elsewhere, WM tasks involve a strong storage component raising the possibility that the observed links between WM and learning might be related to short-term storage rather than to the central executive system. Which aspects of WM – short-term storage or controlled attention- relates to which domain of learning is not yet fully understood (Gathercole, 1999; Süß, Oberauer, Wittmann, Wilhelm, & Schulze, 2002).

Specific contributions of working memory to learning

According to Colom and colleagues (Colom et al., 2008; Colom, Abad et al., 2005; Colom, Flores-Mendoza et al., 2005; Colom, Rebollo et al., 2006), it is short-term storage that largely accounts for the relationship between WM and higher cognitive abilities. In several studies on adults, they have shown that even though WM makes significant contributions to higher cognitive skills when considered in isolation, the unique predictive power of WM after controlling for STM was small (Colom et al., 2008; Colom, Flores-Mendoza et al., 2005). It is, however, worth pointing out that these studies explored links between WM, STM, and a general intelligence factor that was mixing contributions of fluid and crystallized skills from various domains (vocabulary, arithmetic…). It is therefore possible that, in these studies, the strong contributions of verbal STM to certain areas of learning (e.g. vocabulary) might have masked the contribution of WM to other higher cognitive abilities.

Engle and colleagues argue that executive demands, rather then the storage component, of WM span tasks represent the source of the link with higher cognitive abilities (Engle, Kane et al., 1999; Engle, Tuholski et al., 1999). According to their theoretical framework statistically controlling for the common variance between WM and STM tasks should leave a residual that mainly reflects controlled attention. In several studies they have shown that this WM residual is strongly associated with higher level cognitive abilities in adults (Conway et al. 2002; Engle et al., 1999b; Kane et al., 2004).

The approach of statistically factoring out the common variance between STM and WM measures in order to identify the unique contribution of WM to variations in different learning domains, has also been adopted in a series of studies on children. When controlling for STM, Daneman and Blennerhassett (1984) found that the WM residual accounted for significant variance in listening comprehension in 3- to 5-year-olds. Similar findings were reported by Leather and Henry (1994), showing that WM accounted for significant variance in reading and arithmetic of 7- to 8-year-olds, over and above the contributions of STM and phonological ability. In a recent latent variable study on 6- to 9-year-olds, Swanson (2008) has, however, failed to find a significant association between WM and reading after controlling for verbal STM. Nonetheless, links between the WM residual and mathematical abilities emerged.

The conclusion that performance on WM tasks explains unique variance - independent of short-term storage - in academic achievement has since been replicated in several other studies involving typically developing children and using a range of complex span tasks (Kail & Hall, 2001; Towse & Houston-Price, 2001). Recently, Bayliss and colleagues (Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Bayliss et al., 2003) have developed a promising paradigm in which they controlled for independent measures of both storage capacity and processing efficiency in WM task performance. Importantly, their studies have shown that the resulting residual WM variance correlated reliably with measures of reading and mathematics in 7- to 9-year-olds (Bayliss et al., 2003) and in 6-, 8-, and 10-year-olds (Bayliss, Jarrold, Baddeley, Gunn et al., 2005). These findings suggest that there is an additional ability involved in complex span measures that is independent of the processing and storage elements of these tasks, and that contributes to the prediction of reading and mathematics.

Taken together, even though some argue for a negligible role of the central executive in higher cognition (Colom, Rebollo et al., 2006), the overall consensus is that WM makes unique contributions to individual differences in a range of abilities such as listening comprehension, reading, and mathematics. A final question that will therefore be addressed is whether WM is a stronger correlate of theses abilities than STM.

Working memory and short-term memory as predictors of learning

In adults the overall pattern of findings suggests that tasks that combine storage and processing are better predictors of higher level cognitive skills than simple span measures that tap only storage (see Jarrold & Towse, 2006 for a review). For children empirical evidence is less conclusive: In some of the above described research, STM was found to be a weaker predictor of cognitive performance than WM (Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Bayliss et al., 2003; Daneman & Blennerhassett, 1984; Leather & Henry, 1994). In a latent variable study, Kail and Hall (2001) have shown that when controlling for their common variance, WM but not STM was uniquely related to word decoding skills in 7- to 13-year-olds. In contrast, Swanson (2008) found that STM made unique contributions to reading (6- to 9-year-olds).

In a recent study, Cowan et al. (2005) identified digit span as the single best predictor of scholastic abilities in children but not in adults. Digit span was also found in several other developmental studies to be a strong predictor of reading and mathematics (Hutton & Towse, 2001; Towse & Houston-Price, 2001). According to Cowan, the predictive power of simple span tasks in young children is due to the absence of rehearsal in this developmental group. A measure like digit span might therefore reflect the scope of attention in young children, but not in adults, which could explain its predictive relationship with learning (see p. 29 for an overview of this theoretical position). It seems, however, unlikely that the children in Cowan's study - of 9 and 11 years of age - were not making use of rehearsal to support memory performance (Hulme et al., 1984). In 8- and 11-year-olds, Hutton and Towse (2001) have found that when deliberately blocking rehearsal via articulatory suppression, digit recall scores reduced significantly in contrast to a conventional, unblocked digit span procedure. Furthermore, their data showed that articulatory suppression did not significantly improve the relationship between STM and ability, casting doubts on Cowan's idea that the scope of attention mediates the relationship between WM and learning. A more plausible suggestion is that young children's rehearsal strategies might be less automatized and, consequently, more attention demanding (Conway et al., 2002). Simple span tasks might therefore involve more inhibition or attentional control in children then in adults, which might explain the increased predictive power of these measures in younger ages.

This account also provides a possible explanation for the finding that, in some occasions, complex and simple storage measures were equally strong predictors of scholastic abilities in children (Bayliss, Jarrold, Baddeley, & Gunn, 2005; Hutton & Towse, 2001). In their study, Bayliss and colleagues (2005a) found that complex span tasks were not more predictive of reading and mathematics than STM tasks. Importantly, complex span performance remained significantly linked to learning after controlling for the storage and the processing components of the tasks. The authors found the fact that measures of WM tapped more then STM tasks, yet were not more predictive of other ability measures "puzzling". They suggest that WM tasks are multi-determined and that different tasks might predict abilities for different reasons. Another possible explanation is that the relationship between STM measures and learning was mediated by the central executive. Unfortunately, the authors did not report the specific correlation of STM with learning after controlling for the WM measures: If this correlation were significantly lower than before controlling for WM, one could argue that the controlled attention component of the STM tasks was driving the relationship with learning. Indeed, this pattern of findings was observed in several independent developmental studies by Leather and Henry (1994), Kail and Hall (2001), and also Gathercole and Pickering (2000a).

The latter study (Gathercole & Pickering, 2000a) is particularly interesting because it is using a longitudinal latent variable approach to explore the predictive relationship of WM and STM at age 7, with different domains of academic achievement at age 7 and 8. The data showed that verbal STM at 7 was significantly associated with literacy, vocabulary, and arithmetic at the original time of testing, but correlated only with vocabulary one year later. When controlling for performance on the WM tasks, only the link with vocabulary remained significant at the two time points. WM in contrast, shared unique associations with performance in all three areas of learning at age 7, even after verbal STM scores had been taken into account. One year later, these specific links remained significant for literacy and arithmetic but not for vocabulary.

1.3.4. Conclusion

In summary, the presented evidence suggests that verbal STM and WM manifest distinct patterns of associations with different learning domains: Whereas measures of WM appear to predict performance on a range of cognitive abilities, performance on verbal STM tasks seems to be more specifically linked to the language domain and vocabulary in particular. From a theoretical point of view this might reflect the common contribution of skills that are under the control of the central executive, such as controlled attention, to many learning activities and the more specific role of verbal short-term storage in supporting the long-term learning of the phonological structure of new words. Finally, recent evidence (Pickering & Gathercole, 2004) has shown that children with pervasive learning difficulties manifest impairments across all the different subsystems of WM (central executive, visuo-spatial STM, and verbal STM), suggesting that the capacity to process and store material in WM significantly constrains the ability to acquire skills during formal education and therefore directly influences the educational progress of children.

The next chapter will focus more specifically on the longitudinal study presented in this thesis. The general context of the study will be described and the analytical approach adopted throughout the thesis explained. Finally, the research questions and the tasks used to investigate those will be outlined.

CHAPTER TWO

Present Study

2.1. General overview

This thesis presents the findings of a three-wave longitudinal study, following children from a multilingual environment in the Grand-Duchy of Luxembourg between 6 and 8 years. It explores individual differences and developmental links of WM, STM, phonological awareness, fluid intelligence, and different learning domains (vocabulary, comprehension, foreign language learning, reading, spelling, and mathematical skills), assessed at three different developmental levels: kindergarten - when children were mostly non-readers and pre-foreign language learners; first grade - when children had been formally introduced into literacy and their first foreign language German; second grade - when nearly all children could read and instruction of the second foreign language French had just commenced. Each construct of interest was assessed by multiple tasks in order to explore links between latent rather then observed variables. As task-specific variance is largely absent in latent variables, estimating the relationship between latent variables provides a more accurate indication of the degree of association between the underlying constructs of interest than is provided by the correlations between observed measures.

2.2. Context of the study: Linguistic and educational environment

The study involved 122 school children from the Grand-Duchy of Luxembourg. Although the Grand-Duchy is officially trilingual - with Luxembourgish, German, and French being recognized as *official languages* in the country - Luxembourgers are generally speaking monolinguals in *Luxembourgish* and their multilingualism is mainly acquired through scholastic instruction (Fehlen, 2002; Newton, 1996; Trausch, 2002). Nonetheless, the exposure to foreign languages in Luxembourg is higher then in most other European countries: The main TV channels are in German and French, with only one hour per day in Luxembourgish. An extensive socio-linguistic survey on language habitudes has shown that the vast majority of Luxembourgers watche TV in German (CRP-CU, 1998); the same pattern applies for the written press. The high percentage of foreign residents, 38.6 % of the population, fosters a multicultural and linguistically diverse environment (SCRIPT, 2005). French is the main language of exchange with the foreigners; it is also the official language of legislation and of most official documents.

Luxembourgish is mainly used in its spoken form. Although a standard written version of the language exists (Mémorial A N° 112, 1999), it is taught to a minimum in schools and is consequently not mastered correctly by many. Apart from being one of the three official languages, Luxembourgish is also the designated *national language* of the Grand-Duchy (Mémorial A N° 112, 1999); it is spoken throughout the country and is the native language for the vast majority of the Luxembourgish population (see Kirps & Reitz, 2001 for a detailed description of the use of languages in Luxembourg). Luxembourgish is a Moselle Franconian language that belongs to the family of Germanic languages and bears close links with New High German (Newton, 1996). It also integrates a relatively large amount of words of French origin (Kartheiser, 2000). According to Stephens (1976), Luxembourgish is as distinct from Standard German as is Dutch. Important for the present context is that, because of their common Germanic origin, Luxembourgish and German have a very similar phonology that is different from the Romance language French.

Luxembourg's education system is trilingual: In kindergarten, when children are between 5 and 7 years of age, the main emphasis is put on Luxembourgish. Reading instruction, including the teaching of letter knowledge or reading preparation activities, is postponed to the beginning of the first grade were children learn to read and write in German, not in their native language Luxembourgish. In contrast to English, German is a language with relative consistent grapheme-phoneme relations, and accuracy of word decoding is generally obtained quicker then in languages with less transparent orthographies (de Jong & van der Leij, 2002; Goswami, Porpodas, & Wheelwright, 1997). Probably because of the regularity of German, reading is taught in all Luxembourgish schools via a phonics approach (see for a similar situation in the Netherlands de Jong & van der Leij, 1999; or Austria Wimmer, 1993). As a language, German is taught for eight hours a week, whereas Luxembourish is only instructed for one hour per week in first and second grade. In addition, German serves as the language of instruction in most other subjects of the curriculum (e.g. mathematics). French is introduced in the second half of the second grade, with three hours a week of instruction. In its initial stages it is mainly taught orally, with some literacy related activities. French is considerably less consistent than German, especially from phonology to spelling (see Ziegler, Jacobs, & Stone, 1996 for a review). In contrast to German, French is taught according to a whole-language approach with phonics instructions used to a minimum. In theory, teachers are supposed to use the French language 100% of the time during a standard French lesson even at the very initial stages of French instruction (MEN, 1989), in practice this is, however, not the case (see chapter 3). For Luxembourgish children acquiring German is generally easy while learning French is considerably harder (Kirps & Reitz, 2001).

In the Luxembourgish education system school attendance is compulsory from two years of pre-primary education (starting at the age of 4). Primary school is composed of six grades that are subdivided into three cycles of two years each. Important for the present study is that the first and the second grade fall into the same cycle (*cycle inférieur*) that is generally taught by the same teacher. For each grade the core curriculum and the corresponding classroom material is established by the Luxembourgish Ministry of Education (MEN). The national curriculum needs to be followed by all the state schools in the Grand-Duchy in order to preserve the unity of the Luxembourgish school system and its diplomas (MEN, 1989). To progress to the next grade a child must have passed the vast majority of the courses outlined in the curriculum, or the entire year needs to be repeated. Since 2003, the principal of *team-teaching* and/or *learning cycles* has been adopted by some schools in the country. Team-teaching simply means that two or three teachers are instructing in the same grade. Generally, team-teaching is combined with teaching in cycles, an instruction approach which is less strict in segmenting the curriculum into years but instead is more focused on the competences of the individual children (MENFP, SCRIPT, FUNDP, & Collège des inspecteurs, 2004). In this context children from first and second grade are, for most of the subjects, instructed together in one single class, that is supervised by two or three teachers. Furthermore, children have the possibility to move through the first two grades of primary education in one, two, or three years depending on their competences.

2.3. Study design: Longitudinal research and causality

The present study adopted a longitudinal design in which the same children were assessed at three different points in time. This design permitted first the cross-sectional analysis of the data at each wave of the study and second, the exploration of cross-lagged relations (i.e. relations across time) between the constructs of interest. Children were assessed annually from kindergarten to second grade, with a 1-year lag between each study wave. This period of time was selected because intense learning occurs during these childhood years. The first study wave took place in kindergarten as this point in time provides the platform for scholastic learning and progress. Each subsequent measurement interval marked a crucial learning stage: from kindergarten to first grade, children were introduced into literacy, numeracy, and the first foreign language German; from first to second grade, children became more proficient in reading and mathematics, and instruction of the second foreign language French had begun. The particular advantage of this three-wave design is that it can provide more information about the stability and change of the variables and cross-lagged relations than models based on a single time point or a two-wave design (Taris & Kompier, 2003). The presented longitudinal research therefore has the potential to capture the dynamic nature of the processes under study by providing the opportunity to explore potential developmental changes in the relationships between the factors of interest.

As will be described in more detail below, one of the prime goals of the research project was to foster the understanding of the causal processes underpinning the accumulation of knowledge and skills in young children. Even though causation is one of the most controversial topics in philosophy and science, it has been argued that a causal framework is indispensable in research and practice when attempting to explain phenomena (Pedhazur & Schmelkin, 1991). In the context of empirical studies, it is generally agreed that several conditions have to be met in order to draw conclusions about causality (Kenny, 1975; Kline, 2005; Taris, 2000): (1) the presumed cause and outcome variables have to be associated; (2) a theoretical interpretation for the observed relationship should exist; (3) the associations do not disappear when other possible explanatory variables are controlled; (4) the causal variables precede the outcome variables in time; (5) the direction of the causal relations is correctly specified. While the first three conditions are relatively easy to satisfy with a cross-sectional design, condition (4) and (5) can only be met with a longitudinal dataset, in which the temporal order of the variables can be determined unambiguously.

Although it is virtually impossible to meet the requirement of condition (3) - i.e. hold the effects of *all* other variables constant - the present study attempted to rigorously control for potential confounding factors by including possible relevant causal variables into the analyses. In addition to phonological awareness and fluid intelligence, lexical knowledge has been found to make significant contributions to children's learning (Gathercole et al., 1992; Muter et al., 2004; Plaut, McClelland, Seidenberg, & Patterson, 1996); these cognitive abilities were therefore used as covariates in the analysis as they could potentially mediate links between WM/STM and learning. It has also been argued that the best predictor of future behaviour is often past behaviour. The autoregressive effect of a variable measured at a prior point in time on itself at a later time point was therefore taken into account in the causal models (Gollob & Reichardt, 1987; Wagner et al., 1994). From this perspective, a possible relationship between, for example, STM at time point 1 and vocabulary at time point 2 might be an artefact of the correlation between vocabulary at time 1 and vocabulary at time 2. According to Gollob and Reichardt (see also, Wagner et al., 1994), to support a causal interpretation STM should have an extra effect on vocabulary after the effect of vocabulary at a prior time has been taken into account. It is, however, worth pointing out that this approach has not gone unchallenged. In their paper, Stoolmiller and Bank (1995) caution against including autoregressive effects in causal models because, as they argue, autoregressive effects can obscure the detection of important predictors, especially in the case of highly stable variables.

A further important prerequisite to infer causality, postulated by condition (5), is correct specification of the causal direction of the relationship. In the present study most of the causal and effect variables were measured in all the study waves (i.e.

complete panel design); bidirectional relations could therefore be explored (with some exception described in the following chapters). As has been shown in the preceding chapter, considerable evidence suggests that STM plays a significant role in children's vocabulary development (Gathercole et al., 1992); vocabulary development has, however, also been found to enhance subsequent development of verbal STM (Snowling et al., 1991). Comparing the correlation between prior STM and subsequent vocabulary with the reversed causal links between prior vocabulary and later STM skills should therefore provide crucial information about which cross-lagged effect might be causally predominant.

Finally, causal analyses assume that observed variables are measured without errors. In psychological research this assumption is, however, almost never met. Measurement error might severely bias the estimates of causal effects. In the present study multiple measures (or indicators) were therefore obtained for most cognitive abilities of interest, enabling the construction of latent constructs. Such latent factors reflect the common variance of their indicators and importantly, they exclude task specific variance thereby minimized measurement error and providing better estimates of the potential association between the examined constructs than would be yielded by observed measures (see Anderson & Gerbing, 1988 for a review).

Although great care was taken to minimize sources of model misspecification, it must be acknowledged that causality can not be unambiguously established from the longitudinal study presented in the present thesis. The possibility that a particular observed relationship might be mediated by a third factor that was not measured in the study can not be excluded on the basis of observational data (Dowd & Town, 2002). In the present context, causal relations can therefore not be proven; it can merely be argued that certain statistical associations can be understood in causal terms. The present design does, however, provide the opportunity to address a wide range of research questions specified below.

2.4. Aims, objectives, and predictions

The study had three major aims: The first was to explore the underlying factor structure of WM and STM, and their relation with other cognitive skills,

- phonological awareness and fluid intelligence – in a population of young children growing up in the above described multilingual environment. In this context, the following research questions were addressed:

(a) Are WM and STM operating as distinct processes in young Luxembourgish children?
(b) Do phonological awareness task and verbal STM measures reflect the same underlying construct?
(c) What is the nature of the relationship between WM, STM, and fluid intelligence in young children?
(d) How do these abilities develop, i.e. does the identified factor structure change through the years and how stable are these abilities over time?

On the basis of the theoretical framework proposed by Baddeley (2000; i.e. multi-component WM model) and Engle and colleagues (1999a, 1999b; i.e. WM = STM + controlled attention), it was expected that tasks that measure STM should be distinguishable from, but related, to measures of WM. Exploring WM and STM in a population of 6- to 8-year-olds provided the opportunity to directly address the claim made by Engle, et al. (1999b) and Cowan et al. (2005) that WM and STM should be less distinct in younger than in older children due to the presence of controlled attention (or implications of the scope of attention) in assessments of STM in young children. It was further predicted that verbal STM and phonological awareness measures would load onto two separate factors, with phonological awareness tasks largely reflecting conscious metalinguistic knowledge of the phonological structure of words (Boada & Pennington, 2006), whereas assessments of verbal STM should mainly represent the ability to encode and retrieve the serial order of phonological sequences (Gupta et al., 2005). Finally, it was expected that fluid intelligence would be more strongly related to WM than to STM with the possibility that both, WM and fluid intelligence, might be constrained by controlled attention as suggested by Engle, et al. (1999b) and Conway et al. (2003).

The second aim was to investigate the relationship between verbal STM, WM, and learning in young multilingual children. The specific objectives were threefold:

(e) Determine the strength of the relationship of WM/STM with children's learning in the areas of vocabulary, language comprehension, reading, spelling, mathematical skills, and foreign language acquisition. Importantly, the study design permitted to explore links between WM/STM and learning when children were pre-readers (kindergarten), and investigate whether observed relationships would be preserved (or emerge) one and two years later, when literacy and foreign language skills had begun to be acquired.

(f) Identify which aspects of WM - short-term storage or the central executive/controlled attention - relate to which domains of learning.

(g) Explore whether possible links between WM/STM and learning are mediated by related cognitive skills, i.e. phonological awareness, fluid intelligence, and verbal abilities.

Taken together, the main interest was to compare the full and unique relationship of WM/STM with different learning domains as well as the correlations of the different cognitive abilities with each other in order to get a better understanding of the role of WM, STM, and related skills in children's learning.

On the basis of prior evidence it was expected that WM and STM would make differential contributions to learning. More particularly it was predicted that WM would be related to a wide range of learning activities, mostly learning domains that are explicitly taught in school, such as mathematics and literacy. These predictions are based on recent evidence showing that many classroom activities place heavy demands on WM (Alloway & Gathercole, 2006; Gathercole & Alloway, 2008; Gathercole, Lamont et al., 2006). STM on the other hand was thought to be more specifically related to the language domain and more particularly to vocabulary development. These links were expected in the light of extensive research evidence suggesting that verbal STM plays a significant role in vocabulary acquisition by supporting the formation of stable phonological representations of new words in long-term memory (Baddeley et al., 1998; Gathercole et al., 1992; Jarrold et al., 2009). On the basis of current research findings strong predictions regarding the relationship between verbal STM and other domains of learning could not be formulated. Verbal STM might make contributions to language comprehension, serving as a storage buffer in which the heard material is kept active while the child is listening to the sentence and processing it for comprehension. An alternative possibility is that links between verbal STM and language comprehension are mediated by vocabulary knowledge. In the same way, verbal STM might provide a storage space in which decoded sounds are temporarily maintained during reading. It is, however, also possible that links between verbal STM are mediated by phonological awareness as suggested by Wagner et al. (1994) and de Jong and van der Leij (1999).

A further interest of this study was to investigate the contribution of controlled attention to learning in young children. Following Engle et al. (1999b), controlled attention was operationally defined as the variance that is left in WM performance after controlling for the variance common with STM. If capacity for controlled processing makes significant contributions to higher cognitive abilities, as suggested by Engle and colleagues (Engle et al., 1999a; Engle et al., 1999b), strong links between this WM residual and the different learning constructs should be observed.

The third aim of the study was closely linked to the second aim. The main goal was to explore the possible causal relationships of WM/STM with learning, and their development over time. The specific objectives were the following:

(h) Explore different causal links between WM/STM and learning with one-year, and two-year time lags.
(i) Determine whether WM/STM assessments at school entry predict the degree of learning development during the first years of school.
(j) Investigate if possible causal relations are meditated by phonological awareness, fluid intelligence, lexical knowledge, and the autoregressive effect.
(k) Establish the direction of causality, i.e. determine whether relations are one-directional (e.g. STM predicts subsequent vocabulary), reversed (e.g. vocabulary predicts subsequent STM), or reciprocal (e.g. vocabulary and STM mutually influence each other).
(l) Explore the contribution of WM/STM to reading comprehension in second grade, after controlling for decoding skills, listening comprehension, and lexical knowledge.

The predictions were largely identical to the ones formulated under the second aim, i.e. WM capacity should contribute to a wide range of learning activities, whereas STM skills were expected to be more specifically linked to the language domain. On the basis of a longitudinal study by Gathercole and colleagues (1992) - demonstrating that verbal STM at age 4 exerts a causal influence on vocabulary learning at age 5 but that above age 5 vocabulary becomes the major pacemaker in the relationship - reciprocal rather than one directional relations between verbal STM and vocabulary knowledge were expected. As children had a mean chronological age of 6 in the initial study wave, it was predicted that the cross-lagged effect from vocabulary to verbal STM would be causally predominant. A reduction of the contributions of verbal STM to vocabulary development was expected on the basis of the theoretical argument that when children get older their use of lexical-linguistic knowledge to support STM performance increases; verbal STM assessments might therefore reflect less pure indices of underlying STM skills in older then in younger children (Jarrold et al., 2004). Another possibility is that the nature of vocabulary learning undergoes important developmental changes with semantic and lexical coding strategies becoming more important with development (Jarrold et al., 2009; Papagno et al., 1991).

In contrast to native and foreign language learning in German, strong links were expected between verbal STM and French, even when children were older. This prediction was based on empirical findings by Service (1992), showing a relationship between verbal STM abilities in 9-year-old Finnish children, and their later success in acquiring English as a foreign language (see also Masoura & Gathercole, 1999 for evidence of Greek children learning English; and Cheung, 1996 of English secondary language learners in Hong Kong). From a theoretical standpoint several reasons for an expected link between verbal STM and French language learning in Luxembourgish children can be put forward: As the phonological sequences of French words are likely to be unfamiliar for Luxembourgish children, the use of existing lexical knowledge (mainly Luxembourgish and German) or semantic coding strategies to support the temporary memory representation of new words in French is expected to be minimal (Gathercole et al., 1992; Papagno et al., 1991). Furthermore, acquiring new French words does probably not involve significant conceptual development because, most likely, the children will already have the words within their first language lexicon. As verbal STM is thought to be particularly important in the learning of novel phonological sequences (Gathercole & Baddeley, 1989), it might play a particular important role in the acquisition of the unfamiliar phonological structure of French words.

Concerning reading comprehension, both word decoding and language comprehension have been put forward by some as the two major proximal determinants (Hoover & Gough, 1990). In their longitudinal study, de Jong and van der Leij (2002) found that even though word decoding and linguistic comprehension had a substantial impact on the development of reading comprehension, these abilities could not fully explain all individual differences in reading comprehension. The authors suggest that WM capacity, which was not measured in their study, might have impacted on the development of reading comprehension. The present study therefore explored whether or not WM would make additional contributions to reading comprehension, after taking listening comprehension, lexical knowledge, and word decoding into account.

2.5. Task selection

An obvious key to reliably investigate the foregoing research questions is choosing tasks that are valid measures. One of the major challenges in this research project was to create a battery of assessments appropriate for use with multilingual children growing up in Luxembourg. As no psychological test material exists in the Luxembourgish language, adapted versions of English originals or standardized tests from Germany were used; in some cases new measures had to be designed (see chapter 3 for further details).

WM and verbal STM were assessed by multiple measures that are widely used in research with children and that are part of many standardized working memory test batteries (e.g. AWMA, Alloway, 2007; CNRep, Gathercole & Baddeley, 1996; WMTB-C, Pickering & Gathercole, 2001). As the status of visuo-spatial memory tasks with respect to the higher-level structure of working memory is at present unclear and evidence of significant links with learning is sparse (Alloway et al., 2006; Gathercole & Pickering, 2000a; Luo et al., 2006), no visuo-spatial memory measures were included in the present study.

WM was evaluated by two complex span tasks – *backwards digit recall* and *counting recall* - requiring to simultaneously process and store information. In both cases recall was verbal; tasks differed, however, in terms of their processing element. Backwards digit recall is included in numerous standardized cognitive ability test batteries (e.g. WISC, Wechsler, 1991; WJ-III, Woodcock, McGrew, & Mather, 2001) and involves the recall of sequences of spoken digits in reversed order. The task entails verbal processing; sequences of digits need to be mentally transformed while the digits have to be remembered. The counting recall test (Case et al., 1982), in contrast, involves visuo-spatial processing. Coloured dots need to be identified and counted in visually presented displays and the number of counted dots has to be remembered in the right sequence. Both measure have been widely used in research with adults and children (Alloway et al., 2004; Conway et al., 2002; Engle, Kane et al., 1999) and have been found to correlate highly with each other (Alloway et al., 2004). As described in more detail before (p. 31), these complex memory span tasks are supposed to tap both, short-term storage and controlled attention/central executive (Baddeley & Logie, 1999; Engle et al., 1999b). It is worth noting that backwards digit recall is not unanimously regarded as reflecting WM. Some argue that a task entailing simple transposition of order does not involve sufficient controlled attention to reflect WM capacity and should rather be regarded as a STM measure (Cantor et al., 1991; Engle, Tuholski et al., 1999). In young children, reversing the order of digits is, however, likely to be a complex task that is not very proceduralized and consequently more attention demanding than in adults. This proposal is in line with considerable research evidence showing that, in children, backwards digit recall is more strongly associated with other measures of WM than with STM tasks (Alloway et al., 2006; Alloway et al., 2004; Gathercole & Pickering, 2000a).

STM was assessed by two storage-only tasks – *digit recall* and *nonword repetition* - involving the ability to store and immediately recall items in the right sequential order, without any explicit concurrent processing task. In both tasks the presentation of the stimuli was spoken. The to-be-remembered material differed, however, in terms of content domain and familiarity. Digit span is the most widely used measure of verbal STM (Baddeley et al., 1998) and is present in major standardized general ability batteries such as the *Wechsler Intelligence Scale for Children* (Wechsler, 1991) or the *Kaufman Assessment Battery for Children* (Kaufman & Kaufman, 1983). The task involves the immediate sequential recall of digit sequences. The second assessment of verbal STM - nonword repetition - has also been found to be a reliable and valid tool for assessing verbal STM abilities in children (see Gathercole, Willis et al., 1994 for a review). It provides a measure of the accuracy with which a child can repeat unfamiliar phonological forms, ranging in lengths from one to five syllables (Gathercole & Baddeley, 1996). As discussed in detail in the preceding chapter (p: 47), nonword repetition has been suggested by some to tap phonological awareness skills rather then verbal STM (Bowey, 1997, 2006; Metsala, 1999). In the light of extensive research evidence establishing reliable links between nonword repetition and other measures of verbal STM (Alloway et al., 2004; Gathercole & Pickering, 2000a; Gupta, 2003), nonword repetition was included in the present study as a measure of verbal STM.

Although digit recall and nonword repetition are both thought to rely on phonological storage, it is worth pointing out that there are essential differences between the two measures. As the phonological form of digits is highly familiar for children (Gathercole & Adams, 1994), retaining sequences of digits is likely to benefit from lexically mediated support via redintegrative processes (see Baddeley et al., 1998 for a review). Nonword repetition, in contrast, might not be supported by long-term lexical knowledge in the same way as there are no stored phonological representations of nonwords in the mental lexicon (Hulme et al., 1991). Consequently, children might rely to a greater extend on verbal STM when repeating nonwords than sequences of digits (Baddeley et al., 1998; Gathercole & Baddeley, 1989). Findings on the wordlikeness effect suggest, however, that nonword repetition is not a purely nonlexical task and that nonword repetition might benefit from long-term sublexical support, particularly when the nonword stimuli are similar to real words (see p. 37 for a review). For this reason the nonword repetition task used in the present study included both high and low wordlike nonwords, with the repetition of low wordlike nonwords presumably providing a more sensitive measure of verbal short-term memory.

Digit recall and nonword repetition might further differ in terms of the subvocal rehearsal processes they involve. Gathercole and Adams (1994) have shown that rehearsal emerges earlier for digits than for other kinds of words. In their study they found that children as young as 5 made use of rehearsal in a digit span task. For nonword repetition in contrast, subvocal rehearsal has been proposed to be minimal (see Baddeley, et al. 1998, for a review). Taken together, the evidence suggests that, although digit recall and repetition of high wordlike nonwords provide reliable assessments of STM, the repetition of low wordlike nonwords might be particularly sensitive to verbal STM functioning as support from long-term memory and subvocal rehearsal processes are thought to be negligible. According to the theoretical framework of Baddeley and Hitch (1974), repetition of low wordlike nonwords might therefore tap the phonological store of the phonological loop component or, in terms of Cowan's position, reflect the scope of attention (Cowan et al., 2006).

Children were furthermore assessed on measures associated with phonological awareness. The different tasks varied in terms of the size of the phonological unit that needed to be manipulated (e.g. rime, onset, phoneme) and the operations required to solve the task (e.g. substitute phonological segments, judge whether words have sounds in common). In total four tests of phonological awareness were administered: *rhyme detection*, involving the analysis of the rime (Frederickson, Frith, & Reason, 1997); *first sound detection*, entailing the phonemic analysis of the onset (de Jong & van der Leij, 1999); a *Spoonerism task*, requiring the synthesis of onsets and rimes (Frederickson et al., 1997); and the *odd-one-out test*, involving the implicit detection of phonemes (Kirtley, Bryant, Maclean, & Bradley, 1989). In all the tasks children were presented with line drawings in addition to the spoken presentation of the word forms in order to minimize the STM burdens of the tasks. Importantly, rhyme detection was the only task involving a more rudimentary form of phonological awareness in which general phonological aspects of oral language needed to be recognized, whereas the other measures all required an awareness of individual phonemes in words.

Fluid intelligence was evaluated by the *Raven's Coloured Progressive Matrices Test* (Raven, Court, & Raven, 1986) in which children need to select one of six possible pieces that correctly fits into a target gap in a visual pattern. This task was chosen because it is primarily nonverbal and because the adult version (Raven, 1962) has been shown to load highly on a general factor in psychometric studies of intelligence (Carroll, 1993). Furthermore, the measure is one of the most commonly adopted means of testing fluid intelligence; it has been used extensively in studies with adults (Conway et al., 2002; Engle et al., 1999) and children (Bayliss et al., 2003; Gathercole et al., 1997; Swanson, 2008). The task mainly involves abstract reasoning about spatial features and relations, and visual matching of a target to a pattern (Carpenter, Just, & Shell, 1990). It is worth pointing out that given the large amount of visual matching problems included in the Coloured Progressive Matrices it has been suggested by some that, in children, this task might reflect predominantly visuo-spatial abilities rather than general fluid intelligence (Gunn & Jarrold, 2004).

Learning achievements were assessed in all three study waves in the following areas: vocabulary knowledge in the three languages Luxembourgish, German, and French; listening comprehension in Luxembourgish, and decoding in German; in the second wave listening comprehension in German could further be assessed and in the final study wave additional measures of scholastic ability on listening comprehension in French, spelling in German and French, reading comprehension in German, and mathematical abilities could be collected. With the exception of mathematics, evaluated through a teacher questionnaire, all other learning domains were explored objectively by individually administered standardized tests. If possible, published tests were used; due to the specific characteristics of multilingual Luxembourgish children, many published scholastic ability measures from Germany or France were, however, inappropriate for use with the present population. In some cases new measures had to be designed in which both the cognitive and linguistic demands were suitable for developing plurilingual Luxembourgish children (described in more detail in the following chapter 3).

As multiple assessments of each cognitive and scholastic ability were obtained for a large sample of children, it was possible to use confirmatory factor analysis to establish whether the above presented measures were sensitive and appropriate for use with Luxembourgish children and to explore how well the tasks that were selected represented the target constructs.

2.6. Summary and outline of the remaining chapters

In summary, the study will explore how WM, verbal STM, phonological awareness, and fluid intelligence are linked to each other, how these constructs develop, and how they relate to key elements of learning in young, multilingual children growing up in Luxembourg. More specifically, it intends to disentangle the specific effects of WM, STM, and related cognitive abilities on language, literacy, and mathematical development. The research is unique in integrating this array of assessments of cognitive skills and learning domains in a single longitudinal study, involving a large trilingual developmental population. It provides the opportunity to explore a range of theoretical accounts relating to WM and learning using a latent variable approach. Multiple measures of each construct were administered to 122 young Luxembourgish children at three different time-points, ranging from kindergarten to second grade. Confirmatory factor analysis was used to establish that the presumed measurement model was correct, i.e. that the expected clustering of tests into separate subgroups did occur. The relationship among the latent constructs was explored via structural equation modelling, which is essentially a set of regression equations in which various patterns of hypothesis regarding the causal relations among variables can be defined (Kline, 2005).

The remaining part of the thesis is organized into five chapters. Chapter 3 will outline the methodological aspects of the study: The study population and tasks will be presented in detail, the design of the measures will be described, and the research procedure will be address. In the subsequent three chapters the research results will be presented: Chapter 4 is more particularly concerned with the first aim outlined in section 2.4. (p. 65). Data screening procedures and the psychometric properties of the measures will be presented. Descriptive statistics will be provided, and the structure of WM and STM and their distinctiveness from fluid intelligence and phonological awareness will be investigated. Following the two-step approach proposed by Anderson and Gerbing (1988) the measurement models, defining the relations of the observed measures to their posited underlying constructs, will first be explored (chapter 4), before structural models of the causal relations of the constructs to one another will be tested (chapter 5 and 6). Chapter 5 and 6 address the second (pp. 66-67) and the third aim (pp. 68-69) of the study. Chapter 5 will focus on the cross-sectional aspects of the dataset, whereas in chapter 6 the data will be explored longitudinally. The general findings and implications of the study will be discussed in a final chapter 7.

CHAPTER THREE

Methodology

3.1. Subjects

Consent was obtained from the municipal councils, local educational authorities, and the teachers from 15 villages (out of 20 contacted) to take part in the study. The caregivers of all the second year kindergarten children from these villages (16 schools in total) were contacted and requested to fill out a questionnaire that was sent to them. The questionnaire that was developed for the purpose of the present study provided, among other things information on the nationality and the native languages of the caregivers and the children; the main languages spoken at home; and the exposure to foreign languages in the household. In total 263 questionnaires were returned. Only children with the Luxembourgish nationality and with both parents speaking fluently Luxembourgish were recruited for the study.

The initial sample consisted of 122 Luxembourgish children from 38 kindergarten classes (11 schools) from two, out of the three regions in Luxembourg (*Eislèck* and *Guttland*). By careful follow-up and tracking of children who had moved within the country (5 in total), 119 children were retained from the original sample for the three-year duration of the study. One child was promoted and another had to repeat first grade; the third child that was lost had moved during the third study wave and was frequenting a school with a different educational system to the rest of the schools in Luxembourg (Waldorf school). In first and second grade, three of the participating classes were adopting a “learning cycles” approach (21 children) and four were using “team-teaching” (26 children), described in more detail in chapter 2 (p: 62). Importantly, the recruited children from these classes were following the same curriculum at approximately the same point in time as the children from the rest of the classes. Table 3.1. provides a summary of the number of children, schools, and classes participating in each study wave, as well as the educational style adopted in the different classes.

TABLE 3.1.
Number of Children, Schools, Classes, and Teaching Styles According to Study Wave

Study wave	Children	Schools	Classes	Teaching style		
				Standard	Cycles	Team-teaching
Kindergarten	122	11	38	--	--	--
First grade	120	14	32	28	3	4
Second grade	119	16	34	30	3	4

Of the 119 children for whom complete data were available, 61 (51.3%) were boys and 58 (48.7%) were girls (see Table 3.2.). As mentioned before, Luxembourgish was the first language for the totality of the participants. All of the caregivers were fluent in Luxembourgish and indicated speaking always (or most of the time) in Luxembourgish to their children (see Appendix 1, p. 281, for more detailed information on the linguistic background of the sample). Overall the main foreign language that the children were exposed to was German: 97.5% of the caregivers indicated that the children generally watch TV in German (as opposed to 10.9% in French) and 61.3% read to their children in German (2.5% in French).

Ethnicity representation for the participants was 100% Caucasian. The socioeconomic status of the sample was primarily middle class. As can be seen from Table 3.2., 23.9% of the participants' mothers had a high-school diploma, 25.6% had a professional training certificate, and 17.9% had completed higher education. For the fathers the respective frequencies were: 15% for completed high-school, 37.2% for professional training, and 22.1% for higher education. Notably, almost half of the mothers were housewives. For the majority of the families over 100 books were present in the household.

TABLE 3.2.
Demographic Information on the Sample (N = 119)

		Frequency	Percentage
Sex	Boys	61	51.3
	Girls	58	48.7
Amount of books at home[1]	0-50	16	13.9
	51-100	30	26.1
	101-250	31	27.0
	over 251	38	33.0
Education of the mother[2]	Primary school	8	6.8
	Secondary first cycle[6]	17	14.5
	Secondary second cycle[7]	28	23.9
	Professional training	30	25.6
	Higher education	21	17.9
	Other	13	11.1
Activity of the mother[3]	In a profession	58	49.6
	At home	51	43.6
	Part-time job	4	3.4
	Other	4	3.4
Education of the father[4]	Primary school	7	6.2
	Secondary first cycle[6]	8	7.1
	Secondary second cycle[7]	17	15.0
	Professional training	42	37.2
	Higher education	25	22.1
	Other	14	12.4
Activity of the father[5]	In a profession	104	91.2
	At home	5	4.4
	Part-time job	2	1.8
	Other	3	2.6

Note: [1]missing 4; [2]missing 2; [3]missing 2; [4]missing 6; [5]missing 5; [6]5^{ième} or 11^{ième}, approximately equivalent to middle school; [7]1^{ière} or 13^{ième}, approximately equivalent to high-school

The children were followed from their second year of kindergarten to the end of second grade with data being gathered on three occasions. When first tested, children had a mean chronological age of 6 years and 3 month (SD = 3.37) with a range of 5 years; 9 month to 6 years; 10 month. Consent was obtained from the main caregiver of every child participating in the study.

3.2. Pilot study

The test material was piloted on five Luxembourgish children aged 5 to 6, and four Luxembourgish children aged 7 to 8. WM was initially planned to be assessed via a *listening recall* task in which children listen to a series of short sentences, judge whether the sentences are right or wrong, and than recall the final word of each sentence in sequence (Daneman & Carpenter, 1980). The pilot study showed that Luxembourgish kindergarten children found it difficult to only repeat the final word and instead repeated the entire sentence each time (see Daneman & Blennerhassett, 1984 for similar findings on 3- to 5-year-olds). This task difficulty might have been observed because words are not salient units for pre-readers (Ehri, 1975; Holden & MacGinitie, 1972). On the *counting recall* measure, Luxembourgish kindergartners did not manifest corresponding difficulties; this measure (but not listening recall) was therefore retained in the final test battery.

For the phonological awareness measures the pilot study revealed that, as for children in Germany (Landerl & Wimmer, 2008), tasks requiring the manipulation of phonemes were very difficult for Luxembourgish kindergarten children probably because sound games and reading preparation are largely absent from the preschool system in Luxembourg. Only a *rhyme detection* task, entailing the analysis of the larger phonological unit rime, was therefore retained in the final study to assess phonological awareness in kindergarten. Children were, however, able to perform more complex phonological awareness measures, involving the analysis of phonemes, after being introduced into literacy. These preliminary findings are in line with the position of Bryant and colleagues (Bradley & Bryant, 1983; Bryant et al., 1990) that phonological skills based on rime precede reading, whereas phonological awareness of phonemes develops as a consequence of learning to read.

The pilot study further showed that reading tasks, involving explicit decoding of words, were too difficult for Luxembourgish kindergarteners that had not yet been introduced into literacy. The children performed, however, above chance level on more sensitive measures assessing reading related knowledge, such as discriminating real from artificial letters and detecting written words that match pictures. These measures were therefore retained in the final test battery; word decoding was, however, not assessed in kindergarten. The pilot study on older children showed that accuracy of word decoding was almost 100% for the selected word corpus. This might be attributable to the regularity of the German orthography (Goswami et al., 1997; Wimmer, 1993). De Jong and van der Leij (2002) propose that individual differences in the speed of word decoding are important among children learning to read in a language with relative consistent grapheme-phoneme relations such as German (see also Wimmer, 1993). A speed component (i.e. reading rate) was therefore added to the reading measures in addition to accuracy. Children were also assessed on word decoding in French. The main difficulty with this measure was that children often read the French words using a German pronunciation as reading in French had not yet officially started and German was the first language the children had learned to read in. Due to difficulties in scoring, i.e. deciding whether the children had read the French words accurately (decoding versus pronunciation), the French reading measure was excluded from the final assessment battery. Instead, French literacy was assessed through a spelling measure for which scoring was not problematic.

Finally, the pilot study showed that standardized published test material from France – the "*É.CO.S.SE., Une épreuve de compréhension syntaxico-sémantique*" (LeCocq, 1996), a French version of the English TROG by Bishop (1983) and the "*EVIP: Échelle de vocabulaire en images Peabody*" (Dunn, Thériault-Whalen, & Dunn, 1993), a French version of the English Peabody Picture Vocabulary Test by Dunn and Dunn (PPVT-R, 1981) – were too difficult for Luxembourgish speaking children at the initial stages of French instruction. Two new measures were therefore designed in order to assess French vocabulary and language comprehension in Luxembourgish second grade children.

The remaining measures appeared to be adequate for use with Luxembourgish children. The totality of the test material used for the three study waves are presented below. Experimental tasks are described in more detail than published tests.

3.3. Material

Tests were selected to broadly reflect two domains of abilities: basic cognitive processes or fluid cognition and learning achievements representing crystallized knowledge. The basic cognitive processes assessed were fluid intelligence (or abstract reasoning), WM, STM, and phonological awareness. The learning achievement measures were purportedly tapping vocabulary knowledge, listening comprehension, decoding, reading comprehension, spelling, and mathematical abilities. As described previously, multiple tasks were obtained for the majority of the constructs of interest in order to study relationships among latent abilities independent of task-specific factors or measurement error. The reliability and other psychometric properties of the measures will be addressed in chapter 4 (p. 100). As for none of the tests standardized norms on a population of Luxembourgish children were available, raw scores were used as dependent variables for all of the measures. A list of measures and the occasion(s) at which they were administered is presented in Table 3.3.

In each case at least two practice trials with feedback were presented before the main test items were administered in order to ensure that the children understood the task requirements. For some of the assessments translated versions of English originals were used. Test design of these adapted measures followed the same principles underlying the establishment of the English test material. All tests were translated and adapted by a native speaker that was also fluent in English, and task instructions were checked for accuracy and clarity by different independent native speakers. Audio recordings were made by a female native speaker in a neutral accent and digitally edited as necessary using GoldWave (2004). The digital material was presented to the children at a comfortable listening level via a laptop computer with external speakers.

TABLE 3.3.
Measures and Occasions of Administration

Latent construct and measures	Occasion		
Fluid intelligence			
Raven Coloured Progressive Matrices	K	Gr1	Gr2
Working memory			
Counting Recall	K	Gr1	Gr2
Backwards Digit Recall	K	Gr1	Gr2
Verbal short-term memory			
Digit Recall	K	Gr1	Gr2
Nonword Repetition	K	Gr1	Gr2
Phonological awareness			
Rhyme Detection	K	Gr1	Gr2
First Sound Detection	--	Gr1	--
Spoonerism	--	Gr1	Gr2
Odd-One-Out	--	--	Gr2
Vocabulary			
EOWPVT Luxembourgish	K	Gr1	Gr2
EOWPVT German	K	Gr1	Gr2
EOWPVT French	K	Gr1	--
French Expressive Vocabulary Test	--	--	Gr2
French Receptive Vocabulary Test	--	--	Gr2
Listening comprehension			
TROG-Lu	K	Gr1	Gr2
TROG-D	--	Gr1	Gr2
TECOSY	--	--	Gr2
Reading			
Letter Decision	K	--	--
Word Detection	K	--	--
Word Identification Fluency	--	Gr1	Gr2
Sentence Reading Fluency	--	Gr1	Gr2
Nonword Identification Fluency	--	--	Gr2
Spelling			
Spelling in German	--	--	Gr2
Spelling in French	--	--	Gr2
Reading comprehension			
ELFE 1-6	--	--	Gr2
Mathematical abilities			
Number Skills	--	--	Gr2
Simple Arithmetical Operations	--	--	Gr2
Units of Measurement	--	--	Gr2
Geometry	--	--	Gr2
Mathematical Word Problems	--	--	Gr2

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; TECOSY: Test de Compréhension Syntaxique; ELFE: Ein Leseverständnistest für Elementarschüler

3.3.1. Basic cognitive abilities

Fluid intelligence

Fluid intelligence was evaluated by the Raven Coloured Progressive Matrices Test (Raven et al., 1986). In this test, the children were required to complete a geometrical figure by choosing the missing piece among 6 possible drawings. Patterns progressively increase in difficulty. The test consisted of 36 items divided into three sets of 12 (set A, set AB, and set B). Within each set, items were ordered in terms of increasing difficulty. Sets also varied in difficulty, with set B containing the most challenging items. Answers were scored as 1 for a correct answer and 0 for an error. Four scores were calculated: three scores for each set (maximum = 12) and a total overall score with a possible maximum score of 36.

Working memory

Luxembourgish adapted versions of two verbal complex memory span tasks from the computer-based *Automated Working Memory Assessment* (AWMA, Alloway, 2007) were administered[2]: *Counting Recall* and *Backwards Digit Recall*. Both measures were span tasks in which the amount of items to be remembered increased progressively over successive blocks containing 6 trials each. The criterion for moving on to the next block was correct recall of 4 out of the 6 trials. Test administration stopped if the child failed 3 trials in one block.

Counting Recall

In this test the child needed to count and memorize the number of circles in a picture containing triangles and circles. At the end of each trial the child had to recall the number of circles of each picture in the correct order. The test consisted of 7 blocks of 6 trials each, with trials of 1 picture in the first block, increasing to trials of 7

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pictures in the last block. The number of correct recall attempts was scored for each child, with a possible maximum score of 42.

Backwards Digit Recall

The child was required to immediately recall a sequence of spoken digits in the reverse order. The test consisted of 6 blocks of 6 trials each, starting with 2 digits in block one, increasing to sequences of 7 digits in the last block. Each correct response was scored with a possible maximum of 36.

Verbal short-term memory

Verbal STM was assessed with the Luxembourgish translated *Digit Recall* task from the *AWMA* (Alloway, 2007). A *Luxembourgish Nonword Repetition task* (LuNRep) based on the *Children's Test of Nonword Repetition* (CNRep, Gathercole & Baddeley, 1996) was developed for the purposes of the present study and administered as a second measure of verbal STM.

Digit Recall

This task involved the immediately recall of sequences of spoken digits in the order that they were presented. The test consisted of 9 blocks of 6 trials each, starting with one digit and increasing to sequences of 9 digits. The criterion for moving on to the next block was correct recall of 4 trials. After the failure of 3 trials in one block testing stopped. A correct answer received a score of 1, and the possible maximum score on the test was 54.

Nonword Repetition

The child heard a nonsense word - an unfamiliar phonological word form - and had to immediately repeat it. In total 50 nonwords were presented, ranging in lengths from 1 to 5 syllables, with 10 nonwords in each category. The phoneme sequence in each nonword was conform to the phonotactic rules of Luxembourgish, and the items were constructed to correspond to the dominant syllable stress pattern in Luxembourgish for words of that length. Half of the nonwords were rated as highly similar to real words in Luxembourgish (high wordlike), whereas the remaining 25 nonwords were judged to be low wordlike by 20 Luxembourgish adults (see Appendix 2, p. 283, for a detailed description of the design of the nonwords).

The nonwords were auditory presented via a laptop computer, and each child's responses were digitally recorded for later analysis. Recall accuracy as well as phonetic transcription for each individual item was recorded on a response sheet by the experimenter. The digitally recorded responses were later transcribed into phonetic script with the original scoring sheet, recorded at the time of testing, being used to aid phonetic transcription. Responses were scored as incorrect if the child produced a sound that differed from the target nonword by one or more phonemes. For cases in which it was apparent from the child's spontaneous speech that a specific phoneme was consistently misarticulated as another phoneme (e.g. [ʃ] for [s]), credit was given for the consistent substitution. The number of correctly repeated nonwords was calculated for each syllable lengths (maximum = 10) and nonword type (maximum = 25), with a total maximum overall score of 50.

Phonological awareness

In total four phonological awareness measures were administered: The design of the *Rhyme Detection*, *First Sound Detection*, and *Spoonerism* tasks was based on the *Phonological Assessment Battery* (PhAB, Frederickson et al., 1997). The fourth measure, the *Odd-One-Out* task, was an adapted Luxembourgish version of the English *Opening Sound Oddity Task* and the *End Sound Oddity Task* taken from Kirtley and colleagues (1989). For all of the measures, two parts were administered with the first half of the task containing easier trials. Children were given two or three practice trials before each part of the test in order to show them what kind of discrimination or manipulation had to be made.

Rhyme Detection

In this test, sets of three words were orally and visually presented and the child was asked to point to the pictures or name the two words that shared the same rhyme pattern (e.g. *[bam][lut][tut]*). On each trial words differed by their onsets. The test consisted of two parts: 12 easier items in the first part and 8 items where it was harder to detect the difference between the words (with the non-target words sharing parts of the rime; e.g. *[hɔnt][mɔnt][kant]*) in the second part. Items were constructed by using similar rhymes and word structures as the English version of this task in the PhAB (Frederickson et al., 1997). Three scores were calculated: The total number of correct responses on the first part of the test (maximum = 12) and the second part of the test (maximum = 8), as well as the total overall score of correct answers with a possible maximum of 20.

First Sound Detection

The *First Sound Detection* task was a Luxembourgish adaptation of the Alliteration test from the PhAB (Frederickson et al., 1997). The children were required to identify out of three orally and visually presented words, the two that started with the same sound by pointing to the corresponding pictures or by naming the words. In the first 5 trials all the words started with a single consonant (e.g. *[zɔn][lup][zak]*), whereas in the following 5 trials the words started with consonant blends (e.g. *[dʁaʊf][flam][fʁɛʃ]*). Each correct response was scored with a possible maximum score of 10.

Spoonerism

As in the English version of this measure (PhAB; Frederickson et al., 1997), the task contained two parts: Part one consisted of *Semi-Spoonerisms* and required children to replace the opening consonant or consonant cluster (i.e. onset) of a spoken word with a new sound (e.g. *[kuχ]* with *[ts]* gives *[tsuχ]*). Part two contained *Full-Spoonerisms* in which the onsets from two words had to be exchanged (e.g. *[ʃtul] [mɔnt]* gives *[mul] [ʃtɔnt]*). Each part of the test was discontinued after a time limit of 3 minutes or after 3 consecutive errors. On part one, answers were scored as 1 for a correct response and 0 for an error. On part two, the score on each item could range between 0 and 2; with a score of 0 if neither word was correct; 1 if one of the two words was correct; and 2 if both words were correct. The total maximum score on the *Semi-Spoonerism* task was 10, and the possible maximum score on the overall test was 30.

Odd-One-Out

The children were orally and visually presented with three words and had to identify the odd-one that did not match with the two other words either by pointing to the corresponding picture or by naming the word. All the words used in this task were frequent Luxembourgish words containing three sounds (consonant-vowel-consonant structure) selected from school material. The first 8 trials were based on the *opening sound oddity task* (vowel condition) of Kirtley et al. (1989); the three words began with the same consonant and the odd-one contained a different vowel sound (e.g. *[ʃaf][ʃəp][ʃal]).*The following 8 trials were based on the *end sound oddity task* (Kirtley et al., 1989). In these trials the sound that told the two similar words apart from the odd-one was the last consonant (e.g. *[zef][bam][mof]*). The total maximum score on the overall test was 16.

3.3.2. Learning abilities

Vocabulary

Vocabulary knowledge in Luxembourgish, German, and French was assessed. Expressive vocabulary in the three languages was evaluated with the *Expressive One Word Picture Vocabulary Test* (EOWPVT, Brownell, 2000) translated for the purpose of the present study. French vocabulary knowledge was assessed by two additional tasks (expressive and receptive vocabulary) that were purportedly more sensitive measures of differences in early French vocabulary knowledge in young Luxembourgish school children.

Luxembourgish, German, and French Expressive One Word Picture Vocabulary Test

In this test children were required to name a picture consisting of a line drawing of an object, action, or concept arranged in order of increasing difficulty. Each version of the test (Luxembourgish, German, and French) was translated by two different native speakers. The responses of both translations were used to determine the acceptable answers. The pilot study resulted in no further adjustments. The test items were further evaluated after all the data was collected to determine whether additional responses should be counted as correct. No additional acceptable responses were identified. Item order was kept identical to the English original (EOWPVT, Brownell, 2000). No starting criterion was applied; all the children started at item one. Answers were scored as 0 for errors and 1 for a correct answer. Testing stopped after the failure of 8 consecutive items. The measure used for the analysis was the total number of correct responses.

French Expressive Vocabulary Test for Luxembourgish Second Grade School Children

The test consisted of line drawing of objects or concepts that required the production of a spoken word in French. The selected vocabulary was based on the educational program of the second grade French course of primary schools in Luxembourg (FGIL, 1996; MEN, 1986). The images were selected from the Rossion and Pourtois (2004) databank[3] of coloured line drawings of objects (based on Snodgrass & Vanderwart, 1980). In addition, the semantic categories “colour” (2 items) and “numbers” (2 items) were added to the selected picture set. The final test contained 40 items from 7 different semantic categories. Although the totality of the test was administered to all the children, only responses on 23 selected items were retained for the final analysis. The remaining 17 items were excluded because structured teacher interviews (described below, p. 97) revealed that there were considerable differences among classes with regards to progress in the French curriculum. Consequently, a number of teachers had not yet covered some of the original 40 vocabulary items. All of the children had, however, been introduced into the vocabulary tapped by the selected 23 items. The dependent measure was the number of correct responses with a possible maximum of 23.

French Receptive Vocabulary Test for Luxembourgish Second Grade School Children

The children were required to choose from four pictures the alternative that best matched a given word. This measure was a modified version of the published French

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[3] Images courtesy of Michael J. Tarr, Brown University, http://www.tarrlab.org/

receptive vocabulary test "*Échelle de vocabulaire en images Peabody*" (EVIP, Dunn et al., 1993). As the original test, designed for individuals with French as first language, was too difficult for Luxembourgish children, the measure was adapted to match the vocabulary knowledge of Luxembourgish second grade school children. The images from the original test (EVIP; Dunn et al., 1993) were retained; the target vocabulary items were, however, changed and in same cases the configuration of the four pictures was modified. The vocabulary was selected from the school material of the second grade French course of primary schools in Luxembourg. The total number of correct responses on the test was calculated, with a possible maximum score of 40.

Listening comprehension

Listening comprehension was evaluated in Luxembourgish, German, and French. For the Luxembourgish and French language, new measures had to be designed. Listening comprehension in German could be assessed via a published German test (TROG-D, Fox, 2006). In all three languages the selected measures were based on the English *Test for Reception of Grammar* (TROG, Bishop, 1989; TROG, Bishop, 2003), assessing understanding of grammatical contrasts. In this test, children are required to identify a target picture out of a choice of 4 to match a spoken sentence. The test consists of 20 blocks of 4 sentences each, arranged in order of increasing difficulty. Each block describes a different grammatical contrast and is considered as passed if all 4 items are responded to correctly.

Luxembourgish Test for Reception of Grammar: TROG-Lu[4]

A translated Luxembourgish version of the *Test for Reception of Grammar* (TROG-2, Bishop, 2003) was administered. The grammatical contrast tapped by each block as well as the individual sentences were kept identical to the English original. Due to structural differences between Luxembourgish and English, two items had to be removed (Q1 and Q3), resulting in 78 items. The test was translated into Luxembourgish by a native speaker and checked for accuracy by two native

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speakers; one presented with both the English original and the Luxembourgish translation and one presented only with the Luxembourgish version. Each individual item was scored in addition to scoring the entire block, and children had to fail 5 consecutive blocks and 8 consecutive items before testing stopped. The scoring based on each individual item was used as dependent variable with a possible maximum score of 78. Due to time constraints, only half of the items could be administered in first and second grade. Two items of each block were therefore selected for study wave 2 and 3, with a total possible maximum overall score of 40.

German Test for Reception of Grammar: TROG-D

Syntactic comprehension in German was assessed with the *TROG-D* (Fox, 2006), a validated and published German adaptation of the English *TROG* (Bishop, 1989). The German version of the measure consists of 21 blocks with a total of 84 test items. For the present purpose only 20 blocks were administered (Block A tapping comprehension of nouns was excluded). Two items were selected from each block, leading to a possible maximum score of 40. Importantly, the selected sentences differed from the corresponding sentences selected for the Luxembourgish version of this measure. Testing stopped if children failed 5 consecutive blocks and 8 consecutive items.

French Syntactic Comprehension: TECOSY - Test de Compréhension Syntaxique

The TECOSY assesses understanding of French grammatical contrasts introduced at the end (middle) of the second grade in Luxembourgish primary schools. The test was designed for the purpose of the present study and follows the same principles underlying the establishment of the English original (TROG-2, Bishop, 2003). A restricted simple vocabulary based on the educational program of second grade was used in the test sentences. Only grammatical constructions that are introduced in the second grade of Luxembourgish primary schools and that could be depicted unambiguously were selected for inclusion in the test. All of the test pictures were hand drawn and coloured. Lexical and/or grammatical distracters served as foils (a detailed description of the design of the TECOSY is provided in Appendix 3, p. 290). Each grammatical contrast was assessed via a block of 4 items; the total test consisted of 8 blocks. All of the items were administered with no stopping criterion.

As two teachers had not yet introduced the grammatical construction "*derrière*" (behind), two sentences involving this construction were excluded from the final analyses resulting in a total possible maximum score of 30.

Reading

Reading related knowledge was assessed with the *Letter Decision Test* (Baddeley, Gathercole, & Spooner, 2003) and a *Word Detection Task* that was designed for the purpose of the present study. After children had been introduced into literacy, reading could be assessed with more conventional indices of word decoding: *Word Identification*, *Sentence Reading*, and Nonword Identification. As mentioned previously, reading was assessed in German. All of the word decoding measures were fluency tasks, entailing the speeded and accurate decoding of words. The procedures used in the *Word Identification* and *Sentence Reading* tests are similar to the ones developed originally for *Curriculum-Based Measurement* in reading (Deno, 1985), requiring children to read grade-appropriate words or text orally and in a normal pace during 60 seconds.

Letter Decision

The *Letter Decision Test* from the *Reading Decision Test* (Baddeley et al., 2003) was administered to all participants. In this test, the child viewed a symbol and had to decide if it was a written letter or not. The test consisted of 40 symbols, arranged into four columns of ten symbols each. Half of the symbols were alphabetical letters and the other half consisted of made up shapes or upside down letters. Responses were given orally and recorded by the experimenter. The test stopped after 3 minutes or after completion of the 40 items. The number of correct responses was scored, with a possible maximum score of 40.

Word Detection

In the *Word Detection Task*, based on the *Untergrad Lesetest* (Martin & Burton, 2003), the child was required to point to a written German word out of a choice of 4 that corresponded to a picture. Only words that are identical in terms of pronunciation and spelling in Luxembourgish as in German were used. In total, 14 trials had to be completed. The first 7 trials were easier, with words differing considerably from each other, whereas in the second half the 4 words of each trial started with the same letters, making correct identification harder. In the present context, children performed at chance level on the 7 difficult items [$t(118) = 1.19$; $p = .24$]; only the first part of the test was therefore considered. Each correct answer received a score of 1 with a possible maximum score of 7.

Word Identification Fluency

Children were required to read out loud single written words, presented on individual flashcards, during one minute. All the words were written in 72-point font in a typeface that is used in Luxembourgish school books (e.g. a instead of a). The short version of the test - administered in first grade - consisted of 30 words of increasing lengths, starting with words of 3 graphemes and increasing to words of 8 graphemes. Five items of each word length had to be read. The vast majority of the words were nouns (with 2 exceptions) taken form the school material of the first grade in Luxembourg: e.g. *Baum* (tree); *Igel* (hedgehog); *Fenster* (window). If the child sounded out the word accurately it was scored as correct, even if pronunciation was not fast. Mispronunciations due to articulation difficulties were not counted as errors. Furthermore, a word was scored as correct if the child provided a self-correction within the time period allowed. Substitution, deletion, or additions of phonemes were considered as mistakes. The final score was the number of words read correctly in one minute. If the child completed the list of 30 words in less than one minute, the reading time was recorded and the final score was adjusted in the following way:

(number of words read correctly/time in seconds) x 60 = estimated number of words read correctly in 1 minute

In the longer version of the test - administered in second grade - 45 words (37 nouns) were added to the initial word set, leading to a total of 75 words. The added words were increasing in lengths (from 9 to 11 graphemes) with 5 items of each word lengths: e.g. *Kaninchen* (rabbit); *Lokomotive* (engine); *unglaublich* (unbelievable). After item 45 compound words, that are very common in the German language, were used to complete the list e.g. *Wochentag* (weekday); *Osterhase* (Easter bunny). As for the short version of the task, the dependent variable was the number of words read correctly in 1 minute.

Sentence Reading Fluency

This measure involved the accurate reading of connected test. A list of unrelated sentences was presented and children were requested to read each sentence aloud in a natural reading speed. In total 40 short sentences with 269 simple words (12-point font; familiar typeface) were presented on a single page containing one sentence per line. To avoid that children skipped lines, a blank sheet of paper was used as a line guide. The children were prompted to move to the next word after hesitating in reading a word for over 10 seconds. Repetitions, self-corrections, insertions, and mispronunciations due to articulation difficulties were scored as correct. Word substitutions, omitted words, and hesitations (words not read within 10 seconds) were recorded as mistakes. The dependent measure used for the analysis was the number of words read correctly within one minute.

Nonword Identification Fluency

The children were asked to read out loud during 30 seconds, 24 nonwords presented on individual flashcards, written in 72-point font in a familiar typeface (de Jong & van der Leij, 2002). Children were told that the list of words had no meaning. The stimuli were based on Wimmer's nonword reading task used with German speaking children (Wimmer, 1993). In this task each nonword comprised two or three consonant-vowel syllables with little orthographic and phonological similarity to existing German words but simple pronunciation. In contrast to German, the final -e is silent in most Luxembourgish and French words. For three nonwords the final -e was therefore replaced with an -o or an -i (*talire* to *taliro*; *sitime* to *sitimo*; *rone* to *roni*); the remaining nonwords were kept identical to Wimmer's originals (1993). The administration and scoring procedures used in the present context were similar to the *Word Identification Fluency* measure. The final score was the number of nonwords read correctly in 30 seconds.

Spelling

Two different tasks were used to assess children's spelling skills in German and in French. German spelling performance was evaluated with a standardized and published spelling test for second grade school children from Germany: the *Hamburger Schreibprobe für zweite Klasse* (*HSP 2*) developed by May (2007).

Spelling in French was assessed with a similar measure designed for the purpose of the present study.

Spelling in German

Only the *Single Word Spelling* subtest from the *HSP 2* (May, 2007) was administered. In this test, children were asked to write 15 single words that were individually dictated to them in a natural reading prosody. The number of "grapheme hits" (*Graphemtreffer*), i.e. correctly spelled letters or letter combinations (e.g. sch, ah, ie, ck…), was selected as the dependent variable with a total maximum score of 88.

Spelling in French

The design of the French spelling measure was based on the *HSP 2* (May, 2007). Test administration and scoring procedures were kept identical to the German original. Eight French single words, selected from the school material of the second grade in Luxembourg, were individually dictated to the children. The number of correctly spelled graphemes served as the dependent measure with a possible maximum score of 40.

Reading comprehension

The *text comprehension* subtest (*Textverständnistest*) of the paper and pencil version of the standardized German reading comprehension test *ELFE 1-6* (Lenhard & Schneider, 2006) was administered to all children. The *ELFE 1-6* was designed to be used with German speaking children from first through sixth grades. The *text comprehension* subtest assesses a child's ability to find information in a text, infer meaning beyond written sentences, and draw conclusions about text. The test consists of 13 short passages of written text (2-7 sentences), provided in a test booklet, each followed by one or several questions regarding the content of the text with 4 possible answers per question. Children were required to silently read the written texts and select the correct answers to the questions out of the choice of 4. Testing stopped after 7 minutes or after completion of all the questions with a possible maximum score of 20. The measure was group administered with a maximum of 6 children per group.

Mathematical abilities

Mathematical skills were assessed via a teacher rating questionnaire. Teachers were asked to evaluate each child's mathematical competence in five different domains on a scale ranging from 0 (worst grade possible) to 60 (best mark achievable). This rating format was selected as it corresponds to the national grading system of state schools in Luxembourg[5]. The five mathematical domains were chosen on the basis of the national curriculum of the second grade in Luxembourg (MEN, 1989). As teachers in Luxembourg are required to assess each student's progress in these domains three times per year, teachers were highly familiar with the abilities the selected mathematical categories entailed (see MEN, 1989 for a detailed description of the different domains assessed). Teachers were asked to give a rating of their students' skills and knowledge levels in the following domains:

Number Skills (nombres)
Ability to count until 100, read, write and compare numbers.

Simple Arithmetical Operations (opérations)
Proficiency in basic calculations: addition, substation, simple multiplication, and division.

Units of Measurements (mesures)
Knowledge of the fundamental units of measurement: lengths, weight, and time.

Geometry (géométrie)
Recognize and construct basic geometrical figures: triangle, circle, square, and rectangle.

[5] Grades in the Luxembourgish school system are distributed in the following way: 50–60: very good; 40–49: good; 30–39: satisfactory; 20–29: insufficient, weak; 0–19: insufficient, very weak (MEN, 2006).

Mathematical Word Problems (problèmes)
Understanding of mathematical word problems and ability to apply appropriate arithmetic operations to resolve these problems.

Teachers were asked to provide one score for each mathematical domain for every child participating in the study. The 5 scores were used as dependent variables with a total maximum score of 60 in each case.

3.3.3. Structured interviews

Children: Appreciation of French

Children were asked to rate on a scale from 1 (not at all) to 4 (very much) the degree to which they liked/ enjoyed the French language.

Teachers: French teaching approach

Teachers were requested to indicate the lengths of time children had been learning French in school and the progress in the French curriculum at the time of testing (i.e. which vocabulary and grammatical construction had been covered). Furthermore, teachers were asked to indicate the amount of French that they speak in a standard French lesson (in percentage).

3.4. Procedure

The longitudinal design consisted of three measurement occasions within a 3-year time period. The first wave of the data was gathered before the start of formal instruction in reading and foreign languages, when children were in their second year of kindergarten. The next testing session took place exactly one year later, after about 9 month of instruction in reading, mathematics, and German. The final wave of the data was collected 12 month later when children were in second grade and had been introduced into the French language for about 5 month. Children were tested in May-June of each year.

Given the interest in comparisons between individuals within a group, the measures were administered in a fixed sequence designed to vary the nature of the task demands across successive tests. Each child was tested individually (with the exception of the reading comprehension measure that was group administered) in a quiet area of the school in different sessions of 15 to 30 minutes each, on different school days to provide optimal performance on all tasks. As far as possible the measures were grouped according to test language. In kindergarten, testing session one consisted of the Luxembourgish vocabulary and comprehension measures, and the Luxembourgish verbal STM tasks. Session two contained the German vocabulary, the WM, and the nonverbal ability measures; and the third session included the French vocabulary measure, pre-reading (letter decision and word detection), and phonological awareness assessments. In first grade, children first completed the Luxembourgish vocabulary and comprehension measures, and the phonological awareness tasks. The second session comprised assessments of French vocabulary, nonverbal ability, verbal STM, and WM. The last session contained the German vocabulary, comprehension, and reading measures. In the final third study wave the first testing session included all the measures in Luxembourgish (nonverbal ability; WM, verbal STM, phonological awareness, vocabulary, comprehension), the second block grouped all the German measures (vocabulary, comprehension, reading, and writing), and the last block contained the French assessments (vocabulary, comprehension, and writing). Reading comprehension was group administered in a separate testing session. It is worth mentioning that in the last study wave, the French assessments were only administered after the totality of the participants had completed all other measures. This strategy was employed in order to avoid that child number 119 would have received considerable more instruction in the French language then child number one.

CHAPTER FOUR

Results I - Factor structure

The present chapter is divided into four main sections: The first section addresses the data screening procedures and the psychometric properties of the measures used in the three study waves. In the second part, descriptive statistics of the tests are presented. In the third section confirmatory factor analysis is used to evaluate the adequacy of the measurement model. More specifically, the aim was to explore the underlying factor structure of WM and STM in a population of young multilingual children, their distinctiveness from related cognitive abilities (i.e. fluid intelligence and phonological awareness) and their stability over time. In the final section the main findings of the analyses are discussed.

4.1. Preliminary data analysis

4.1.1. Data screening

Data were screened using a variety of techniques (e.g. examination of histograms, boxplots, calculation of skewness and kurtosis) to identify potential floor or ceiling effects, missing values, the presence of outliers, and to assess the assumptions of multivariate analysis. The different variables were examined separately for each of the three study waves.

As expected, floor effects were observed on the French Expressive One Word Picture Vocabulary Test. This task proved to be too difficult for Luxembourgish children in kindergarten and in first grade who had not yet been introduced into French; this measure was therefore dropped from all subsequent analysis. Missing values were encountered on some items of the teacher rating questionnaire in the third study wave: One teacher did not rate children's performance on units of measurements (7.6% of the cases), and for 22.7% of the sample ratings on geometry were missing. The teachers concerned had not yet introduced these mathematical domains in their classrooms; the two variables (units of measurement and geometry) were therefore excluded from the analyses.

All of the variables were checked for the fit between their distributions and the assumption of univariate normality. The three mathematical ability measures manifested substantial departures from normality, with standardized skewness values ranging from -7.86 to -6.15 and standardized kurtosis between 1.92 and 5.69. Logarithmic transformations[6] of the variables reduced the extreme skewness to standardized values between -1.71 and .05 and standardized kurtosis ranging from -2.25 to -1.93. With the exception of the sentence reading fluency task in first grade manifesting positive skew (z = 5.93), the remaining variables did not depart severely from normality. First grade sentence reading fluency was logarithmically transformed, resulting in satisfactory standardized skew and kurtosis values of -.22 and .65 respectively.

The 5831 cases, with transformation applied to the mathematical ability variables and the sentence reading fluency task in first grade, were screened for univariate outliers. Univariate outliers were defined as values more then 3 *SD* above or below the group mean (Kline, 2005). In kindergarten 3 out of 1309; in first grade 5 out of 1666; and in second grade 7 out of 5831 cases in the dataset met one of these criteria. Univariate outliers were replaced with scores corresponding to plus or minus 3 *SD* as appropriate. Multivariate outlier analysis, using Mahalanobis' distance with $p < .001$, and multivariate normality analyses were conducted for each of the performed structural equation modelling analysis and are reported with their respective analysis.

4.1.2. Psychometric properties of the measures

Reliability coefficients of the scores on the majority of the measures were determined for a sample of 61 children in kindergarten, 60 children in first grade, and 119 children in second grade. For nonword repetition reliability was established for a

[6] Due to negative skew, the variables were reflected before applying the log transformation. For facilitation of interpretation variables were re-reflected after transformation (see Tabachnick & Fidell, 2007).

sample of 61 children in kindergarten, and for 119 children in both first and second grade. Reliability of the scores on rhyme detection was determined for the total sample in kindergarten and second grade and a sample of 60 children in first grade. As recommended by Nunnally (1978), internal reliability estimates for the scores on the different measures were calculated using Cronbach's alpha or the Kuder - Richardson coefficient 20 (K-R 20), providing a measure of internal consistency for scales with dichotomously coded variables (Anastasi & Urbina, 1997; Portney & Watkins, 2000). Reliability coefficients of the scores on all the measures, for the different study waves are presented in Table 4.1.

TABLE 4.1.
Reliability Coefficients for the Different Study Waves

Measures		Kindergarten		First grade		Second grade	
		N	r_{xx}	N	r_{xx}	N	r_{xx}
Fluid intelligence							
Raven[b]		61	.71	60	.74	119	.67
Working memory							
Counting Recall[a]		61	.85	60	.81	119	.89
Backwards Digit Recall[a]		61	.85	60	.84	119	.80
Verbal short-term memory							
Digit Recall[a]		61	.84	60	.91	119	.89
Nonword Repetition[a]		61	.79	119	.81	119	.83
		30	.78[d]	25	.82[d]	28	.72[d]
Phonological awareness							
Rhyme Detection[b]	Total	119	.73	--	--	--	--
	Easy	119	.68	--	--	--	--
	Difficult	119	.48	60	.07	119	.26
First Sound Detection[b]		--	--	60	.42	--	--
Spoonerism		--	--	60	.76	119	.87[a]
Odd-One-Out[b]		--	--	--	--	119	.59
Vocabulary							
EOWPVT Luxembourgish[b]		61	.91	60	.86	119	.85
		61	.90[e]	60	.83[e]	119	.76[e]
EOWPVT German[b]		61	.96	60	.90	119	.88
		61	.95[e]	60	.86[e]	119	.83[e]
French Expressive Vocabulary[b]		--	--	--	--	119	.83
French Receptive Vocabulary[b]		--	--	--	--	119	.75
Listening comprehension							
TROG-Lu[b]		61	.86	60	.47	119	.63
		61	.82[e]	--	--	--	--
TROG-D[b]		--	--	60	.70	119	.65
TECOSY[b]		--	--	--	--	119	.71
Reading							
Letter Decision[b]		61	.53	--	--	--	--
Word Detection[b]		61	.60	--	--	--	--
Word Identification Fluency[c]		--	--	119	.92	119	.94
Sentence Reading Fluency[c]		--	--	119	.86	119	.93
Nonword Identification Fluency[c]		--	--	--	--	119	.65
Spelling							
Spelling in German[b]		--	--	--	--	119	.91
Spelling in French[b]		--	--	--	--	119	.86
Reading comprehension							
ELFE[b]		--	--	--	--	119	.83
Mathematical abilities							
Number Skills[c]		--	--	--	--	119	.62
Arithmetical Operations[c]		--	--	--	--	119	.83
Mathematical Word Problems[c]		--	--	--	--	119	.87

Note. Raven: Raven Coloured Progressive Matrices Test; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; TECOSY: Test de Compréhension Syntaxique; ELFE: Ein Leseverständnistest für Elementarschüler; [a]reliabilities are coefficient alpha; [b]reliabilities are K-R 20; [c]internal-consistency reliabilities were not available for these tasks. The reported values represent lower-bound reliability estimates derived by dividing the squared loading of the variable on its factor by its variance; [d]interrater reliability; [e]reliability without items with extreme responses.

The two WM tasks and the digit recall measure consisted of 6 trials at different list length. For each of the three tasks 6 sub-scores were computed by combining the first, second, third, fourth, fifth, and sixth trials at each different list length into a single score. Cronbach's alpha was then established from these sub-scores. For the nonword repetition measure 10 sub-scores were devised, each of which contained 5 nonwords of each of the 5 syllable lengths. Cronbach's alpha was computed from the 10 sub-scores. As can be seen in Table 4.1., the scores on the WM and STM measures manifested good reliability with alphas ranging from .79 to .91. For nonword repetition, interrater reliability was established by having 25% of the kindergarten, 21% of the first grade, and 23% of the second grade recorded data scored by a second qualified rater. The index of interrater reliability based on Cohen's Kappa[7] (Cohen, 1960), taking into account the agreement occurring by chance, was .78 for the kindergarten scores, .82 for first grade, and .72 for second grade which can be considered a substantial strengths of agreement for all three measurement occasions (Landis & Kock, 1977).

For the remaining measures K-R 20 was computed (with exception of the Spoonerism task in second grade for which Cronbach's alpha was calculated). Scores on the Raven Coloured Progressive Matrices manifested low yet tolerable reliability. For the rhyme detection measure results showed that the scores in first and second grade did not manifest acceptable reliability, possibly due to ceiling effects. In first grade all but four children obtained a score of 4 or above, and in second grade only two children received a score below 4 (out of 8) on this measure. Rhyme detection was therefore excluded from the analyses of the first and second grade data. For the remaining phonological awareness measures (first sound detection, Spoonerism, odd-one-out) reliability of the scores was satisfactory. Internal consistency of the learning ability measures was good with reliability coefficients ranging from .46 to .91. Most importantly, scores on the French assessment measures (expressive vocabulary, receptive vocabulary, spelling, and TECOSY), that were designed from scratch for the purpose of the present study, were highly reliably with r_{xx}'s ranging from .71 to

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[7] Cohen's Kappa is the ratio of the proportion of agreement (corrected for chance) divided by the maximum number of times raters could agree (corrected for chance). K = Pr(*a*) – Pr(*e*) / 1 – Pr(*e*); where Pr(*a*) is the relative observed agreement among raters and Pr(*e*) is the hypothetical probability of chance agreement (Cohen, 1960).

.91. Reliability coefficients were not computed for the speeded reading measures (word identification fluency and sentence reading fluency) and the mathematical ability scores. The reported values in Table 4.1. represent lower-bound reliability estimates derived by dividing the squared loading of the variable on its factor by its variance.

To avoid possible translation bias, item analysis was performed on the Expressive One Word Picture Vocabulary Test (EOWPVT, Luxembourgish and German) in all the study waves and the Luxembourgish TROG in kindergarten. Item difficulty was based on the proportion of individuals passing an item (*p*). The correlation of item difficulty to item order for the EOWPVT was .89 for the Luxembourgish and .84 for the German version in kindergarten (N = 61); .77 for both the Luxembourgish and the German version in first grade (N = 60); and .82 for the Luxembourgish and .76 for the German version in second grade (N = 119). For the Luxembourgish TROG in kindergarten, correlation of item difficulty to block order was .82. Reliability estimates for the EOWPVT and the TROG were recalculated to determine the effects of items with extreme responses on reliability (i.e., *p* less than .20 or greater than .80). As shown in Table 4.1., the resulting estimates did not change considerably.

4.2. Descriptive statistics

Descriptive statistics for the kindergarten, first, and second grade measures are presented in Table 4.2. The analyses are divided into two sections: The first section will focuse on developmental differences in raw scores across the three study waves, whereas the second part of the analyses will focus on the correlations between the different measures in each study wave.

TABLE 4.2.
Descriptive Statistics for the Kindergarten, First, and Second Grade Study Waves

Measures	Max.	Kindergarten			First grade			Second grade		
		Mean	*SD*	Range	Mean	*SD*	Range	Mean	*SD*	Range
Age(in month)	--	75.13	3.37	69-82	87.03	3.44	80-94	99.03	3.44	92-106
Fluid intelligence										
Raven total	36	18.95	4.31	8-31	23.65	4.03	15-34	25.99	3.44	17-33
Raven set A	12	7.73	1.57	3-12	8.94	1.30	6-12	9.55	1.19	6-12
Raven set AB	12	6.36	2.08	2-11	8.30	1.93	4-12	9.35	1.53	5-12
Raven set B	12	4.86	1.61	1-10	6.40	1.91	3-12	7.08	1.96	3-11
Working memory										
Counting Recall	42	9.69	3.07	5-19	14.45	3.12	7-22	18.17	3.61	8-26
Backwards Digit Recall	36	5.90	2.42	0-12	8.84	2.42	5-15	11.41	2.52	6-19
Verbal short-term memory										
Digit Recall	54	20.50	3.17	14-30	23.03	3.51	15-32	24.55	3.23	18-32
Nonword Repetition total	50	35.19	6.14	18-46	38.33	5.10	23-47	38.76	5.20	24-49
High Wordlike Nonword Repetition	25	17.99	3.05	9-23	19.35	2.45	12-24	19.56	2.55	13-25
Low Wordlike Nonword Repetition	25	17.21	3.57	8-25	18.99	3.02	10-24	19.19	3.08	10-25
Phonological awareness										
Rhyme Detection total	20	14.06	3.21	5-20	--	--	--	--	--	--
Rhyme Detection easy	12	8.82	2.22	2-12	--	--	--	--	--	--
Rhyme Detection difficult	8	5.22	1.58	1-8	--	--	--	--	--	--
First Sound Detection	10	--	--	--	7.11	1.60	3-10	--	--	--
Spoonerism total	30	--	--	--	--	--	--	16.13	6.26	1-29
Spoonerism easy	10	--	--	--	6.03	2.73	0-10	--	--	--
Odd One Out	16	--	--	--	--	--	--	12.62	2.28	6-16
Vocabulary										
EOWPVT Luxembourgish	--	59.15	11.43	34-80	68.97	7.66	46-88	75.39	7.52	53-91
EOWPVT German	--	32.98	18.71	0-80	63.86	10.26	33-87	73.25	8.81	46-91
French Expressive Vocabulary Test	23	--	--	--	--	--	--	12.99	4.68	2-22
French Receptive Vocabulary Test	40	--	--	--	--	--	--	26.59	4.74	17-40
Listening comprehension										
TROG-Lu	78	51.97	9.51	23-72	--	--	--	--	--	--
TROG-Lu short	40	26.97	5.38	11-37	31.38	2.72	23-39	33.72	2.65	26-39
TROG-D	40	--	--	--	29.64	3.28	21-36	32.00	2.89	23-38
TECOSY	30	--	--	--	--	--	--	20.61	4.06	10-30
Reading										
Letter Decision	40	28.40	3.31	20-35	--	--	--	--	--	--
Word Detection	7	2.79	1.93	0-7	--	--	--	--	--	--
Word Identification Fluency	1min	--	--	--	16.70	7.23	2-35	31.70	8.86	9-58
Sentence Reading Fluency[a]	1min	--	--	--	22.73	18.59	3-146	63.60	28.77	8-150
Nonword Identification Fluency	30s	--	--	--	--	--	--	9.83	3.27	0-20
Spelling										
Spelling in German	88	--	--	--	--	--	--	79.78	5.45	63-88
Spelling in French	40	--	--	--	--	--	--	31.50	5.48	15-40
Reading comprehension										
ELFE	20	--	--	--	--	--	--	6.51	3.25	0-16
Mathematical abilities[b]										
Number Skills	60	--	--	--	--	--	--	57.15	3.66	44-60
Arithmetical Operations	60	--	--	--	--	--	--	54.83	6.00	32-60
Mathematical Word Problems	60	--	--	--	--	--	--	52.61	8.34	30-60

Note . Max: Maximum possible score; Raven: Raven Coloured Progressive Matrices Test; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; TECOSY: Test de Compréhension Syntaxique; ELFE: Ein Leseverständnistest für Elementarschüler; [a]This variable was log transformed for the first grade sample. The reported mean and standard deviation are for the untransformed variables. [b]These variables were log transformed for the second grade sample. The reported means and standard deviations are for the untransformed variables.

4.2.1. Developmental comparisons

A series of repeated measure analyses of variance were conducted on the tasks that were administered on more then one occasion. Study wave was specified as the within-subject factor. Repeated contrasts were conducted in which performance in wave two was compared to performance in wave one, and wave three was compared to wave two. Table 4.3. summarizes the outcome of the univariate *F*-tests, the effect sizes, and the significant contrasts for each comparison. According to the guidelines by Cohen (1988), η^2 of .01, .09, and .25 correspond to small, medium, and large effect sizes respectively. As can be seen in Table 4.3., all of the univariate *F*-tests were significant. Test performance increased significantly over the years on measures of both basic cognitive processes and learning achievement. Pairwise comparisons revealed that, with the exception of nonword repetition for which performance in first and second grade did not differ, scores on all of the measures increased significantly from kindergarten to first grade and from first to second grade. It should be noted that repetition of high wordlike nonwords was higher than repetition of low wordlike nonwords, replicating the usual wordlikeness effect observed in other studies (Gathercole, 1995b). In kindergarten the repetition of high wordlike nonwords was significantly better than the repetition of low wordlike nonwords [$t(118) = 3.32$; $p < .05$; $d = .23$]. The same pattern was observed in first and second grade, however, in both cases the differences just failed to reach significance: first grade $t(118) = 1.81$, $p = .07$; second grade $t(118) = 1.80$, $p = .07$, with $d = .13$ in both cases.

A final set of analyses compared performance of Luxembourgish and German expressive vocabulary in each study wave. In all three measurement occasions children performed significantly better in native than in German vocabulary: Kindergarten, $t(118) = 19.71$, $p = .00$; first grade, $t(118) = 9.67$, $p = .00$; second grade, $t(118) = 4.81$, $p = .00$. The differences between the languages decreased as children became older.

TABLE 4.3.
Developmental Comparisons

Measures	K	Gr1	Gr2			
	Mean	Mean	Mean	*F*	η^2	Contrasts
Fluid intelligence						
Raven total	18.95	23.65	25.99	228.14**	.66	K<Gr1<Gr2
Raven set A	7.73	8.94	9.55	77.73**	.40	K<Gr1<Gr2
Raven set AB	6.36	8.30	9.35	144.27**	.55	K<Gr1<Gr2
Raven set B	4.86	6.40	7.08	70.14**	.37	K<Gr1<Gr2
Working memory						
Counting Recall	9.69	14.45	18.17	350.91**	.75	K<Gr1<Gr2
Backwards Digit Recall	5.90	8.84	11.41	227.04**	.66	K<Gr1<Gr2
Verbal short-term memory						
Digit Recall	20.50	23.03	24.55	149.54**	.56	K<Gr1<Gr2
Nonword Repetition total	35.19	38.33	38.76	60.61**	.34	K<Gr1=Gr2
High Wordlike	17.99	19.35	19.56	30.47**	.20	K<Gr1=Gr2
Low Wordlike	17.21	18.99	19.19	42.65**	.26	K<Gr1=Gr2
Vocabulary						
EOWPVT Luxembourgish	59.15	68.97	75.39	400.92**	.77	K<Gr1<Gr2
EOWPVT German	32.98	63.86	73.25	743.06**	.86	K<Gr1<Gr2
Listening comprehension						
TROG-Lu short	26.97	31.38	33.72	177.09**	.60	K<Gr1<Gr2
TROG-D	---	29.64	32.00	96.02**	.45	Gr1<Gr2
Reading						
Word Identification Fluency	---	16.70	31.70	803.24**	.87	Gr1<Gr2
Sentence Reading Fluency[a]	---	22.73	63.60	540.08**	.82	Gr1<Gr2

Note . Raven: Raven Coloured Progressive Matrices Test; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; TECOSY: Test de Compréhension Syntaxique; ELFE: Ein Leseverständnistest für Elementarschüler; [a]This variable was log transformed for the first grade sample. The reported mean is for the untransformed variable; K: kindergarten; Gr1: first grade; Gr2: second grade; $^{**}p < .01$

4.2.2. Correlations

As support for a particular confirmatory factor analysis model is based on the pattern of correlations among observed variables, zero-order correlations were analysed prior to testing specific factor models. It was expected that observed variables hypothesized to tap a particular latent factor would correlate at least moderately among themselves - in other word manifest satisfactory convergent validity - , whereas measures that were hypothesised to tap different factors should not be strongly associated. Correlations between all pairs of variables are presented in Table 4.4., Table 4.5. and, Table 4.6., for the kindergarten, first, and second grade measures respectively. In most cases the intercorrelations between measures purportedly tapping the same underlying construct were higher than between-construct coefficients. This was true for all of the three study waves described in more detail below.

Kindergarten

Zero-order correlations for the kindergarten measures are displayed in Table 4.4. Within each area of cognitive skill, measures correlated with one another. Correlations between nonword repetition and digit recall, associated with verbal STM were high (*r* = .59). Digit recall manifested slightly higher correlations with the repetition of low wordlike nonwords (*r* = .56) than with high wordlike nonwords (*r* = .53). This difference was, however, not significant (*t* = -.52) as established by William's t –test (Steiger, 1980). Counting recall and backwards digit recall, indexing WM, were moderately correlated with one another (*r* = .38). Luxembourgish and German vocabulary correlated highly (*r* = .63) and correlated significantly also with TROG-Lu scores (*r's* of .41 and .42). The two reading measures correlated at .39.

The highest correlations across constructs were obtained between verbal STM with vocabulary and listening comprehension (*r's* ranging from .25 to .45). WM correlated moderately with listening comprehension (*r's* of .29 and .38) and fluid intelligence (*r's* of .27 and .34). Further, WM manifested associations with STM with high correlations between both STM measures and backwards digit recall (*r's* of .40 and .41) and weaker correlations with counting recall (*r's* of .13 and .27). Phonological awareness correlated highest with the TROG-Lu (*r* = .30) and manifested moderate associations with word detection (*r* = .20) and native vocabulary knowledge (*r* = .20). Phonological awareness did not manifest strong associations with WM and STM measures, correlating only mildly with nonword repetition (*r* = .22), digit recall (*r* = .19), and backwards digit recall (*r* = .21).

TABLE 4.4.
Correlations Between the Main Scores for Kindergarten Using Pearson's Correlation Coefficient (N = 119)

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. Age	--													
Fluid intelligence														
2. Raven	.18	--												
Verbal short-term memory														
3. Nonword Repetition	.16	.15	--											
4. High Wordlike	.11	.17	**.91**	--										
5. Low Wordlike	.18	.12	**.93**	**.70**	--									
6. Digit Recall	.05	.12	**.59**	**.53**	**.56**	--								
Working memory														
7. Counting Recall	.08	**.27**	.13	.12	.11	**.27**	--							
8. Backwards Digit Recall	.13	**.34**	**.40**	**.36**	**.38**	**.41**	**.38**	--						
Phonological awareness														
9. Rhyme Detection	.08	.10	**.22**	.17	**.24**	**.19**	-.04	**.21**	--					
Vocabulary														
10. EOWPVT Luxembourgish	.12	.17	**.45**	**.41**	**.42**	**.25**	.02	**.20**	**.20**	--				
11. EOWPVT German	.04	.07	**.42**	**.39**	**.39**	**.32**	.09	**.22**	.15	**.63**	--			
Listening comprehension														
12. TROG-Lu	.11	**.42**	**.45**	**.40**	**.44**	**.41**	**.29**	**.38**	**.30**	**.41**	**.42**	--		
Reading														
13. Word Detection	.05	.16	**.18**	.14	**.18**	**.22**	**.19**	**.19**	**.20**	.10	.04	**.23**	--	
14. Letter Decision	**.22**	**.24**	.05	.05	.05	.05	**.18**	.15	.04	-.05	-.08	.13	**.39**	--

Note . Raven: Raven Coloured Progressive Matrices Test; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; significant values marked in boldface, $p < .05$

First grade

Correlations between all pairs of variables in first grade are presented in Table 4.5. The nonword repetition and digit recall measures, tapping verbal STM, were highly correlated ($r = .60$). In contrast, counting recall and backwards digit recall, tapping WM, manifested a weaker association ($r = .19$) that was, however, significant. Both WM measures also correlated significantly with fluid intelligence, indexed by the Raven's (*r*'s of .19 and .25). The two phonological awareness tasks correlated at .40. Interestingly, the first sound detection task manifested medium links with measures of verbal STM (*r*'s ranging from .27 to .33); corresponding links between Spoonerism and verbal STM were, however, not observed (*r*'s of .33 and .27). Furthermore, the phonological awareness tasks were significantly linked with fluid intelligence (*r*'s of .19 and .14). Correlations between Luxembourgish and German vocabulary were high ($r = .83$); these measures were also strongly linked with listening comprehension (*r*'s ranging from .42 to .60). The TROG measures in

Luxembourgish and German correlated at .46, and the two reading tasks manifested strong links with $r = .89$.

The highest correlations between basic cognitive processes and learning achievements were observed for verbal STM with vocabulary and listening comprehension (*r's* ranging from .24 to .39) and between phonological awareness and reading (*r's* ranging from .39 and .49). Fluid intelligence manifested medium associations with listening comprehension (*r*'s of .31 and .37) and weaker correlations with vocabulary (*r's* of .22 and .29). Furthermore, moderate associations were observed between verbal STM and reading (*r*'s ranging from .19 to .28) and between phonological awareness and listening comprehension (*r*'s ranging from .24 to .37). The phonological awareness measures manifested medium links with native vocabulary knowledge (*r*'s of .28 and .30) and weaker associations with German vocabulary (*r*'s of .15 and .22). The WM measures were not strongly linked with any of the learning constructs. Medium associations were observed between backwards digit recall with native vocabulary knowledge ($r = .22$), and between counting recall with listening comprehension in German and reading (*r*'s of .18 and .21).

TABLE 4.5.
Correlations Between the Main Scores for First Grade Using Pearson's Correlation Coefficient (N = 119)

Measure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. Age	--															
Fluid intelligence																
2. Raven	.17	--														
Verbal short-term memory																
3. Nonword Repetition	.01	.16	--													
4. High Wordlike	.06	.15	**.91**	--												
5. Low Wordlike	-.03	.15	**.94**	**.70**	--											
6. Digit Recall	-.09	.18	**.60**	**.54**	**.55**	--										
Working memory																
7. Counting Recall	.08	**.25**	-.05	-.12	.01	.08	--									
8. Backwards Digit Recall	.09	**.19**	**.19**	**.19**	.16	.14	**.19**	--								
Phonological awareness																
9. First Sound Detection	-.03	**.21**	**.33**	**.28**	**.33**	**.27**	.14	**.25**	--							
10. Spoonerism	.10	**.19**	**.19**	.16	**.19**	.14	**.21**	.06	**.40**	--						
Vocabulary																
11. EOWPVT Luxembourgish	.12	**.29**	**.39**	**.37**	**.35**	**.24**	.08	**.22**	**.28**	**.30**	--					
12. EOWPVT German	.09	**.22**	**.35**	**.37**	**.29**	**.28**	.06	.12	.15	**.22**	**.83**	--				
Listening comprehension																
13. TROG-Lu	.01	**.31**	**.32**	**.30**	**.29**	**.31**	.12	.15	**.24**	**.24**	**.42**	**.44**	--			
14. TROG-D	.11	**.37**	**.38**	**.38**	**.31**	**.30**	**.18**	.14	**.37**	**.37**	**.57**	**.60**	**.46**	--		
Reading																
15. Word Identification Fluency	.13	.14	**.27**	**.20**	**.28**	**.21**	**.18**	.10	**.39**	**.46**	**.28**	**.26**	**.29**	**.31**	--	
16. Sentence Reading Fluency[a]	.08	.09	**.22**	**.19**	**.22**	**.22**	**.21**	.08	**.43**	**.49**	**.26**	**.25**	**.25**	**.32**	**.89**	--

Note. Raven: Raven Coloured Progressive Matrices Test; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; [a]log transformed; significant values marked in boldface, $p < .05$

Second grade

Zero-order correlations for the second grade measures are presented in Table 4.6. Consider first the measures tapping basic cognitive processes: Intercorrelations between tasks supposedly assessing the same latent construct were substantial in magnitude with *r*'s of .61 for the verbal STM tasks; .36 for the WM measures; and .69 for the two phonological awareness tasks. Notably, the within-construct coefficients were higher than the between-construct coefficients, suggesting good internal validity of the measures purportedly tapping three separate but related cognitive processes. As in kindergarten, digit recall correlated higher with the repetition of low wordlike nonwords ($r = .61$) than with high wordlike nonwords ($r = .52$). This difference was, however, not significant ($t = -1.59$). Fluid intelligence correlated highest with phonological awareness (*r*'s of .29 and .33) and manifested moderate associations with WM (*r*'s of .20 and .25).

For the learning ability measures the data showed that vocabulary knowledge in German and Luxembourgish were strongly related (r = .83). The French vocabulary measures, although highly associated between each other (r = .65), did not manifest strong links with German and Luxembourgish vocabulary (r's ranging from .01 to .26), providing preliminary evidence that individual differences in vocabulary knowledge may be composed of separable components for different languages. Reading comprehension correlated highly with word decoding (r's ranging from .59 to .82). These associations are not surprising given that the reading comprehension measure involved a strong reading component. In order to get a "purer" index of the comprehension aspect of this measure, a regression analysis was conducted in which reading comprehension was predicted by sentence reading. Reading comprehension variance unpredicted by sentence reading was taken to compute a residual reading comprehension score. As shown in Table 4.6., this newly created variable (residual ELFE) correlated significantly with the TROG measures in Luxembourgish and in German (r's of .27 and .29). The latter were significantly associated with each other (r = .63) and also with vocabulary knowledge in Luxembourgish and in German (r's ranging from .49 to .60). The French comprehension task (TECOSY) manifested modest links with Luxembourgish and German listening comprehension (r's of .32 and .26). Importantly, the TECOSY correlated highly with French vocabulary (r's of .59 and .65). Strong links were observed between the different reading assessments (r's of .78 and .93). These measures were also highly associated with the two spelling tasks (r's ranging from .48 to .71) that correlated at .64. Correlations between the mathematical ability measures were high, ranging from .70 to .85.

Concerning correlations between basic cognitive processes and learning achievements, the data showed that fluid intelligence correlated highest with Luxembourgish and German vocabulary and listening comprehension (r's ranging from .29 to .33), and with two of the three mathematical ability measures (arithmetical operations, r = .28 and mathematical word problems, r = .27). For verbal STM, the highest correlations were obtained with the vocabulary and the listening comprehension measures in Luxembourgish and in German (r's ranging from .21 and .42). Notably, WM was not linked to any of the vocabulary assessments but manifested medium associations with most of the remaining learning achievement measures. For the two phonological awareness tasks no clear pattern emerged; both measures manifested medium associations with all of the learning achievement measures.

In order to get a clearer understanding of the above described patterns of correlations in terms of latent factors, confirmatory factor analyses were conducted and are described in the following section.

TABLE 4.6.

Correlations Between the Main Scores for Second Grade Using Pearson's Correlation Coefficient (N = 119)

Mesure	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
1. Age	--																										
Fluid intelligence																											
2. Raven	.11	--																									
Verbal short-term memory																											
3. Nonword Repetition	.05	.17	--																								
4. High Wordlike	.03	.14	**.91**	--																							
5. Low Wordlike	.06	**.18**	**.94**	**.70**	--																						
6. Digit Recall	.01	**.20**	**.61**	**.52**	**.61**	--																					
Working memory																											
7. Counting Recall	.13	**.20**	.13	.10	.14	.16	--																				
8. Backwards Digit Recall	.05	**.25**	**.24**	**.20**	**.24**	**.32**	**.36**	--																			
Phonological awareness																											
9. Spoonerism	.05	**.29**	**.42**	**.39**	**.38**	**.35**	**.23**	**.30**	--																		
10. Odd-One-Out	-.02	**.33**	**.26**	**.22**	**.26**	.16	**.24**	**.23**	**.69**	--																	
Vocabulary																											
11. EOWPVT Luxembourgish	.16	**.33**	**.42**	**.35**	**.41**	**.29**	.14	.15	**.31**	**.28**	--																
12. EOWPVT German	.09	**.29**	**.33**	**.29**	**.32**	**.21**	.17	.10	**.25**	**.20**	**.83**	--															
13. French Expressive Vocabulary	.02	-.01	**.24**	.16	**.28**	.08	.13	.07	**.27**	**.31**	**.26**	**.20**	--														
14. French Receptive Vocabulary	.00	-.05	**.22**	.14	**.26**	.16	.08	.07	**.19**	**.23**	.12	.01	**.65**	--													
Reading comprehension																											
15. ELFE	.10	.11	**.28**	**.24**	**.26**	**.21**	**.29**	**.20**	**.34**	**.37**	**.34**	**.37**	**.40**	**.36**	--												
16. Residual ELFE	.09	.07	.10	.13	.06	.06	.16	.01	.02	.03	**.31**	**.29**	.06	.09	**.58**	--											
Listening comprehension																											
17. TROG-Lu	.05	**.33**	**.28**	**.28**	**.24**	**.23**	**.28**	**.31**	**.45**	**.41**	**.49**	**.51**	**.20**	.15	**.39**	**.29**	--										
18. TROG-D	.05	**.31**	**.43**	**.40**	**.38**	**.31**	**.28**	**.28**	**.40**	**.35**	**.60**	**.60**	**.20**	.15	**.36**	**.27**	**.63**	--									
19. TECOSY	.04	.09	.16	.08	**.21**	**.21**	**.21**	**.18**	**.35**	**.40**	.15	.10	**.59**	**.65**	**.38**	.08	**.32**	**.26**	--								
Reading																											
20. Word Identification Fluency	.11	.05	**.29**	**.25**	**.28**	.15	**.23**	**.23**	**.45**	**.44**	.15	**.18**	**.45**	**.38**	**.78**	.03	**.26**	**.24**	**.38**	--							
21. Sentence Reading Fluency	.06	.09	**.27**	**.21**	**.28**	**.21**	**.24**	**.24**	**.40**	**.43**	**.19**	**.25**	**.45**	**.38**	**.82**	.00	**.27**	**.25**	**.40**	**.93**	--						
22. Nonword Identification Fluency	.07	.04	.18	.13	**.19**	.14	**.29**	**.31**	**.40**	**.40**	.01	.09	**.24**	.19	**.59**	-.07	**.29**	**.11**	**.22**	**.78**	**.78**	--					
Spelling																											
23. Spelling in German	.06	.05	**.32**	**.31**	**.28**	**.18**	**.26**	**.29**	**.51**	**.45**	**.22**	**.33**	**.50**	**.28**	**.63**	.10	**.35**	**.30**	**.41**	**.71**	**.70**	**.56**	--				
24. Spelling in French	.05	-.03	**.33**	**.31**	**.30**	.09	**.18**	.14	**.40**	**.33**	.13	.13	**.57**	**.33**	**.44**	-.02	**.19**	**.18**	**.30**	**.59**	**.55**	**.48**	**.64**	--			
Mathematical abilities																											
25. Number Skills	.16	.15	**.22**	**.19**	**.21**	.05	**.27**	.07	**.36**	**.52**	**.21**	**.18**	**.45**	**.28**	**.40**	-.01	**.28**	**.26**	**.38**	**.53**	**.50**	**.36**	**.52**	**.45**	--		
26. Arithmetical Operations	.05	**.28**	**.26**	**.22**	**.25**	.13	**.40**	**.19**	**.43**	**.55**	**.33**	**.31**	**.42**	**.25**	**.53**	.11	**.33**	**.35**	**.43**	**.55**	**.57**	**.42**	**.61**	**.52**	**.70**	--	
27. Mathematical Word Problems	.02	**.27**	**.22**	.15	**.24**	**.16**	**.31**	.13	**.45**	**.56**	**.32**	**.31**	**.45**	**.25**	**.53**	.05	**.28**	**.31**	**.45**	**.56**	**.61**	**.41**	**.56**	**.48**	**.74**	**.85**	--

Note . Raven: Raven Coloured Progressive Matrices Test; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; ELFE: Ein Leseverständnistest für Elementarschüler; TECOSY: Test de Compréhension Syntaxique; significant values marked in boldface, $p < .05$

4.3. Confirmatory factor analysis/ measurement models

Confirmatory factor analyses (CFA) were carried out for a preliminary test of the adequacy of the measurement model for each of the proposed factors. The main aims of these analyses were twofold: to evaluate the adequacy with which the observed tasks represented the purported underlying factors of interest and to specify the degree to which the postulated constructs were separable or shared the same underlying ability or mechanism. For this purpose different factor models were compared. With exception of the reading comprehension task for which a transformed measure was used as an index of language comprehension (residual ELFE), the indicators of each latent construct were the tasks listed with them in the method section in chapter 3.

All statistical analyses were performed on the covariance structure not the correlations presented in Tables 4.4. to 4.6. Maximum likelihood estimation was applied with the computer program *AMOS* (Analysis of Moment Structures, Arbuckle, 2006) to estimate the models' parameters and fit indices. Goodness of fit for the estimated models was assessed by different fit indices. The most commonly used fit index is the χ^2 statistic, assessing the difference between the sample covariance matrix and the implied covariance matrix from the hypothesized model (Fan, Wang, & Thompson, 1999). Small and nonsignificant χ^2 values indicate good fit. As the sample size increases the sensitivity of the χ^2 test increases, potentially resulting in small differences causing misfit (Hu & Bentler, 1995). For this reason additional absolute fit indices were examined that are more sensitive to model specification than to sample size (Jaccard & Wan, 1996; Kline, 2005). The *Comparative Fit Index* (CFI, Bentler, 1990) and the *Incremental Fit Index* (IFI, Bollen, 1989) assess whether the hypothesised model provides a better fit than a null model in which the relationships between the latent variables are not specified and consequently are set to 0. For CFI and IFI, values equal to or higher than .90 indicate good fit (Hoyle, 1995). Finally, the *Root Mean Square Error of Approximation* (RMSEA, Browne & Cudeck, 1993) index was used. This fit index refers to the lack of fit, per degree of freedom, of the model to the population covariance matrix. An RMSEA value of .08 or less is acceptable, and a value of .05 indicates a good fit (McDonald & Ho, 2002).

To determine whether one model was significantly better than another, χ^2 difference tests on nested models were performed. In this test the χ^2 of the fuller model is subtracted from the χ^2 of the nested model with fewer free parameters. If the χ^2 difference is statistically significant, the fuller model provides a better fit to the data. An alpha level of .05 was used for all the reported χ^2 difference tests. Non-hierarchical factor models were compared via the *Akaike Information Criterion* index (AIC, Akaike, 1987); in each case the model with the smallest AIC value was preferred (Kline, 2005).

The latent factors were scaled by fixing the loading of one of the indicators to 1. In all subsequent figures, circles designate latent variables and rectangles represent the observed variables from which the latent variables are derived. Numbers on double-headed arrow paths represent the correlation between the latent variables; squaring them provides an indication of the proportion of shared variance. Numbers on single headed-arrow paths leading from the latent construct to the observed variables represent the factor loadings of the tasks. As in regression analyses, standardized estimates were obtained by transforming all measures to the same scale. As the magnitude of unstandardized coefficients is hard to interpret, only the standardized estimates are reported in the following figures.

The first part of the analyses will focus on the different learning ability constructs. An initial set of models will explore the associations between the different learning measures by fitting one-, two- and three-factor CFA models. The starting point for all the analyses was a single factor model in which each indicator was specified to load on only one factor, following the logic that if a single factor model cannot be rejected there is little reason in evaluating more complex models. Separate analyses were performed for each grade.

4.3.1. Learning abilities

Kindergarten

In kindergarten five learning ability measures were analysed: expressive vocabulary in Luxembourgish and German (EOWPVT); listening comprehension in

Luxembourgish (TROG-Lu); word detection; and letter decision. No multivariate outliers were identified. Variables appeared to be multivariate normal with a standardized kurtosis of -.15. Fit indices for all the subsequent models are provided in Table 4.7.

TABLE 4.7.
Fit Indices for the Learning Ability Models in Kindergarten

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Model 1:							
Single factor model	28.48	5	.00	.78	.79	.20	48.48
Model 2:							
2-factor model: language & reading	9.01	5*	.11	.96	.96	.08	29.01
Model 3:							
3-factor model: vocabulary, comprehension, & reading	2.86	3	.41	1.00	1.00	.00	26.86

Note . *error variance of the w*ord detection* task constrained to .005

In model 1, all five variables were specified to load onto a common factor. Values of selected fit indices in Table 4.7. clearly show that this single-factor model poorly explained the data with a highly significant χ^2 value; CFI and IFI values below .90; and an RMSEA above .05, providing the rationale for evaluating further multi-factorial models. Next, a two-factor model was fitted to the data with letter decision and word detection loading onto a separate reading construct. The results of the fit indices are generally favourable of this two-factor model with the exception of the RMSEA value that was slightly high. The main problem with this model was the negative error variance for the word detection task. The phenomenon of a negative error variance, known as Heywood case, is more likely to occur in the context of a medium sample size ($N < 150$) and of less then three indicators per latent construct (Chen, Bollen, Paxton, Curran, & Kirby, 2001). In the present case the observed negative error variance might therefore be a result of sampling fluctuations around a positive error variance in the population. Given that the error variance was not significantly different from 0, it was constrained to .005 as recommended by Bentler (1976).

Inspection of the standardized residual covariances[8] revealed that the standardized residuals for the TROG-Lu measure were considerably higher then for the rest of the measures, indicating that the two-factor model did not provide a good account of the correlations of this particular measure. A final third model was therefore explored in which the TROG-Lu variable was specified to load onto a separate construct. Because scores of a single indicator are unlikely to have no measurement error, the error term of the TROG-Lu was constrained to an estimate based on the previously established reliability of this measure (Kline, 2005)[9]. The fit indices of this three-factor model were excellent with a non-significant χ^2 value, CFI and IFI values of 1, and an RMSEA of 0. The AIC index in Table 4.7. indicates that the model provided a significantly better account of the data then the single factor model 1 and the two-factor model 2. The standardized residual covariances of model 3 were low, ranging from -1.05 to .90. The model solution is summarized in Figure 4.1.

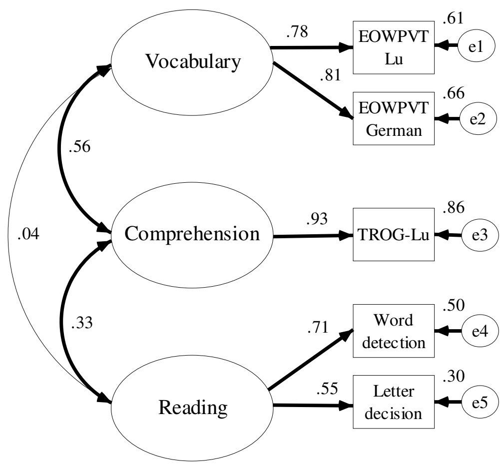

FIGURE 4.1.
Model 3: Three-factor CFA model for the learning ability measures in kindergarten; Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; Lu: Luxembourgish.

First grade

In first grade children completed six assessments of learning abilities: expressive vocabulary (EOWPVT) and listening comprehension (TROG) in Luxembourgish and

[8] representing estimates of the number of standard deviations the observed residuals are from the zero residuals that would exist if model fit were perfect (Byrne, 2001)
[9] $(1 - r_{xx}) * s^2_{TROG}$

in German, word identification, and sentence reading (log transformed). Fit indices of the different models are provided in Table 4.8. Variables manifested multivariate normality with a standardized kurtosis of -.38. No multivariate outliers were detected.

TABLE 4.8.
Fit Indices for the Learning Ability Models in First Grade

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Model 1:							
Single factor model	183.17	9	.00	.58	.59	.40	207.17
Model 2:							
2-factor model: language & reading	12.75	8	.12	99.00	99.00	.07	38.75
Model 3:							
3-factor model: vocabulary, comprehension, & reading	1.92	6	.93	1.00	1.00	.00	31.92
Model 4:							
3-factor model: Luxembourgish, German, & reading	11.42	6	.08	.99	.99	.09	41.42

As for the kindergarten measures the single factor model 1 did not provide a good fit to the data with a significant χ^2 value, CFI and IFI values below .60, and an RMSEA of .40. Most notably, the standardized residuals for the two reading measures were high, indicating that the single factor model did not account well for the relationship of these two measures. Furthermore, the paths coefficients linking the reading measure to the common factor were lower than for the rest of the measures.

In model 2, the two reading measures (word identification and sentence reading) were therefore specified to load onto a separate reading factor. Model 2 provided satisfactory fit indices with a significant χ^2, CFI and IFI values above .95, and an RMSEA below .08. Model 2 was significantly better than the single factor model 1 [$\Delta\chi^2(1) = 170.42$, $p < .01$]. The next model tested the hypothesis that the common language factor could be further divided into a vocabulary and a comprehension component. Model 3 consisted of a three-factor model in which the TROG measures in German and Luxembourgish were specified to load on a common comprehension factor, and the two vocabulary measures were linked to a distinct vocabulary factor; the third factor consisted of the reading measures. This model is summarized in Figure 4.2. and fit indices in Table 4.8. show that this three-factor model provided an excellent fit to the data with a non-significant χ^2 value, CFI and IFI indices of 1, and an RMSEA of 0. The highest standardized residual covariance for this model was .41. Model 3 provided a significantly better fit to the data than the single factor model 1 [$\Delta\chi^2(3) = 181.25$, $p < .05$] and the two-factor model 2 [$\Delta\chi^2(2) = 10.83$, $p < .05$].

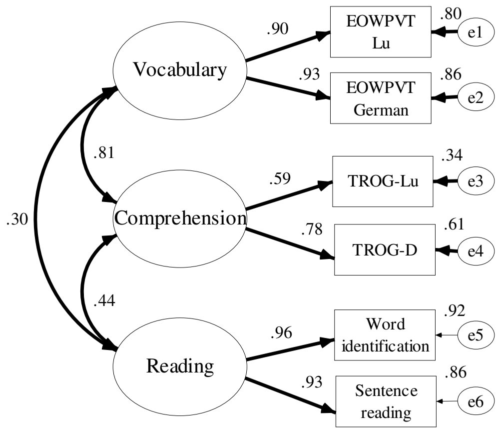

FIGURE 4.2.
Model 3: Three-factor CFA model for the learning ability measures in first grade; Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct; EOWPVT: Expressive One Word Picture Vocabulary Test; TROG: Test for Reception of Grammar; Lu: Luxembourgish; D: German

Finally, the hypothesis was tested that the data could be best characterized by a model consisting of language specific constructs. In model 4, the two measures in Luxembourgish (EOWPVT Luxembourgish and TROG-Lu) and the two measures in German (EOWPVT German and TROG-D) were specified to load onto two separate factors that were distinct from a third reading factor. The AIC index in Table 4.8. indicates that model 4 did fit the data less well than model 3. The hypothesis of separate Luxembourgish and German language factors in young Luxembourgish children was therefore rejected.

Second grade

In second grade, 16 measures of academic performance were obtained. In order to avoid model complexity different aspects of the data were modelled separately. The first set of models explored the underlying structure of the language measures (vocabulary and comprehension in Luxembourgish, French, and German). The second set of models focused on the reading, spelling, and mathematical ability measures. The transformed reading comprehension measure (residual ELFE) was used in all of the subsequent analyses.

The first set of analyses included the eight language variables: expressive vocabulary in Luxembourgish, German, and French, receptive vocabulary in French, listening comprehension in Luxembourgish, German, and French, and the transformed reading comprehension variable. Fit indices of the different models are represented in Table 4.9. The measures did not violate the assumption of multivariate normality with a standardized kurtosis of 1.84. No multivariate outliers were detected.

TABLE 4.9.
Fit Indices for the Language Models in Second Grade

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Model 1:							
Single factor model	178.76	20	.00	.62	.63	.26	210.76
Model 2:							
2-factor model: vocabulary & comprehension	152.32	19	.00	.68	.70	.24	186.31
Model 3:							
3-factor model: voc. Lux./German, voc. French & comprehension	87.37	18*	.00	.83	.84	.18	123.37
Model 4:							
3-factor model: voc. Lux./German, French, & comprehension	23.34	17	.14	.98	.98	.06	61.34

Note . Voc: vocabulary; Lux: Luxembourgish; *error variance of French Expressive Vocabulary constrained to .005

Following the logic of the preceding analyses, the starting point was a single factor model. As expected model 1 was rejected on the basis of the fit indices (significant χ^2; CFI and IFI values below .64; RMSEA of .26) opening the possibility for assessing multi-factorial models. Model 2 consisted of a two-factor model, with the vocabulary measures in Luxembourgish, German, and French loading on one factor, and the listening comprehension measures in the three languages and reading comprehension loading on a separate comprehension factor. Although this two-factor model fitted the data significantly better than the single factor model 1 [$\Delta\chi^2(1) = 26.44$, $p < .05$], the χ^2 of this model remained highly significant and the CFI, IFI, and RMSEA indices unsatisfactory, leading to the rejection of model 2. Importantly, in model 2 the loadings of the two French vocabulary measures onto the common vocabulary factor were low (.12 *ns*; and .27), in contrast to the Luxembourgish and German vocabulary measures that manifested strong loadings onto the common latent vocabulary factor (.93 and .90 respectively).

Model 3 explored the possibility that the two French vocabulary measures loaded onto a separate third factor. In this model the residual variance of the French expressive vocabulary measure was negative; it did, however, not differ significantly from 0 and was therefore constrained to .005 (Bentler, 1976). Again fit improved significantly over the two-factor model 2 [$\Delta\chi^2(2) = 64.95$, $p < .05$] but remained largely unsatisfactory (significant χ^2; CFI and IFI below .85, and RMSEA > .15). Inspection of the residual covariances matrix revealed that the model did not account well for the relationship of the French comprehension measure with expressive and receptive French vocabulary (standardized residual covariances of 5.29 and 6.32). In model 4, French comprehension was therefore linked to the same factor as the French expressive and receptive vocabulary measures. This change resulted in a well fitting model, with a nonsignificant χ^2 value and satisfactory CFI, IFI, and RMSEA indices. Furthermore, the problem of the negative error variance disappeared and all of the standardized residual covarainces fell between -1.33 and 1.45. Model 4 manifested a substantially lower AIC value then model 3, indicating that model 4 provided a better account of the data. The model solution is summarized in Figure 4.3.

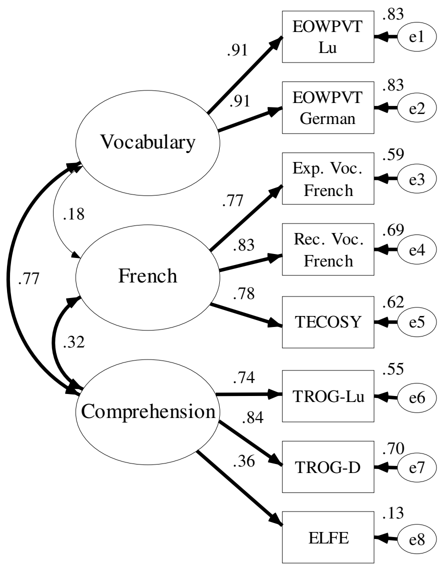

FIGURE 4.3.
Model 4: Three-factor CFA model for the language measures in second grade;
Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct;
EOWPVT: Expressive One Word Picture Vocabulary Test; Exp. Voc: Expressive Vocabulary; Rec. Voc. Receptive Vocabulary;
TECOSY: French listening comprehension; TROG: Test for Reception of Grammar;
ELFE: German reading comprehension; Lu: Luxembourgish; D: German

The second part of the analyses focused on the eight remaining reading, spelling, and mathematical ability measures. Fit indices of the different models are represented in Table 4.10.

TABLE 4.10.
Fit Indices for the Learning Ability Models (Reading, Spelling, and Maths) in Second Grade

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Model 1:							
Single factor model (literacy measures only)	20.17	5	.00	.97	.97	.16	40.17
Model 2:							
2-factor model: reading & spelling	2.72	4	.61	1.00	1.03	.00	24.72
Model 3:							
3-factor model: reading, spelling, & mathematical abilities	25.19	17	.09	.99	.99	.06	63.19

The measures did not violate the assumption of multivariate normality with a standardized kurtosis of .09. Furthermore, no multivariate outliers were detected. First only the five reading and spelling measures were included in the analyses[10]. Two models were contrasted: model 1 consisted of a single factor model with all five measures loading on a common literacy construct; model 2 tested the hypothesis that the two spelling measures related to a common factor that was separate from a reading factor defined by the three reading measures. The single factor model 1 provided an unsatisfactory fit to the data (significant χ^2, and RMSEA > .15). In contrast, fit indices of model 2 indicated that this model provided a good account of the data with a highly non-significant χ^2 value, CFI and IFI values of 1, and an RMSEA of .00. Standardized residual covariances fell between -.27 and .12. A χ^2 difference test revealed that model 2 provided a significantly better account of the data than model 1 [$\Delta\chi^2(1) = 17.45$, $p < .05$].

In the next model the three mathematical ability measures were further added into the analyses. Model 3 is represented in Figure 4.4. and consists of the two previously identified reading and writing constructs, and a third mathematical ability factor - indexed by the three scores obtained from the teacher rating questionnaire. This model fitted the data well with a non-significant χ^2 value, CFI and IFI values of .99, and an RMSEA of .06. Standardized residual covariances ranged from -.66 to .42.

[10] When the mathematical ability measures were included at this stage of the analyses the model did not converge to an admissible solution. The underlying factor structure of the reading and spelling measures was therefore identified prior to adding a mathematical construct in Model 3.

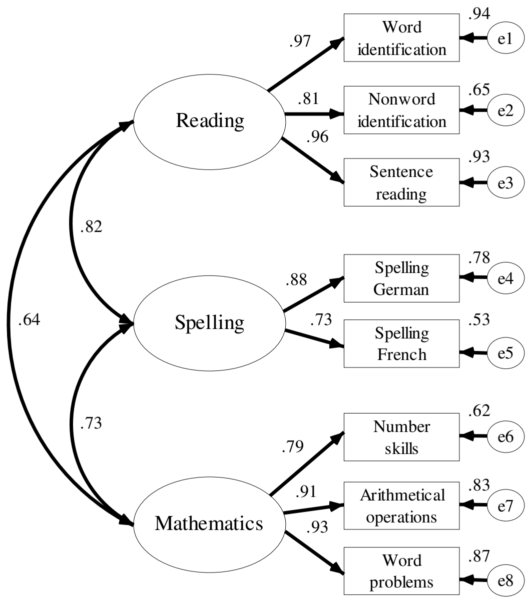

FIGURE 4.4.
Model 3: Three-factor CFA model for the learning ability measures in second grade; Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

4.3.2. Working memory and short-term memory

After having established satisfactory measurement models for the learning ability measures, the next part of the analyses focused on the WM and STM tasks. As before, separate analyses were performed for each study wave. The first step in the analyses was to confirm the theoretical position of separate verbal STM and WM constructs. For this purpose one and two-factor CFA models were fitted to the data. The fit indices of the different models tested are reported in Table 4.11. Furthermore, the analyses explored whether the measured variables were related to each other in the same way over the three-year time period by fitting the same model simultaneously across the three study waves.

In each study wave children were assessed on nonword repetition, digit recall, counting recall, and backwards digit recall. For none of the three studies the assumption of multivariate normality was violated with standardized kurtosis values of .70 for kindergarten; -.29 for first grade, and 2.07 for second grade. No multivariate outliers were identified.

TABLE 4.11.
Fit Indices of the Working Memory Models for the Different Study Waves

Study wave	$\chi 2$	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
			Model 1. Single factor model				
Kindergarten	12.35	2	.00	.89	.89	.21	28.35
First grade	7.22[a]	3	.06	.93	.93	.11	21.22
Second grade	11.96	2	.00	.87	.88	.20	27.96
			Model 2. 2-factor model				
Kindergarten	3.61	1	.06	.97	.97	.15	21.61
First grade	3.12[b]	2	.21	.98	.98	.07	19.12
Second grade	.00	1	.94	1.00	1.01	.00	18.00
			Model 3. 2-factor model: backwards digit recall and digit recall constrained error variance				
Kindergarten	4.49	2	.11	.97	.97	.10	20.49
First grade	4.11	2	.13	.96	.97	.09	20.11
Second grade	.00	2	.99	1.00	1.02	.00	16.00
			Model 4: 2-factor multidimensional model				
Kindergarten	3.61	1	.06	.97	.97	.15	21.61
First grade	2.35[b]	2	.31	.99	.99	.04	18.35
Second grade	.00	1	.94	1.00	1.01	.00	18.00
			Model 5: 2-factor multidimensional model: backwards digit recall and digit recall constrained				
Kindergarten	4.09	2	.13	.98	.98	.09	20.09
First grade model A	3.67	2	.16	.97	.97	.08	19.67
model B	3.76	3	.29	.98	.99	.05	17.76
Second grade	.16	2	.92	1.00	1.02	.00	16.16

Note. [a]error variance of nonword repetition constrained to .005; [b]error variance of backwards digit recall constrained to .005

Single factor model

A single factor model was fitted to the kindergarten, first, and second grade data in separate analyses. Fit indices in Table 4.11. indicate that for none of the studies this one-factor model provided a good account of the data. For the first grade data an improper solution emerged, with a negative error variance of the nonword repetition measure. This negative value did not differ significantly from 0 and was therefore constrained to.005. Across the three study waves χ^2 values were non-significant (with exception of the problematic first grade model), CFI and IFI were relatively low, and RMSEA values were above .10.

Two-factor model

The next set of models explored the possibility that digit recall and nonword repetition were linked to one common STM factor, and counting recall and backwards digit recall loaded on a separate WM factor (model 2; Figure 4.5.). The correlation between the factors provided an estimation of the degree to which the two constructs were related.

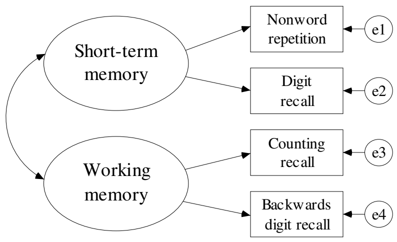

FIGURE 4.5.
Two-factor model

Across the three testing waves the two-factor model 2 (Table 4.11.) provided a good fit to the data with non-significant χ^2 values, CFI and IFI indexes above .96, and low RMSEA values (with the exception of the kindergarten model for which the RMSEA was .15). In all three study waves the two-factor model 2 accounted significantly better for the data than the single factor model 1 [kindergarten: $\Delta\chi^2(1) = 8.74$; first grade: $\Delta\chi^2(1) = 4.1$; second grade: $\Delta\chi^2(1) = 11.96$; $p < .05$, in all cases], supporting the hypothesis that the two target STM tasks and the two WM measures reflect different latent variables.

Although model 2 provided a satisfactory account of the data, there were two main problems with this model: First, as for the single factor model 1, a negative error variance for one of the measures (backwards digit recall) emerged in first grade. Furthermore, the RMSEA value of the kindergarten model was relatively high, indicating that the model might be overly complex. Inspection of the critical ratios for parameter differences[11] of the kindergarten model suggested that constraining the error variance of digit recall and backwards digit recall to be equal might improve model fit. Data on digit recall and backwards digit recall were obtained by using a very similar instrument, with both tasks involving the manipulation of numbers; it is therefore plausible that the two measures would behave in a similar way. The critical ratios for parameter differences were consistent with this hypothesis. When constraining the error variances of these two tasks to be equal (model 3, Table 4.11.), the χ^2 in kindergarten changed by .88; a non-significant increase for a change of 1 degrees of freedom. Most notably, adding this constrain improved the RMSEA index (.10) which was now in the range of tolerable model fit.

[11] Produced by AMOS: if two parameter estimates turn out to be nearly identical model fit can be improved by postulating a new model where those two parameters are specified to be exactly equal.

As for the kindergarten data, constraining backwards digit recall and digit recall residuals to be equal did not worsen model fit for the second grade model [model 3-model 2: $\Delta\chi^2(1) = .00$, $p < .01$] and resolved the problem of the negative error variance for the first grade data. For all three study waves, model 3 reached an admissible and satisfactory solution with standardized residual covariances ranging from -95 to .69 for kindergarten, -1.15 to .62 for first grade, and -.01 to .04 for second grade. The models are summarized in Figure 4.6. for kindergarten, Figure 4.7. for first grade, and Figure 4.8. for second grade.

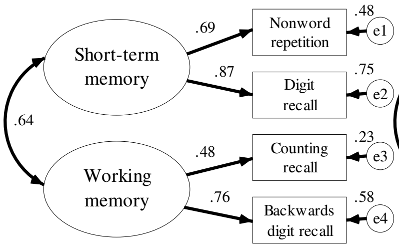

FIGURE 4.6.
Model 3: Kindergarten

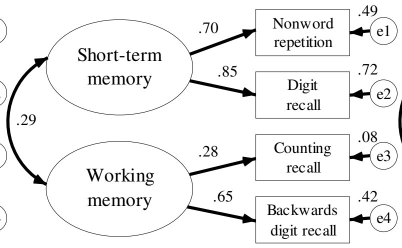

FIGURE 4.7.
Model 3: First grade

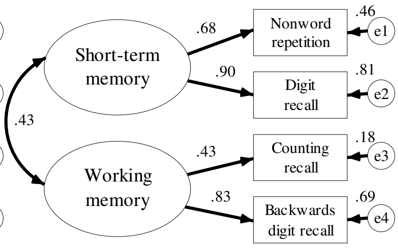

FIGURE 4.8.
Model 3: Second grade

Two-factor CFA models for the WM and STM measures (with digit recall and backwards digit recall constrained); Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

It is worth pointing out that the factor loadings of the STM measures onto their common underlying construct appeared to be relatively stable across the three study waves. In the same way, the standardized factor loading of the counting recall and the backwards digit recall measures were similar in magnitude in kindergarten and in second grade. In first grade, however, the loadings of these two measures were considerable lower, especially for the counting recall measure (.28). Furthermore, in first grade the association between the two latent construct was lower (.29) than in the kindergarten and in the first grade models (.64 and .43 respectively).

The next set of models tested an equivalent version of the two-factor model 2, featuring replacement of the correlation between the two latent constructs with the specification that counting recall and backwards digit recall are multidimensional (Figure 4.9.). Fit indices of this model 4 are presented in Table 4.11.

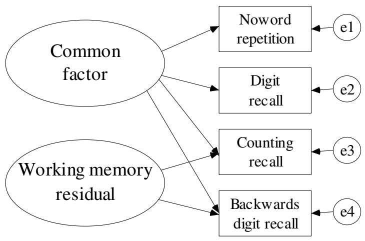

FIGURE 4.9.
Multidimensional two-factor model

Although the factors are assumed to be orthogonal in this model, all four indicators have loadings on a common factor which accounts for their observed correlations just as well as model 2[12]. In the case of equivalent models the predicted correlations and values of fit statistics are identical and the choice between models is of a theoretical rather than of a mathematical nature (Kline, 2005). In the present case the multidimensional model 4 was favoured over the independent model 2 upon the basis of substantial prior evidence that complex WM span tasks depend both on the central executive (controlled attention) and on domain-specific storage (Alloway et al., 2006). As for model 2, the kindergarten RMSEA was high in model 4, and the error variance of backwards digit recall had to be constrained in order to avoid a negative value (explaining the difference in fit indices for the equivalent models 2 and 4 in first grade). In the same way as in model 3, an equality constraint was therefore imposed on the error terms of digit and backwards digit recall in model 5. This resulted in a non-significant increase of fit in all three models [kindergarten, $\Delta\chi^2(1) = .48$; first grade, $\Delta\chi^2(1) = 1.32$; second grade $\Delta\chi^2(1) = .16$, $p > .10$ in each case], an acceptable RMSEA value for the kindergarten model, and an admissible solution for the first grade data. Model 5 was therefore preferred over model 4.

In first grade the factor loading of counting recall on the common factor was low with a non-significant standardized estimate of .03. Although model 5 (A) provided a good account of the first grade data, the model might be unnecessary complex. In model 5B the path between counting recall and the common factor was therefore eliminated in first grade, leading to a non-significant χ^2 increase of .09 for a change of 1 degree of freedom. The factor loading of counting recall on the common factor was also non-significant in second grade; the association was, however, stronger than in first grade (.19; $p = .07$) and the link was therefore maintained.

[12] Note that because the factors are specified as independent it is necessary to constrain the factor loadings of counting recall and backwards digit recall to be equal in order to identify this model.

Model 5 (5B for first grade) provided a good account of the data with standardized covariance residuals ranging from -.81 to .48 for kindergarten, -.55 to .90 for first grade, and -.20 to .08 for second grade. The models are summarized in Figure 4.10, 4.11, and 4.12 for the kindergarten, first, and second grade study waves respectively. Model 5 was maintained as base model for the subsequent analyses.

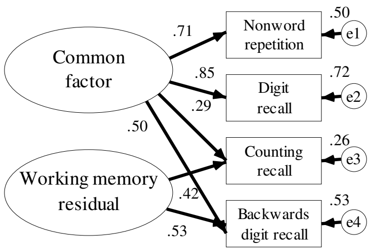

FIGURE 4.10.
Model 5: Kindergarten

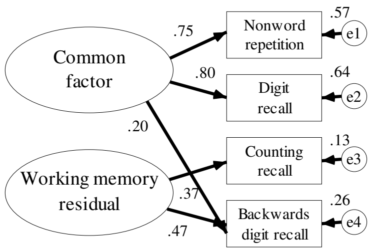

FIGURE 4.11.
Model 5B: First grade

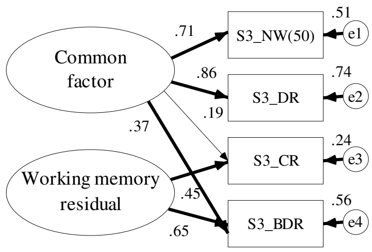

FIGURE 4.12.
Model 5: Second grade

Two-factor CFA multidimensional models for the WM and STM measures (with digit recall and backwards digit recall constrained); Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

Multiple group analyses

The preceding analyses suggest that the general two-factor structure of WM seems to hold through the years. This hypothesis was assessed more directly by conducting multiple group analyses in which participants in each study wave were considered as different groups. The same baseline model, represented in Figure 4.9. was fitted simultaneously across the three groups (model A). Fit indices in Table 4.12. indicate that this multiple group model A was acceptable at any conventional significance level. As expected, the hypothesized multidimensional two-factor structure therefore appeared to be valid across the three study waves.

TABLE 4.12.
Fit Indices for the Multiple Group Analyses

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Three waves: K-Gr1-Gr2							
Model A	7.92	6	.24	.99	.99	.03	55.92
Model B	14.69	12	.26	.99	.99	.02	50.69
Model C	31.40	22	.09	.96	.96	.03	47.40
Two waves: K-Gr1							
Model A2	7.76	4	.10	.98	.98	.06	39.76
Model B2	13.90	7	.05	.95	.96	.06	39.90
Model C3	24.99	12	.01	.91	.91	.07	40.99
Two waves: K-Gr2							
Model A3	4.25	4	.37	1.00	1.00	.02	36.25
Model B3	5.62	7	.58	1.00	1.00	.00	31.62
Model C3	14.50	12	.27	.99	.99	.03	30.50
Two waves: Gr1-Gr2							
Model A4	3.83	4	.43	1.00	1.00	.00	35.83
Model B4	6.08	7	.53	1.00	1.00	.00	32.08
Model C4	11.00	12	.53	1.00	1.00	.00	27.01

Note . K: kindergarten; Gr1: first grade; Gr2: second grade

The next step was to determine whether parameter values changed significantly across the years. In multiple group model B, factor loadings (the regressions of the variables onto their associated factors) were constrained to be equal. Fit statistics in Table 4.12. were acceptable and the χ^2 difference with model A was non-significant [$\Delta\chi^2(6) = 6.77$, $p > .10$], indicating that model B, specifying an age invariant factor pattern, provided a good account of the data. In a final model C, the variances of the residuals and of the latent factors were constrained to be equal in addition to the specification of invariant factor loadings. This model fitted the data well, with a non-significant χ^2 value, CFI and IFI indices of .96, and an RMSEA of .03 (Table 4.12.). Compared to model B, the χ^2 increase of 16.71 for 10 degrees of freedom was non-significant. Model C, specifying complete factor invariance across the ages could therefore be accepted as providing a good account of the data.

Factor invariance across ages was investigated in more detail by fitting the same model across only two groups at a time in three sets of analyses: kindergarten-first grade, kindergarten-second grade, and first grade-second grade. As in the preceding analyses model A specified the same factor structure but did not impose constraints on any parameter estimates; model B constrained the factor loadings to be equal; and in model C factor loadings as well as error and factor variances were constrained to be identical. Fit indices for the different models are presented in Table 4.12. For all three comparisons, the common factor structure provided an acceptable fit to the data (model A2, A3, and A4). Furthermore, model B and model C, specifying invariant factor estimates, fitted the data well for the multiple group analyses first grade-second grade and kindergarten-second grade. For the kindergarten-first grade comparison, the data showed that model B2 provided an acceptable account of the data that fitted the data as well as model A2 [$\Delta\chi^2(3) = 6.14$, $p > .05$]. Model C2 was, however, significantly worse than model B2 [$\Delta\chi^2(5) = 11.09$, $p < .05$], suggesting that complete factor invariance can not be assumed between kindergarten and first grade.

4.3.3. Working memory, short-term memory, and related cognitive abilities

The main aim of the following analyses was to explore the relationship between WM and STM with phonological awareness and fluid intelligence. For this purpose measures of phonological awareness and of fluid intelligence were added in separate analyses to the previously identified multidimensional two-factor model (Figure 4.9.). The first part of the results will focus on the relationship between WM, STM, and phonological awareness, whereas the second part of the analyses will explore the links between WM, STM, and fluid intelligence.

Phonological awareness

The main interest of the following analyses was to investigate if the phonological awareness measures would relate to the common factor, representing a potential phonological processing construct, or if the data could be better represented by a three-factor model, with phonological awareness representing an independent factor. In all of the subsequent analyses two models were contrasted: Model 1, represented in Figure 4.13., consisted of a two-factor structure in which the phonological awareness measures were specified to relate to the common factor, together with the WM and the STM measures. Model 2, represented in Figure 4.14., consisted of a three-factor model in which the phonological awareness measures were tapping a separate factor, distinct from verbal STM and WM.

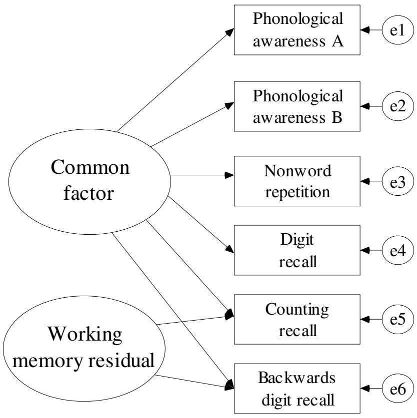

FIGURE 4.13.
Two-factor model
Common phonological processing factor and working memory

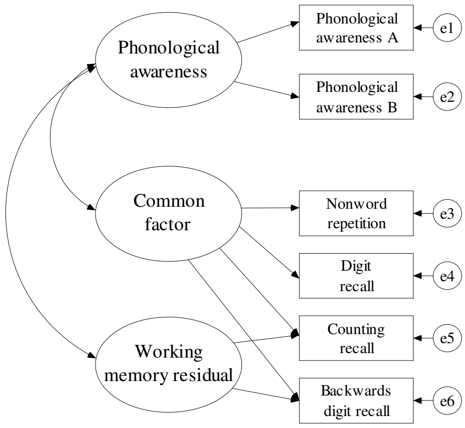

FIGURE 4.14.
Three-factor model
Phonological awareness, common factor, and working memory

Two- and three-factor models were fitted to the data of each grade in separate analyses. In each study wave children were assessed on different phonological awareness measures. Fit indices for all the models tested are provided in Table 4.13.

TABLE 4.13.
Fit Indices for Confirmatory Factor Analysis Including WM, STM, and Phonological Awareness Measures

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Kindergarten							
Model 1:							
2-factor model	43.29	9	.00	.75	.76	.18	67.30
Model 2:							
3-factor model	15.60	8[a]	.05	.94	.95	.09	41.60
First grade							
Model 1:							
2-factor model	28.10	10	.00	.81	.82	.12	50.10
Model 2:							
3-factor model	8.63	8	.37	.99	.99	.03	34.63
Second grade							
Model 1:							
2-factor model	66.50	9	.00	.69	.70	.23	90.50
Model 2:							
3-factor model	7.68	8[b]	.46	1.00	1.00	.00	33.68

Note . [a]error variance of the rhyme easy task constrained to .005; [b]error variance of the *Spoonerism task* constrained to .005

Kindergarten

In kindergarten children were assessed on two measures of rhyme detection. The data manifested multivariate normality, with a standardized kurtosis of 1.13; no multivariate outliers were detected. The two-factor model 1 provided a bad fit to the data with a highly significant χ^2 value, and unsatisfactory CFI, IFI, and RMSEA indices. Residual covariances were largest for the two rhyme measures suggesting that a three-factor model might fit the data better. This hypothesis was confirmed: When fitting model 2, in which the two rhyme measures were specified to load onto a separate factor, the χ^2 value reduced by 27.7 for a decrease of 2 degrees of freedom ($p < .001$). In the models initial solution the error variance of one rhyme detection measure (rhyme easy) was negative but not significantly different from 0. In a subsequent model this estimate was therefore constrained to .005 (Bentler, 1976). The overall fit indices in Table 4.13. suggest that this three-factor model provided an adequate account of the data. The model solution is summarized in Figure 4.15. Notably, the rhyme detection construct was significantly linked to the common factor but not to the WM residual latent construct.

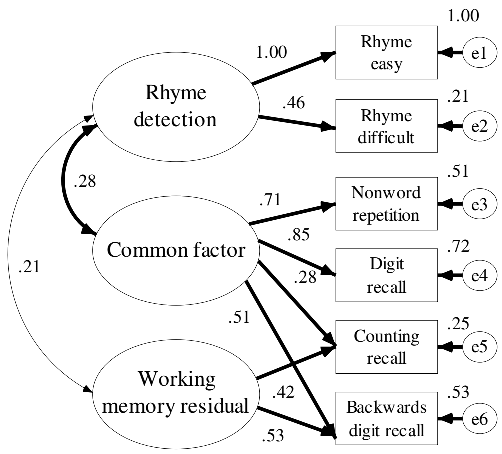

FIGURE 4.15.
Model 2: Three-factor CFA model
for the phonological awareness, WM, and STM measures in kindergarten;
Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

First grade

Two measures of phonological awareness were obtained in first grade: first sound detection and Spoonerism. The data appeared to manifest multivariate normality with no multivariate outliers. As in kindergarten, the two-factor model 1 was rejected on the basis of the indices provided in Table 4.13. demonstrating poor model fit. Fit indices of model 2 indicated that a three-factor solution provided a good account of the data (non-significant χ^2; CFI and IFI of .99; RMSEA of .03) that was significantly better than the two-factor model 1 [$\Delta\chi^2(2) = 19.47$, $p < .05$]. The model solution is summarized in Figure 4.16. Importantly, phonological awareness manifested strong links with both the common factor and the WM residual latent construct.

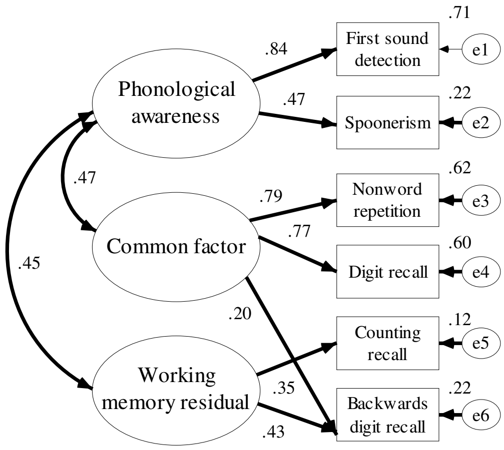

FIGURE 4.16.
Model 2: Three-factor CFA model
for the phonological awareness, WM, and STM measures in first grade;
Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

Second grade

In second grade, children completed two tasks purportedly tapping phonological awareness: Spoonerism and the odd-one-out task. The six measures included in the analyses did not manifest severe departures from multivariate normality, with a standardized kurtosis value of 2.7. No multivariate outliers were detected. As in the previous years, the two-factor model 1 provided a bad account of the data. Model 2 in contrast, proved to be an excellent fit to the data with a non-significant χ^2, CFI and IFI values of 1, and an RMSEA of .00 (Table 4.13). Because the error variance of the Spoonerism task was negative but not significantly different from 0, it was constrained to .005. Model 2 provided a significantly better account of the data than the two-factor model 1 [$\Delta\chi^2(1) = 58.82$, $p < .05$]. The model solution is summarized in Figure 4.17. Phonological awareness was significantly linked to the common factor but did not manifest significant associations with the WM residual latent construct.

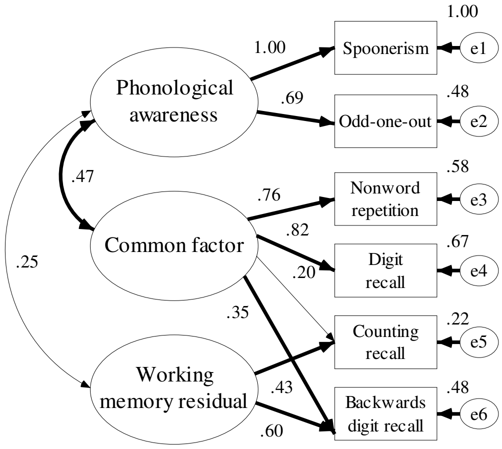

FIGURE 4.17.
Model 2: Three-factor CFA model
for the phonological awareness, WM, and STM measures in second grade;
Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

Fluid intelligence

For fluid intelligence only one observed measure was obtained: the Raven Coloured Progressive Matrices Test (Raven et al., 1986). Single indicator constructs can be modelled in different ways in structural equation modelling: As in path analyses, the measure can be included as an observed variable without a measurement error term. Alternatively, the error term can be fixed to a constant based on the measure's reliability. Finally, to optimize the models solution and avoid biasing effects of error, distinct subsets of items within the scale can be combining. This technique is known as *parcelling* (Kishton & Widaman, 1994; Little, Cunningham, Shahar, & Widaman, 2002). Given that the Raven Coloured Progressive Matrices Test consists of three subscales (see chapter 3, p. 84 for further details) the latter technique of parcelling was adopted in the present context. In all the analyses the latent variable fluid intelligence was thus indexed by three observed variables: Raven A; Raven AB; and Raven B sub-scores[13]. The three variables were screened in the same way as the rest of the measures and met the necessary assumptions for structural equation modelling.

[13] All the analyses were conducted again with the Raven overall score as outcome variable and with the error term constrained to an estimate based on the measures established reliability. The results did not change considerably.

The main aim of the analyses was to specify whether the data was best characterized by a common WM-fluid intelligence construct or if a three-factor model with separate, but associated, WM and fluid intelligence latent factors would provide a better account of the data.

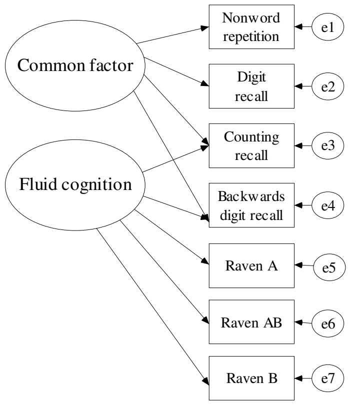

FIGURE 4.18.
Two-factor model
Fluid cognition and common factor

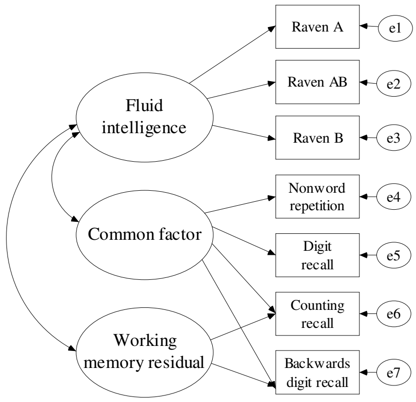

FIGURE 4.19.
Three-factor model
Fluid intelligence, common factor, and working memory

Two different models were therefore fitted to the data: In the two-factor model 1, represented in Figure 4.18., the Raven's sub-scores were linked to the same factor as the WM measures. In the three-factor model 2, represented in Figure 4.19., the Raven's sub-scores were specified to load onto a separate factor, distinct from verbal STM and WM. These two- and three-factor models were fitted to the data of each study wave in separate analyses, and fit indices for all the models are provided in Table 4.14.

TABLE 4.14.
Fit Indices for Confirmatory Factor Analysis Including WM, STM, and Fluid Intelligence Measures

Model	$\chi 2$	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
			Kindergarten				
Model 1:							
2-factor model	17.25	14	.24	.98	.98	.04	45.25
Model 2:							
3-factor model	10.80	12	.55	1.00	1.01	.00	42.80
			First grade				
Model 1:							
2-factor model	17.24	15	.30	.98	.98	.04	43.24
Model 2:							
3-factor model	11.71	13	.55	1.00	1.01	.00	41.71
			Second grade				
Model 1:							
2-factor model	23.12	14	.06	.93	.93	.07	51.12
Model 2:							
3-factor model	8.16	12	.77	1.00	1.03	.00	40.16

Kindergarten

All the variables in the analyses manifested multivariate normality with a standardized kurtosis of .54 and no multivariate outliers. Fit statistics in Table 4.14 show that the three-factor model 2 provided a significantly better account of the data than the two-factor model 1 [$\Delta\chi^2(2) = 6.45$, $p < .05$]. Fit indices of model 2 were excellent with a significant χ^2 value, CFI and IFI values of 1, and an RMSEA of 0. The model solution is summarized in Figure 4.20. Fluid intelligence manifested strong links with the WM residual latent construct but not with the common factor.

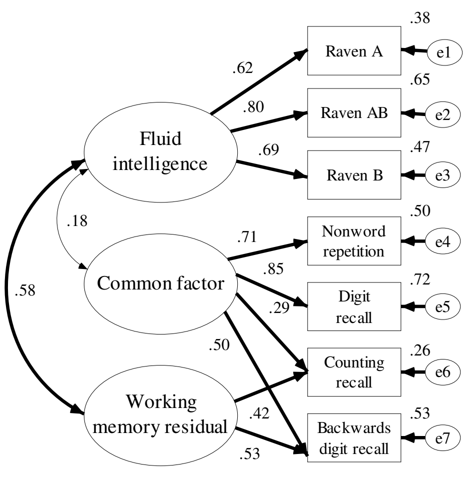

FIGURE 4.20.
Model 2: Three-factor CFA model for the fluid intelligence, WM, and STM measures in kindergarten; Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

First grade

The data manifested multivariate normality (standardized kurtosis of -.74) with no multivariate outliers. As in kindergarten, the three-factor model 2 fitted the data well with a significant χ^2 value, CFI and IFI values of 1, and an RMSEA of 0 (Table 4.14). It is important to point out that, according to the χ^2 difference test, model 2 just failed to provide a better account of the data than the simpler two-factor model 1 [$\Delta\chi^2(2) = 5.53$, $p = .06$]. The AIC statistic, in contrast, suggests that model 2 should be preferred over model 1. Furthermore, the standardized residual covariances for the Raven's sub-scores were high in model 1 (ranging from 1.4 to 2.27) which further supports the position that model 2 provides a better account of the data than model 1. Model 2 is represented in Figure 4.21. As for the kindergarten data, fluid intelligence was significantly linked to the WM residual but not to the common factor.

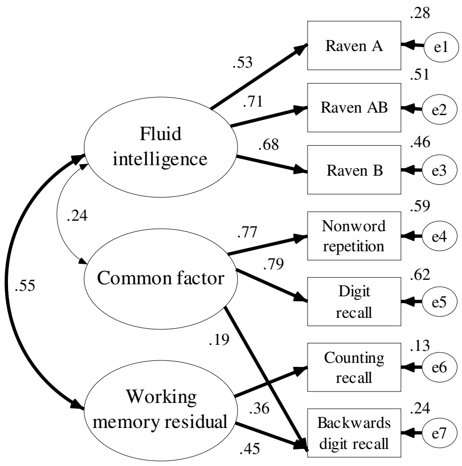

FIGURE 4.21.
Model 2: Three-factor CFA model
for the fluid intelligence, WM, and STM measures in first grade;
Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

Second grade

The measures included in the analyses did not manifest severe departures from multivariate normality with a standardized kurtosis of 1.08. No multivariate outliers were detected. As in the previous years, the three-factor model 2 (Table 4.14.; Figure 4.22) provided a good account of the data that was significantly better than the two-factor model 1 [$\Delta\chi^2(2) = 14.95$, $p < .05$]. It is worth pointing out that in contrast to the models in kindergarten and first grade, fluid intelligence was significantly associated with both the WM residual and the common factor.

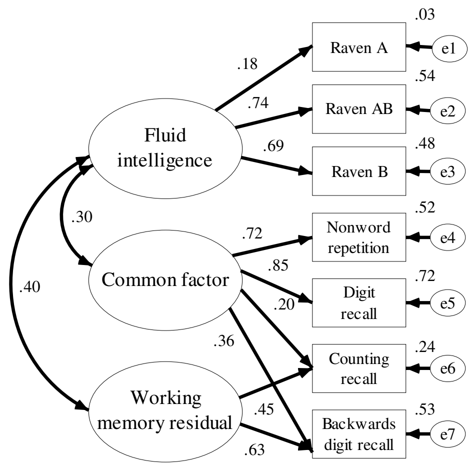

FIGURE 4.22.
Model 2: Three-factor CFA model
for the fluid intelligence, WM, and STM measures in second grade;
Lines in boldface indicate coefficients significant at the .05 level; Numbers next to the circles are proportions of variance in the observed variable explained by the latent construct.

4.3.4. Stability of the measures

The stability of a measure or a latent construct refers to the consistency of individual differences from one year to the next (Wagner et al., 1997). Correlations of a latent construct with itself across the span from kindergarten to second grade are presented in Table 4.15. The numbers in the table can be interpreted as correlation coefficients; they do, however, not correspond to Pearson's product-moment correlation coefficients. Instead, they are standardized maximum likelihood estimates of covariances among latent factors.

The latent variables were built in the same way as in the models described above. For the common (verbal STM) and residual WM factor, as well as vocabulary, and fluid intelligence, the same measures were used in each study wave. For phonological awareness, comprehension, and reading the observed measures differed across the years. Correlation estimates between latent factors were obtained by optimizing the fit between the variance-covariance matrix, implied by the specified model and parameter estimates, and the actual variance-covariance matrix obtained from the sample. In each case model fits were excellent with non-significant χ^2 values (p's ranging from .12 to .87); CFI and IFI indices between .98 and 1; and RMSEA values ranging from .00 to .07.

The results indicated that individual differences in verbal STM were extremely stable over the years. This suggests that children who presented low verbal STM skills in kindergarten continued to be relatively weak in this ability up to second grade. Stability of the residual WM construct was lower but seemed to increase with time. Notably are also the strong autocorrelations of the vocabulary and comprehension factors across the three study waves (r's ranging from .75 to .99) and also the high correlations of first grade and second grade reading. Important for the present context is that this high stability leaves little room for individual difference variability that can be accounted for by other factors.

TABLE 4.15.
Stability of the Latent Constructs Over Time

	Time interval		
Latent variable	K-Gr1	Gr1-Gr2	K-Gr2
1. Verbal STM	.98	1.00	.98
2. WM	.46	.77	.60
3. Phonological awareness	.57	.91	.46
4. Fluid intelligence	.78	.90	.74
5. Vocabulary	.90	.96	.89
6. Comprehension	.80	.99	.75
7. Reading	.31	.85	.28

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; all correlations are significant at $p < .05$

4.4. Discussion

The present chapter had three main objectives: First, to explore the psychometric properties of the measures used in the study and the adequacy with which they represent their purported underlying constructs of interest; Second, to investigate the underlying factor structure of WM and STM in a population of young, multilingual children; Third, to explore the relationship between WM, STM, and related cognitive abilities – phonological awareness and fluid intelligence. Each of these objectives are addressed in turn in the proceeding sections.

4.4.1. Psychometric properties of the measures and adequacy of the measurement model

The data showed that, with one exception, all of the measures manifested acceptable reliability across the three waves of the study and showed steady improvement in accuracy over the years. This finding is particular important for the measures that were particularly designed for the present study – expressive and receptive French vocabulary, French spelling, the Luxembourgish Nonword Repetition Task (LuNRep), and the "Test de Compréhension Syntaxique" (TECOSY). As hardly any test material exists in the Luxembourgish language or has been adjusted for use with multilingual Luxembourgish children, the design of these reliable and valid new measures might have important implications for future research projects involving Luxembourgish school children.

Confirmatory factor analysis showed that the learning ability measures in kindergarten and first grade loaded as predicted on the expected number of factors. In both study waves three different learning constructs were identified: vocabulary knowledge, language comprehension, and reading. In second grade the same factor structure emerged in addition to a spelling and a mathematical construct. Importantly, the latent constructs comprehension and vocabulary were strongly linked in all three testing occasions in line with previous evidence showing that vocabulary knowledge is critical for many aspects of language processing abilities (Baddeley et al., 1998; Gathercole et al., 1992).

One surprising aspect of the data was that the French vocabulary and comprehension measures, in contrast to the corresponding assessments in the foreign language German, did not relate to the native vocabulary and comprehension measures but instead defined a separate French language construct. These findings seem to suggest that early acquisition of an unfamiliar foreign language might draw on different underlying mechanisms than new word learning in a familiar second language. In other words, 8-year-old Luxembourgish children might acquire the foreign language French in a qualitatively different way to the foreign language German.

One possibility is that the high degree of phonological overlap between Luxembourgish and German may favour a word learning strategy in which new German words are being acquired by direct association with the equivalent native words. German vocabulary might therefore be learned via a process of bootstrapping onto the secure knowledge base already established for the native language (Chen & Leung, 1989; Masoura & Gathercole, 1999). Acquiring new words in French might not benefit in the same way from existing lexical knowledge in the native language, as the phonological structure of French words is very different from words in Luxembourgish. This account is consistent with previous evidence, showing that new word learning in a foreign language is based on lexical and semantic mediation techniques if the foreign language to be learned is very similar to a language that is mastered proficiently. In contrast, new word learning in an unfamiliar foreign language, such as French, that does not share many lexical and semantic features with the native language Luxembourgish might rely on more basic cognitive processes, with verbal STM as one potential candidate (Gathercole & Thorn, 1998; Papagno et al., 1991).

The analysis further showed that the selected WM and STM measures manifested satisfactory convergent validity. Importantly, nonword repetition was more strongly associated with the other measure of verbal STM - digit recall - than with the phonological awareness tasks, providing support for the position that nonword repetition is a valid measure of verbal STM (Baddeley et al., 1998; Baddeley & Wilson, 1993; Butterworth et al., 1986; Gathercole et al., 1999; Gathercole et al., 1992; Gupta, 2003) and contradicting others claiming that the ability to repeat nonwords is mainly mediated by phonological awareness (Bowey, 1997, 2006; Hu & Schuele, 2005; Metsala, 1999; Snowling et al., 1991).

Another measure that has engendered some controversy in the literature is backwards digit recall, regarded by some as a valid measure of WM (Alloway et al., 2004; Gathercole & Pickering, 2000a), whereas others argue that this task mainly reflects short-term storage (Cantor et al., 1991; Engle et al., 1999b). In the present study, backwards digit recall was included as a measure of WM on the basis of the theoretical argument that for young children reversing the order of digits is an attention demanding tasks and is therefore likely to draw on resources from the central executive. The results are consistent with this position; in all three study waves backwards digit recall was significantly linked to the other WM measure - counting recall. It is, however, worth pointing out that backwards digit recall was also related to assessments of STM, in line with the position that in addition to tapping controlled attention, backwards digit recall also involves short-term storage. Interestingly, the factor loadings for backwards digit recall on the verbal STM latent construct was higher than for counting recall, suggesting that backwards digit recall reflects a stronger STM component than counting recall.

4.4.2. Underlying factor structure of working memory and short-term memory in young multilingual children

The data are consistent with a WM system with separate but related elements, corresponding to verbal STM and controlled attention/central executive, in line with the theoretical framework on adults proposed by Baddeley (2000) and Engle et al. (1999a; 1999b). More specifically, the two simple storage tasks - requiring the maintenance of sequential order information with no explicit concurrent processing task - defined a STM factor, whereas the two complex span measures - involving the simultaneous storage and processing of information - defined a WM construct. Importantly, a model forcing a single factor onto the data could be rejected in all three study waves, contradicting previous evidence on adults (Colom, Rebollo et al., 2006) and on children (Hutton & Towse, 2001) showing WM and STM tasks as loading on the same factor. The results also address the hypothesis put forward by Engle et al. (1999b) and Cowan et al. (2005) that WM and STM should be less distinct in younger then in older children or adults due to less automated rehearsal and chunking processes and consequently increased implications of controlled attention in assessments of STM in young children. Contrary to this hypothesis and in agreement with others (Alloway et al., 2006; Gathercole et al., 2004; Kail & Hall, 2001; Swanson, 2008), the same two-factor structure that Engle et al. (1999b) identified in adults was found in children as young as 6 years of age. Furthermore, the correlations between the WM and STM factors were smaller than in the Engle et al. (1999b) study, suggesting greater independence among these latent constructs in children than in adults.

Another important feature of the results was that complex span tasks shared substantial variance with measures of simple storage, but that they also reflected some unique variance (see Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Swanson, 2008 for similar findings). Baddeley (2000) and Engle et al. (1999b) propose that the shared variance should conceptually correspond to short-term storage, and the residual factor should reflect the additional executive attention processes engaged by the dual task nature of the WM span tasks. According to this theoretical standpoint, and in agreement with the present findings, performance on verbal complex span measures of WM reflects both storage in a short-term store and attentional support from the central executive, whereas the WM residual, obtained by statistically controlling for the common variance between WM and STM tasks, should mainly reflect controlled attention.

A further significant finding was the remarkable consistency of the factor structure across the developmental period from kindergarten to second grade. Multiple group analysis showed that WM and STM tasks were tapping comparable constructs across the three age groups. Additional support for the stability of individual differences in STM and WM was provided by the high correlations of each latent construct with itself across the different measurement occasions. These results extend previous findings by Alloway et al. (2006) on children between 4 and 11 years of age, by Gathercole et al. (2004) on 4- to 15-year-olds, and by Swanson (2008) on 6- to 9-year-olds. Importantly, the conclusions reached in these studies were only suggestive because the findings were based on cross-sectional data. The longitudinal latent variable approach adopted in the present context therefore provides more convincing evidence in favour of viewing WM and STM as stable and coherent individual difference variables across the early childhood years.

This finding might have important practical implications. Given the increasing evidence of potential causal relations between WM and learning, a subject that will be discuss in depth in the following chapters, the present finding of the stability of individual difference in young children's WM and STM abilities reinforces the value of early screening of these abilities to identify children who are at present and future educational risk.

4.4.3. Relationship between working memory, short-term memory, and related cognitive abilities

The last section of this discussion will address the relationship between WM, and STM with related cognitive abilities: phonological awareness and fluid intelligence. Consider first the findings in relation to phonological awareness. The data showed that in all three study waves phonological awareness was clearly separable from both WM and STM (see also, Alloway et al., 2004; de Jong & van der Leij 1999; Wagner et al., 1997). This aspect of the data indicates that in this sample of Luxembourgish children, phonological storage and awareness abilities do not originate from a common phonological construct as suggested by Bowey (1996, 2001, 2006; see also Metsala, 1999; Wagner & Torgesen, 1987). Instead, the data are in line with the position that phonological awareness tasks primarily represents conscious metalinguistic knowledge of the phonological structure of words (Boada & Pennington, 2006), whereas assessments of verbal STM mainly reflect the ability to encode and retrieve the serial order of phonological sequences (Gupta et al., 2005).

It is worth pointing out that even though verbal STM and phonological awareness were distinguishable constructs they also manifested strong links, raising the possibility that both ability might be determined by a third unobserved factor; potentially the quality of phonological representations (Boada & Pennington, 2006; Gathercole et al., 1992; Service et al., 2007). There were also some indications in the data that the central executive component of WM might contribute to performance on phonological awareness tasks (Gathercole, 2006; Leather & Henry, 1994; Wagner & Torgesen, 1987), possibly by providing the attentional resources necessary for maintaining relevant task information in an active state while at the same time manipulating them. In most of the phonological awareness tasks children had to store the phonology of a word in memory and simultaneously compare it to the phonology of several other words.

In the same way as for phonological awareness, individual differences in fluid intelligence were separable from variations in verbal STM and the central executive component of WM. Importantly, the data showed that, as in adults (Conway et al., 2002; Engle et al., 1999b; Kane et al., 2004), fluid intelligence was more strongly related to the WM residual then to STM in this population of young children. These findings are consistent with the view that the WM residual variance mainly reflects executive controlled attention that might be responsible for the link with fluid intelligence (Conway et al., 2002; Engle et al., 1999b).

4.4.4. Conclusion

Taken together, the present findings indicate that verbal STM, central executive, phonological awareness, and fluid intelligence are distinct but highly related constructs in 5- to 9-year-old multilingual children, growing up in Luxembourg. These findings are in line with previous developmental studies on English speaking monolingual children (Alloway et al., 2004; Swanson, 2008). Furthermore, the data presented in this chapter provided preliminary evidence that WM and STM manifest differential associations with learning over the years. Whereas, WM and phonological awareness seemed to be related to many areas of learning, verbal STM appeared to be more specifically linked to the language domain. The following chapters will extend on this point, by exploring links between WM, STM, and the different learning constructs at the level of latent variables.

CHAPTER FIVE

Results II - Cross-sectional analyses

The principal aim of the following analyses was to explore cross-sectional relations between the different memory constructs and learning in each study wave. The analyses compare alternative models of the theoretical structure of WM and learning constructs. The chapter is structured into three main sections. Section one explores the relationship between WM, STM, and the different learning constructs by fitting different CFA models and structural regression models to the data in order to test competing theoretical models of the associations between the measures and to compare the goodness of fit of each model. The second section will focuses on the specific contributions of WM and STM to learning, by controlling for related cognitive abilities. A series of hierarchical regressions analysis will be performed on the covariance structure in order to get a better understanding of the unique contributions of WM and STM to learning independent of fluid intelligence, phonological awareness, and verbal abilities. Furthermore, the analysis will specify the unique contributions of phonological awareness to learning. Finally, in the last section of this chapter, the main findings will be discussed.

5.1. Working memory, short-term memory, and learning

In a first step different CFA models explored the correlations of verbal STM and WM with the different learning constructs and fluid intelligence in each study wave. In these CFA models the links between WM and STM with learning were estimated without controlling for the WM-STM intercorrelations. In order to investigate more specific links between the latent constructs, a series of structural regression models were computed in a second part of the analysis.

5.1.1. Confirmatory factor analysis models

Separate CFA models were performed for each learning construct, for each wave of the study. In total 15 models were tested: three models (one for each wave) for vocabulary, comprehension, reading, and fluid intelligence; and one model for each, spelling, French language, and mathematical abilities in second grade. The basic model used for CFA is depicted in Figure 5.1.

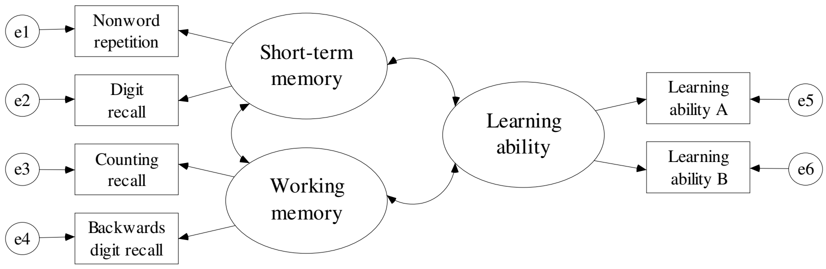

FIGURE 5.1.
Three-factor CFA model

In all the analyses the factor loadings and error variances were fixed to the values obtained from the measurement models outlined in chapter 4. Given that for most of the latent constructs only two observed measures were obtained, fitting the models in this way gives a cleaner estimation of the relationship between the constructs without distorting the character of the latent factors (Engle et al., 1999b). For two models in second grade multivariate outliers were detected. Two cases were therefore excluded from the analyses involving the vocabulary factor, and one subject was excluded from the analyses including the mathematical factor in second grade. After removal of these cases no further multivariate outliers were detected, and the distribution of scores for all of the analyses manifested multivariate normality.

Fit statistics in Table 5.1. indicate that all of the models tested provided a good account of the data with significant χ^2 values, CFI and IFI indices above .97, and RMSEAs below .07.

TABLE 5.1.
Fit Indices for Confirmatory Factor Analysis Including STM, WM, and Learning for the Different Study Waves

Study wave	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
			Vocabulary				
Kindergarten	17.91	15	.27	.98	.98	.04	29.91
First grade	15.05	15	.45	1.00	1.00	.00	27.05
Second grade[1]	21.00	15	.14	.97	.97	.06	33.00
			Comprehension				
Kindergarten	9.33	9	.41	1.00	1.00	.02	21.33
First grade	12.07	15	.67	1.00	1.03	.00	24.07
Second grade	18.36	22	.68	1.00	1.02	.00	30.36
			Reading				
Kindergarten	8.21	15	.91	1.00	1.06	.00	20.21
First grade	14.02	15	.52	1.00	1.00	.00	26.02
Second grade	24.08	22	.34	.99	.99	.03	36.08
			Fluid intelligence				
Kindergarten	11.55	22	.97	1.00	1.06	.00	23.55
First grade	14.55	22	.88	1.00	1.06	.00	26.55
Second grade	9.32	22	.99	1.00	1.10	.00	21.32
			Spelling				
Second grade	18.31	15	.25	.98	.98	.04	30.31
			French language				
Second grade	16.87	22	.77	1.00	1.02	.00	28.87
			Mathematical abilities				
Second grade[2]	31.89	22	.08	.97	.97	.06	43.89

Note . [1]N = 117; [2]N = 118

The correlations of the WM and verbal STM factors with the learning constructs on each occasion are presented in Table 5.2. As mentioned before, the structural coefficients represent the relation of verbal STM and WM with the given learning construct without controlling for their intercorrelations.[14]

[14] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average correlation coefficients between STM and learning changed by .04 for kindergarten, .03 for first grade, and .05 for second grade. For WM and learning correlation coefficients changed on average by .04 for kindergarten, .04 for first grade and .07 for second grade.

TABLE 5.2.
Correlations of the STM and WM Factors With the Different Learning Constructs in Each Study Wave

	Vocabulary			Comprehension			Reading			Fluid intelligence			Spelling	French	Math.
Factors	K	Gr1	Gr2 [1]	K	Gr1	Gr2	K	Gr1	Gr2	K	Gr1	Gr2	Gr2	Gr2	Gr2 [2]
STM	**.51**	**.40**	**.40**	**.55**	**.55**	**.43**	**.29**	**.30**	**.24**	.18	**.25**	**.28**	**.27**	**.24**	.18
WM	**.31**	.27	.13	**.55**	**.36**	**.46**	**.40**	.21	**.33**	**.54**	**.43**	**.42**	**.38**	.18	**.30**

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; [1]N = 117; [2]N = 118; ; significant coefficients marked in boldface, $p < .05$

The results in Table 5.2. show that verbal STM was strongly linked to vocabulary and comprehension and manifested weaker, yet significantly, associations with reading across the three study waves. Furthermore, verbal STM manifested medium associations with fluid intelligence in first and second grade, and spelling and French in second grade. WM correlated highest with comprehension and fluid intelligence in the three waves and was also significantly associated with vocabulary and pre-reading skills in kindergarten, and reading, spelling, and mathematical abilities in second grade.

5.1.2. Structural regression models

Structural regression (SR) models were used to address the question of whether STM and WM differentially relate to learning. These models provide the opportunity to examine more complex hypotheses about how underlying factors relate to each other by specifying direct path (unidirectional arrows) instead of correlations (bidirectional arrows) between predictors and predicted latent variables. Specific patterns of relationships among latent variables can be explicitly tested. Furthermore, SR models allow one to estimate the amount of variance in each predicted variable that is explained by all of the predictors considered together (Kline, 2005).

In order to explore the specific and the general contributions of STM and WM to learning nested factor models, as described by Gustafsson and Balke (1993), were fitted to the data. These models consist of one general and independent specific factors that are uncorrelated with the general construct. The variance of each observed variable is thus partitioned into a part due to the general factor and a part accounted for by the specific factor. Regression of a latent learning construct on these factors reveals the independent contributions of the general and the specific factors.

In all the models tested, the four memory tasks were specified as indicators of the general factor. Two types of models were contrasted: In one set of models - model A, represented in Figure 5.2. - counting recall and backwards digit recall were specified as indicators of a specific WM factor (identical approach as adopted in chapter 4). This type of model provides an estimation of the relationship between WM and learning after taking STM into account.

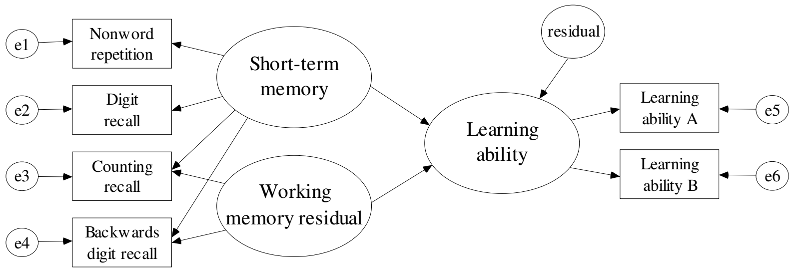

FIGURE 5.2.
Model A: nested factor model

In another set of models - model B, represented in Figure 5.3 - nonword repetition and digit recall were specified to load onto a specific verbal STM construct. This model explores the relationship of verbal STM with learning after controlling for the common variance with the WM measures.

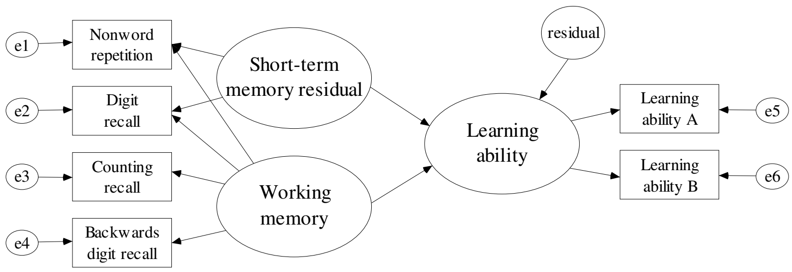

FIGURE 5.3.
Model B: nested factor model

With exception of the cross-factor loadings that were freely estimated, factor loadings and error variances of the observed variables were fixed to the values obtained in the measurement models. Conceptually the common factor purportedly represents either STM (model A) or WM (model B), and the specific factor reflects the residual after the general factor has been partialled out. Taking the example of model A, the standardized path coefficients of the general and the specific factors with the given learning construct can be interpreted as the respective correlations between STM and learning and the semipartial correlation of WM with learning after controlling for STM.

For each learning ability four sets of models were compared: The “full model” in which both verbal STM and WM were linked to the learning construct in question; two “reduced models”, with paths from either verbal STM or WM to learning; and the “no-path” model with no links from verbal STM and WM to learning. Models were compared by χ^2 difference tests. If the χ^2 difference test indicated that the fit of the reduced model was not statistically worse than a more complex model the more parsimonious model was preferred. The “no-path” model should provide a significantly worse fit than the preferred model if the given learning construct is related to any of the memory factors. Non-hierarchical factor models were compared by the AIC statistics.

As described in detail above, two types of models were fitted to the data with all the memory tasks as indicators of a general construct and either STM measures only (model A) or WM measures only (model B) as indicators of a specific construct. In addition to exploring associations with learning, the relationship between the different memory components and fluid intelligence was investigated. Analyses followed the same logic as for the learning constructs. For simplicity, only the standardized path coefficients between the latent constructs are presented. The paths linking the latent constructs to the observed measures as well as the variances of the error terms remained the same as those in the previously described CFA models in chapter 4. In all of the subsequent tables the total R^2 (variance accounted for by the model) is provided in italics.

Kindergarten

In kindergarten different sets of SR models were tested linking WM and verbal STM to vocabulary, comprehension, pre-reading skills, and fluid intelligence in separate analyses. Consider first the fit statistics of model A, in which the relationship between working memory and learning was explored after STM had been taken into account. A summary of the fit statistics and the standardized path coefficients is presented in Table 5.3.

TABLE 5.3.
Kindergarten Fit Statistics and Standardized Regression Coefficients for Model A (Controlling for Verbal STM) Linking STM and WM to the Different Learning Constructs

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients STM	Path coefficients WM
				Vocabulary					
Model 1: WM and STM	17.79	14	.22	.98	.98	.05	31.79	.51	-.01
Model 2: STM only	**17.80**	**15**	**.27**	**.98**	**.98**	**.04**	**29.80**	**.50**	--
Model 3: WM only	38.15	15	.00	.87	.87	.11	50.15	--	.09
Model 4: No path	38.41	16	.00	.88	.85	.11	48.41	--	--
Total R^2 model 1	*.26*								
				Comprehension					
Model 1: WM and STM	**9.30**	**8**	**.32**	**.99**	**.99**	**.04**	**23.30**	**.55**	**.26**
Model 2: STM only	13.26	9	.15	.97	.97	.06	25.26	.58	--
Model 3: WM only	37.09	9	.00	.79	.79	.16	49.09	--	.43
Model 4: No path	44.74	10	.00	.73	.73	.17	54.74	--	--
Total R^2 model 1	*.37*								
				Reading					
Model 1: WM and STM	8.16	14	.88	1.00	1.05	.00	22.16	.29	.28
Model 2: STM only	**10.69**	**15**	**.77**	**1.00**	**1.04**	**.00**	**22.69**	**.31**	--
Model 3: WM only	12.86	15	.61	1.00	1.02	.00	24.86	--	.33
Model 4: No path	16.44	16	.42	1.00	1.00	.02	26.44	--	--
Total R^2 model 1	*.16*								
				Fluid intelligence					
Model 1: WM and STM	11.49	21	.95	1.00	1.05	.00	25.49	.18	.55
Model 2: STM only	25.30	22	.28	.98	.98	.04	37.30	.23	--
Model 3: WM only	**13.79**	**22**	**.91**	**1.00**	**1.04**	**.00**	**25.79**	--	**.59**
Model 4: No path	29.37	23	.17	.97	.97	.05	39.37	--	--
Total R^2 model 1	*.34*								

Note . The endorsed model is marked in boldface.

The χ^2 difference tests indicated that for vocabulary and reading, the full model 1 fitted the data significantly better than the reduced model 3 with a single path from WM [vocabulary: $\Delta\chi^2(1) = 20.36$, $p < .01$; reading: $\Delta\chi^2(1) = 4.70$, $p < .05$]. The full model 1 was, however, not significantly better than the reduced model 2 with a single path from verbal STM [vocabulary: $\Delta\chi^2(1) = .01$; reading: $\Delta\chi^2(1) = 2.53$; $p > .10$ in both cases]. In both cases model 2 provided a significantly better account of the data than the no-path model [vocabulary: $\Delta\chi^2(1) = 20.61$, $p < .01$; reading: $\Delta\chi^2(1) = 5.75$, $p < .05$]. The opposite pattern of results was observed for fluid intelligence: The preferred model in this case was the reduced model 3, linking only WM to fluid intelligence. Model 3 produced as good of a fit to the data as the full two-path model 1 [$\Delta\chi^2(1) = 2.30$, $p > .10$] and fitted the data significantly better than the no-path model 4 [$\Delta\chi^2(1) = 15.58$, $p < .01$]. Finally, for comprehension none of the tested reduced models were as good as the original full two-path model 1 [model 2: $\Delta\chi^2(1) = 3.96$, $p < .05$; model 3: $\Delta\chi^2(1) = 27.79$, $p < .01$; model 4: $\Delta\chi^2(2) = 35.44$, $p < .01$].

The results of model B (Table 5.4.), exploring the specific contributions of verbal STM to learning, showed that STM remained significantly associated with vocabulary and comprehension even after WM was controlled. The full model 1 provided a significantly better account of the data than any of the reduced models for vocabulary [model 2: $\Delta\chi^2(1) = 6.09$, $p < .05$; model 3: $\Delta\chi^2(1) = 7.78$, $p < .01$; model 4: $\Delta\chi^2(1) = 20.67$, $p < .01$] and for comprehension [model 2: $\Delta\chi^2(1) = 21.82$, $p < .01$; model 3: $\Delta\chi^2(1) = 3.92$, $p < .05$; model 4: $\Delta\chi^2(1) = 35.93$, $p < .01$]. For reading and fluid intelligence the reduced model 3, linking only the general WM construct to the given outcome factor, was preferred over the full model 1 [reading: $\Delta\chi^2(1) = .08$, $p > .10$; fluid intelligence: $\Delta\chi^2(1) = 2.53$, $p > .10$], the no-path model 4 [pre-reading: $\Delta\chi^2(1) = 8.21$; fluid intelligence: $\Delta\chi^2(1) = 15.46$; $p < .05$ in all cases], and the reduced model 2 [reading: $\Delta AIC = 6.95$; fluid intelligence: $\Delta AIC = 15.3$].

TABLE 5.4.
Kindergarten Fit Statistics and Standardized Regression Coefficients for Model B (Controlling for WM) Linking STM and WM to the Different Learning Constructs

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients STM	Path coefficients WM
				Vocabulary					
Model 1. WM and STM	**17.62**	**14**	**.22**	**.98**	**.98**	**.05**	**31.62**	**.39**	**.33**
Model 2. STM only	23.71	15	.07	.95	.95	.07	35.71	.50	--
Model 3. WM only	25.40	15	.04	.94	.94	.07	37.40	--	.45
Model 4. No path	38.29	16	.00	.88	.88	.11	48.29	--	--
Total R^2 Model 1	*.26*								
				Comprehension					
Model 1. WM and STM	**8.70**	**8**	**.36**	**.99**	**.99**	**.03**	**22.79**	**.25**	**.56**
Model 2. STM only	30.52	9	.00	.84	.84	.14	42.52	.48	--
Model 3. WM only	12.62	9	.18	.97	.97	.06	24.62	--	.64
Model 4. No path	44.63	10	.00	.74	.74	.17	54.63	--	--
Total R^2 Model 1	*.38*								
				Reading					
Model 1. WM and STM	8.03	14	.89	1.00	1.05	.00	22.03	.04	.40
Model 2. STM only	15.06	15	.45	1.00	1.00	.00	27.06	.18	--
Model 3. WM only	**8.11**	**15**	**.92**	**1.00**	**1.06**	**.00**	**20.11**	--	**.41**
Model 4. No path	16.32	16	.43	1.00	1.00	.01	26.32	--	--
Total R^2 Model 1	*.16*								
				Fluid intelligence					
Model 1. WM and STM	11.26	21	.96	1.00	1.05	.00	25.26	-.22	.54
Model 2. STM only	29.09	22	.14	.96	.96	.05	41.09	-.06	--
Model 3. WM only	**13.79**	**22**	**.91**	**1.00**	**1.04**	**.00**	**25.79**	--	**.49**
Model 4. No path	29.25	23	.17	.97	.97	.05	39.25	--	--
Total R^2 Model 1	*.34*								

Note . The endorsed model is marked in boldface.

Taken together, the results of the kindergarten data suggest that both verbal STM and WM made significant contributions to vocabulary and comprehension when considered independently. The general verbal STM factor accounted for 26% and 30% of the respective variances in vocabulary and comprehension, and the general WM construct explained 11% of the variance in vocabulary and 31% of the variance in comprehension. When their specific contributions were considered, the results showed that the link between verbal STM and vocabulary was maintained. WM in contrast, did not manifest significant associations with vocabulary once verbal STM was controlled. Both memory constructs appeared to make significant specific contributions to comprehension.

The data further showed that the general WM factor accounted for a significant 16% of the variance in reading. When verbal STM was considered, WM maintained a medium association with reading (accounting for 8% of its variance) that failed, however, to reach significance. The general STM factor was weakly, yet significantly, linked with reading, explaining 8% of its variance; when WM was controlled this associations dropped to a non-significant level. Finally, for fluid intelligence the results were very clear: The specific WM factor accounted for a significant 24% of the variance in fluid intelligence, whereas neither the specific nor the general STM factor was significantly linked with fluid intelligence.[15]

First grade

As in kindergarten, the SR models in first grade explored the relationship between verbal STM and WM with vocabulary, comprehension, reading, and fluid intelligence in four separate set of analyses. The results of model A are summarized in Table 5.5. and of model B in Table 5.6.

For model A (Table 5.5.), the results show that for the three sets of models involving vocabulary, comprehension, and reading, eliminating the link of the specific WM factor with the given learning construct (model 2) did not significantly worsen model fit in relation to the full two-path model 1 [vocabulary: $\Delta\chi^2(1) = 1.32$; comprehension: $\Delta\chi^2(1) = 1.84$; reading: $\Delta\chi^2(1) = .81$; $p > .10$ in all cases] and remained significantly better than the no-path model 4 [vocabulary: $\Delta\chi^2(1) = 15.03$; comprehension: $\Delta\chi^2(1) = 21.32$; reading: $\Delta\chi^2(1) = 8.25$; $p = < .01$ in all cases]. In contrast, eliminating the path of verbal STM with learning (model 3) worsened model fit considerably compared to model 1 [vocabulary: $\Delta\chi^2(1) = 14.55$; comprehension: $\Delta\chi^2(1) = 20.61$; reading: $\Delta\chi^2(1) = 7.96$; $p < .01$ in all cases]. The results for fluid intelligence differed from the learning ability constructs; the full model 1 fitted the data significantly better than any of the reduced models [model 2: $\Delta\chi^2(1) = 5.17$; model 3: $\Delta\chi^2(1) = 4.02$; model 4: $\Delta\chi^2(2) = 9.67$, $p < .05$ in all cases].

[15] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average standardized regression coefficients between STM and learning changed by .04 for model A and by .06 for model B. For WM and learning, standardized regression coefficients changed on average by .03 for model A, and .04 for model B.

TABLE 5.5.
First Grade Fit Statistics and Standardized Regression Coefficients for Model A (Controlling for Verbal STM) Linking STM and WM to the Different Learning Constructs

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients	
								STM	WM
				Vocabulary					
Model 1: WM and STM	14.97	14	.38	.99	1.00	.02	28.97	.40	.16
Model 2: STM only	**16.29**	**15**	**.36**	**.99**	**.99**	**.03**	**28.29**	**.41**	--
Model 3: WM only	29.52	15	.01	.93	.93	.09	41.52	--	.21
Model 4: No path	31.32	16	.01	.93	.93	.09	41.32	--	--
Total R^2 model 1	*.19*								
				Comprehension					
Model 1: WM and STM	12.06	14	.60	1.00	1.02	.00	26.06	.55	.21
Model 2: STM only	**13.90**	**15**	**.53**	**1.00**	**1.01**	**.00**	**25.90**	**.56**	--
Model 3: WM only	32.67	15	.00	.83	.83	.10	44.67	--	.29
Model 4: No path	35.22	16	.00	.82	.82	.10	45.22	--	--
Total R^2 model 1	*.35*								
				Reading					
Model 1: WM and STM	14.00	14	.45	1.00	1.00	.00	28.00	.30	.13
Model 2: STM only	**14.81**	**15**	**.46**	**1.00**	**1.00**	**.00**	**26.81**	**.30**	--
Model 3: WM only	21.96	15	.11	.97	.97	.06	33.96	--	.16
Model 4: No path	23.06	16	.11	.97	.97	.06	33.06	--	--
Total R^2 model 1	*.10*								
				Fluid intelligence					
Model 1: WM and STM	**14.51**	**21**	**.85**	**1.00**	**1.05**	**.00**	**28.51**	**.25**	**.38**
Model 2: STM only	19.68	22	.60	1.00	1.02	.00	31.68	.26	--
Model 3: WM only	18.53	22	.67	1.00	1.03	.00	30.53	--	.40
Model 4: No path	24.18	23	.39	.99	.99	.02	34.18	--	--
Total R^2 model 1	*.20*								

Note . The endorsed model is marked in boldface.

The fit indices of model B (Table 5.6.) showed that when controlling for WM, verbal STM remained significantly associated with vocabulary and comprehension. In each case, the full model 1 provided a significantly better account of the data than any of the reduced models [model 2 and 3: $\Delta\chi^2(1)$ ranging from 4.00 to 11.15, *p*s < .05; model 4: vocabulary: $\Delta\chi^2(2) = 16.76$ and comprehension: $\Delta\chi^2(2) = 23.61$, $p < .01$ in both cases]. For reading, the preferred model was the reduced model 2 linking only the specific verbal STM factor to reading. Model 2 produced as good of a fit to the data as the full two-path model 1 [$\Delta\chi^2(1) = 2.29$, $p > .05$] and provided a better account of the data than the no-path model 4 [$\Delta\chi^2(1) = 6.93$, $p < .01$] or the reduced model 3 [ΔAIC = 2.53]. Finally, for fluid intelligence the best account of the data was provided by model 3 that fitted the data as good as the more complex full model 1 [$\Delta\chi^2(1) = .98$, $p > .10$] and significantly better than the no-path model 4 [$\Delta\chi^2(1) = 8.76$, $p < .01$] and the reduced model 2 [ΔAIC = 6.08].

TABLE 5.6.
First Grade Fit Statistics and Standardized Regression Coefficients for Model B (Controlling for WM) Linking STM and WM to the Different Learning Constructs

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients STM	Path coefficients WM
				Vocabulary					
Model 1: WM and STM	**14.46**	**14**	**.42**	**1.00**	**1.00**	**.02**	**28.46**	**.33**	**.29**
Model 2: STM only	18.46	15	.24	.98	.98	.04	30.46	.39	--
Model 3: WM only	22.67	15	.09	.96	.96	.07	34.67	--	.45
Model 4: No path	31.22	16	.01	.93	.93	.09	41.22	--	--
Total R^2 model 1	*.20*								
				Comprehension					
Model 1: WM and STM	**11.51**	**14**	**.64**	**1.00**	**1.02**	**.00**	**25.51**	**.46**	**.38**
Model 2: STM only	16.74	15	.33	.98	.98	.03	28.74	.54	--
Model 3: WM only	22.66	15	.09	.93	.93	.07	34.66	--	.65
Model 4: No path	35.12	16	.00	.82	.82	.10	45.12	--	--
Total R^2 model 1	*.36*								
				Reading					
Model 1: WM and STM	13.73	14	.47	1.00	1.00	.00	27.73	.25	.21
Model 2: STM only	**16.02**	**15**	**.38**	**1.00**	**1.00**	**.02**	**28.02**	**.29**	--
Model 3: WM only	18.55	15	.23	.99	.99	.04	30.55	--	.30
Model 4: No path	22.95	16	.11	.97	.97	.06	32.95	--	--
Total R^2 model 1	*.11*								
				Fluid intelligence					
Model 1: WM and STM	14.33	21	.85	1.00	1.06	.00	28.33	.13	.43
Model 2: STM only	21.39	22	.50	1.00	1.00	.00	33.39	.21	--
Model 3: WM only	**15.31**	**22**	**.85**	**1.00**	**1.06**	**.00**	**27.31**	--	**.47**
Model 4: No path	24.07	23	.40	.99	.99	.02	34.07	--	--
Total R^2 model 1	*.20*								

Note . The endorsed model is marked in boldface.

In summary, the data showed that in first grade the general verbal STM factor was significantly associated with learning, accounting for 16% of the variance in vocabulary, 30% of the variance in comprehension, 9% of the variance in reading, and a significant 6% of the variance in fluid intelligence. When the common variance with WM was taken into account, verbal STM still explained a significant 11% of the variance in vocabulary, 21% of the variance in comprehension, and 6% of the variance in reading. The association with fluid intelligence was, however, no longer significant. For WM, the results showed that the general WM construct was significantly associated with vocabulary, comprehension, and fluid intelligence accounting for 8%, 14%, and 18% of their respective variances. Once verbal STM was controlled, the associations with the language factors (vocabulary and comprehension) were no longer significant. The link with fluid intelligence was, however, maintained with the WM residual accounting for 14% of the variance in fluid intelligence.[16]

Second grade

For second grade seven different sets of SR models were tested, exploring links between verbal STM and WM with vocabulary, comprehension, French language, reading, spelling, mathematical abilities, and fluid intelligence in separate analyses. The results of these analyses are summarized in Table 5.7. for model A and in Table 5.8. for model B.

For model A (Table 5.7.), the data showed that for comprehension, reading, spelling, and fluid intelligence, the full model 1 produced a significantly better account of the data than the no-path model 4 [comprehension: $\Delta\chi^2(2) = 23.36$; reading: $\Delta\chi^2(2) = 11.43$; spelling: $\Delta\chi^2(2) = 12.83$; fluid intelligence: $\Delta\chi^2(2) = 12.69$; $p = < .01$ in all cases] and both of the reduced one-path models [comprehension: model 2: $\Delta\chi^2(1) = 6.59$, model 3: $\Delta\chi^2(1) = 15.26$, $p < .01$ in both cases; reading: model 2: $\Delta\chi^2(1) = 5.05$, model 3: $\Delta\chi^2(1) = 5.60$, $p < .05$ in both cases; spelling: model 2: $\Delta\chi^2(1) = 6.03$, model 3: $\Delta\chi^2(1) = 5.92$, $p < .05$ in both cases; fluid intelligence: model 2: $\Delta\chi^2(1) = 6.23$, model 3: $\Delta\chi^2(1) = 5.60$, $p < .05$ in both cases]. For vocabulary and French language the one-path model 2, specifying a link between verbal STM and language only, was preferred over the full model 1 [vocabulary: $\Delta\chi^2(1) = .48$; French: $\Delta\chi^2(1) = .48$; $p > .10$ in both cases]. For both abilities, model 2 provided a significantly better account of the data then the no-path model 4 [vocabulary: $\Delta\chi^2(1) = 14.90$, $p < .01$; French: $\Delta\chi^2(1) = 5.02$, $p < .05$] and the reduced model 3 [vocabulary: ΔAIC = 14.75; French: ΔAIC = 4.30]. For mathematical abilities model 3, with a single path from WM, fitted the data as good as the more complex full model 1 [$\Delta\chi^2(1) = 2.86$, $p > .05$] and significantly better than the no-path model 4 [$\Delta\chi^2(1) = 4.63$, $p < .05$] and the reduced model 2 [ΔAIC = 1.18].

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[16] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average standardized regression coefficients between STM and learning changed by .00 for model A and by .06 for model B. For WM and learning, standardized regression coefficients changed on average by .11 for model A, and .01 for model B.

TABLE 5.7.
Second Grade Fit Statistics and Standardized Regression Coefficients for Model A (Controlling for Verbal STM) Linking STM and WM to the Different Learning Constructs

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients	
								STM	WM
				Vocabulary					
Model 1: WM and STM	20.98	14	.10	.97	.97	.07	34.98	.40	-.08
Model 2: STM only	**21.46**	**15**	**.12**	**.97**	**.97**	**.06**	**33.46**	**.40**	--
Model 3: WM only	36.21	15	.00	.91	.91	.11	48.21	--	-.05
Model 4: No path	36.36	16	.00	.92	.92	.10	46.36	--	--
Total R^2 model 1	*.17*								
				Comprehension					
Model 1: WM and STM	**18.35**	**21**	**.63**	**1.00**	**1.01**	**.00**	**32.35**	**.43**	**.30**
Model 2: STM only	24.94	22	.30	.98	.98	.03	36.94	.45	--
Model 3: WM only	33.61	22	.05	.93	.93	.07	45.61	--	.38
Model 4: No path	41.71	23	.01	.89	.89	.08	51.71	--	--
Total R^2 model 1	*.28*								
				French language					
Model 1: WM and STM	16.87	21	.72	1.00	1.02	.00	30.87	.24	.08
Model 2: STM only	**17.35**	**22**	**.74**	**1.00**	**1.02**	**.00**	**29.35**	**.24**	--
Model 3: WM only	21.65	22	.48	1.00	1.00	.00	33.65	--	.11
Model 4: No path	22.37	23	.50	1.00	1.00	.00	32.37	--	--
Total R^2 model 1	*.06*								
				Reading					
Model 1: WM and STM	**24.08**	**21**	**.29**	**.99**	**.99**	**.03**	**38.08**	**.24**	**.25**
Model 2: STM only	29.13	22	.14	.98	.98	.05	41.13	.25	--
Model 3: WM only	29.68	22	.13	.98	.98	.05	41.68	--	.28
Model 4: No path	35.51	23	.05	.97	.97	.07	45.51	--	--
Total R^2 model 1	*.12*								
				Spelling					
Model 1: WM and STM	**18.31**	**14**	**.19**	**.97**	**.97**	**.05**	**32.31**	**.27**	**.30**
Model 2: STM only	24.34	15	.06	.94	.94	.07	36.34	.28	--
Model 3: WM only	24.23	15	.06	.94	.94	.07	36.23	--	.33
Model 4: No path	31.14	16	.01	.91	.91	.09	41.14	--	--
Total R^2 model 1	*.16*								
				Mathematical abilities					
Model 1: WM and STM	31.85	21	.06	.97	.97	.07	45.85	.18	.24
Model 2: STM only	35.89	22	.03	.96	.96	.07	47.89	.19	--
Model 3: WM only	**34.71**	**22**	**.04**	**.96**	**.96**	**.07**	**46.71**	--	**.26**
Model 4: No path	39.34	23	.02	.95	.95	.08	49.34	--	--
Total R^2 model 1	*.89*								
				Fluid intelligence					
Model 1: WM and STM	**9.31**	**21**	**.99**	**1.00**	**1.09**	**.00**	**23.31**	**.28**	**.33**
Model 2: STM only	15.54	22	.84	1.00	1.05	.00	27.54	.30	--
Model 3: WM only	14.91	22	.87	1.00	1.06	.00	26.91	--	.37
Model 4: No path	22.00	23	.52	1.00	1.01	.00	32.00	--	--
Total R^2 model 1	*.19*								

Note . The endorsed model is marked in boldface.

The results of model B, represented in Table 5.8., indicate that for French language the no-path model 4 provided a significantly better account of the data than the more complex two- and one- path models [model 1: $\Delta\chi^2(2) = 5.5$; model 2: $\Delta\chi^2(1) = 2.26$; model 3: $\Delta\chi^2(1) = 2.45$; $p > .05$ in all cases]. For vocabulary, the preferred model was the reduced model 2, linking only verbal STM to vocabulary. Model 2 produced as good of a fit to the data as the full two-path model 1 [$\Delta\chi^2(1) = 1.2$, $p > .10$] and fitted the data significantly better then the no-path model 4 [$\Delta\chi^2(1) = 14.2$, $p < .01$]. For comprehension, the best account of the data was provided by the full model 1, producing a significantly better fit than any of the reduced models [model 2: $\Delta\chi^2(1) = 14.85$, $p < .01$; model 3: $\Delta\chi^2(1) = 5.27$, $p < .05$; model 4: $\Delta\chi^2(2) = 23.44$, $p < .01$]. For the remaining learning abilities (reading, spelling, mathematics, and fluid intelligence) the single path model 3 was preferred. Model 3 fitted the data as good as the two-path model 1 [reading: $\Delta\chi^2(1) = 1.08$; spelling: $\Delta\chi^2(1) = 1.00$; mathematics: $\Delta\chi^2(1) = .13$; fluid intelligence: $\Delta\chi^2(1) = .88$; $p > .10$ in all cases] and provided a significantly better account of the data than the no-path model 4 [reading: $\Delta\chi^2(1) = 10.38$; spelling: $\Delta\chi^2(1) = 11.92$; mathematics: $\Delta\chi^2(1) = 7.34$; fluid intelligence: $\Delta\chi^2(1) = .11.81$; $p < .01$ in all cases].

TABLE 5.8.
Second Grade Fit Statistics and Standardized Regression Coefficients for Model B (Controlling for WM) Linking STM and WM to the Different Learning Constructs

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients	
								STM	WM
Vocabulary									
Model 1: WM and STM	21.00	14	.10	.97	.97	.07	35.00	.39	.13
Model 2: STM only	**22.20**	**15**	**.10**	**.97**	**.97**	**.06**	**34.20**	**.41**	**--**
Model 3: WM only	33.34	15	.00	.92	.92	.10	45.34	--	.20
Model 4: No path	36.36	16	.00	.92	.92	.10	46.36	--	--
Total R^2 model 1	*.17*								
Comprehension									
Model 1: WM and STM	**18.27**	**21**	**.63**	**1.00**	**1.02**	**.00**	**32.27**	**.26**	**.46**
Model 2: STM only	33.12	22	.06	.94	.94	.06	45.12	.35	--
Model 3: WM only	23.54	22	.37	.99	.99	.02	35.54	--	.50
Model 4: No path	41.71	23	.01	.89	.89	.08	51.71	--	--
Total R^2 model 1	*.28*								
French language									
Model 1: WM and STM	16.87	21	.72	1.00	1.02	.00	30.87	.18	.18
Model 2: STM only	19.13	22	.64	1.00	1.01	.00	31.13	.21	--
Model 3: WM only	19.32	22	.62	1.00	1.01	.00	31.32	--	.20
Model 4: No path	**22.37**	**23**	**.50**	**1.00**	**1.00**	**.00**	**32.37**	**--**	**--**
Total R^2 model 1	*.06*								
Reading									
Model 1: WM and STM	24.05	21	.29	.99	.99	.03	38.05	.11	.33
Model 2: STM only	33.25	22	.06	.97	.97	.07	45.25	.16	--
Model 3: WM only	**25.13**	**22**	**.29**	**.99**	**.99**	**.03**	**37.13**	**--**	**.35**
Model 4: No path	35.51	23	.05	.97	.97	.07	45.51	--	--
Total R^2 model 1	*.12*								
Spelling									
Model 1: WM and STM	18.22	14	.20	.97	.97	.05	32.22	.11	.39
Model 2: STM only	28.87	15	.02	.92	.92	.09	40.87	.18	--
Model 3: WM only	**19.22**	**15**	**.20**	**.97**	**.97**	**.05**	**31.22**	**--**	**.40**
Model 4: No path	31.14	16	.01	.91	.91	.09	41.14	--	--
Total R^2 model 1	*.16*								
Mathematical abilities									
Model 1: WM and STM	31.89	21	.06	.97	.97	.07	45.89	.04	.30
Model 2: STM only	38.69	22	.01	.95	.95	.08	50.69	.09	--
Model 3: WM only	**32.02**	**22**	**.08**	**.97**	**.97**	**.06**	**44.20**	**--**	**.30**
Model 4: No path	39.36	23	.02	.95	.95	.08	49.36	--	--
Total R^2 model 1	*.09*								
Fluid intelligence									
Model 1: WM and STM	9.31	21	.99	1.00	1.09	.00	23.31	.12	.42
Model 2: STM only	19.96	22	.58	1.00	1.02	.00	31.96	.19	--
Model 3: WM only	**10.19**	**22**	**.98**	**1.00**	**1.09**	**.00**	**22.19**	**--**	**.44**
Model 4: No path	22.00	23	.52	1.00	1.00	.00	32.00	--	--
Total R^2 model 1	*.19*								

Note . The endorsed model is marked in boldface.

Taken together, the results from second grade showed that verbal STM manifested strong links with vocabulary, accounting for 16% of its variance when considered as a general factor and explaining a significant 15% of vocabulary's variance when WM was controlled. Both verbal STM and WM made general and specific contributions to language comprehension. The general verbal STM and WM factors explained 18% and 21% of the respective variance in comprehension, whereas the specific WM factors accounted for 9% of the variance in comprehension and the specific STM factor for 7% of the variance in comprehension. For French language, the results showed that the general verbal STM factor explained a significant 6% of its variance, however, once WM was taken into account this percentage dropped to a negligible 3%. The results further showed that the general verbal STM and WM factors were significantly associated with literacy and fluid intelligence, accounting respectively for 6% and 11% of the variance in reading, 7% and 15% of the variance in spelling, and 8% and 18% of the variance in fluid intelligence. Importantly, the link of WM with the literacy constructs (reading and spelling) and fluid intelligence was maintained even when STM was taken into account; the specific WM factor explaining 6% of the variance in reading, 9% of the variance in spelling, and 11% of the variance in fluid intelligence. The opposite pattern was, however, not observed: The specific STM factor accounted for a negligible 1% of the variance in reading, spelling, and fluid intelligence once WM was controlled. Finally, for mathematical abilities the data showed that the specific WM factor accounted for a significant 6% of its variance, whereas neither the specific nor the general STM construct were significantly linked with mathematical skills.[17]

5.1.3. Summary

A summary of the standardized path coefficients for the three testing waves is presented in Table 5.9. The results of the analyses indicate that WM and verbal STM contribute differently to performance on higher order cognitive abilities.

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[17] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average standardized regression coefficients between STM and learning changed by .07 for model A and by .04 for model B. For WM and learning, standardized regression coefficients changed on average by .06 for model A and for model B.

TABLE 5.9.
Summary of the Standardized Path Coefficients According to Study Wave

	Model A		Model B	
Study wave	STM	WM residual	STM residual	WM
		Vocabulary		
Kindergarten	.51**	-.01	.39**	.33*
First grade	.40**	.16	.33**	.29*
Second grade	.40**	-.08	.39**	.13
		Comprehension		
Kindergarten	.55**	.26*	.25*	.56**
First grade	.55**	.21†	.46**	.38*
Second grade	.43**	.30*	.26*	.46**
		Reading		
Kindergarten	.29*	.28†	.04	.40**
First grade	.30**	.13	.25*	.21
Second grade	.24*	.25*	.11	.33**
		Fluid intelligence		
Kindergarten	.18	.55**	-.22	.54**
First grade	.25*	.38*	.13	.43**
Second grade	.28*	.33*	.12	.42**
		French		
Second grade	.24*	.08	.18	.18
		Spelling		
Second grade	.27*	.30*	.11	.39**
		Mathematics		
Second grade	.18	.24*	.04	.30**

Note. †$p < .10$; *$p < .05$; **$p < .01$

In each wave of the study, STM manifested strong links with vocabulary that were independent of WM. WM was also significantly associated with vocabulary; these links disappeared, however, once STM was taken into account, suggesting that the STM component of the WM measures was driving the relationship. The opposite pattern of results was observed for fluid intelligence; links with STM appeared to be largely driven by WM, which in turn manifested strong and specific associations with fluid intelligence in each study wave. Both memory components were found to make specific contributions to language comprehension.

For reading, the pattern of associations seemed to change over the years. In kindergarten, when pre-reading skills were assessed, the relationship with STM appeared to be largely driven by WM. WM did, however, not seem to make significant contributions to reading in the initial stages of formal reading instruction. Verbal STM, in contrast, manifested specific links with reading in first grade. One year later, in second grade, links between reading and WM emerged and seemed to drive the STM-reading association. The same pattern was observed for spelling in second grade: WM manifested specific associations with spelling, whereas verbal STM did not account for unique variance in spelling once WM was controlled. The results further showed that the general STM factor, in contrast to WM, manifested medium associations with French. The opposite was observed for mathematical abilities in second grade: WM, but not STM, made specific contributions to mathematics in second grade.

5.2. Specific effects of STM and WM on learning controlling for related cognitive abilities

A major aim of the study was to explore the specific effects of STM and WM on learning, independent of related cognitive abilities such as phonological awareness, fluid intelligence, and other possible causal factors. For this purpose hierarchical, or fixed-order, regression analyses were conducted. In contrast to standard SR models in which all the latent predictors are specified as simultaneous causes of the outcome factor, hierarchical regression models, just like regular hierarchical regression analyses with observed variables, allow one to enter the latent predictors into the regression equation in a pre-specified order. As has been shown before, WM and verbal STM manifested strong links with fluid intelligence, phonological awareness, and learning. Hierarchical regression analyses provide a more adequate description of the specific variance that the memory constructs contribute to learning, by controlling for the variance that might be attributed to related cognitive abilities. It also avoids the problem of multicollinearity that can arise if correlated predictors are entered simultaneously into the analyses. Although hierarchical regression analyses are of common practice with observed variables, its use with latent factors is recent and consequently less regular. The method adopted in the present study is based on an approach by de Jong (1999), in which a Cholesky factoring is applied to the latent predictors (see also, Loehlin, 1996).

All the models were specified as second-order factor models. The second-order factors were uncorrelated and their number was identical to the first-order predictor factors. The dependent latent factor was regressed onto all of the second-order factors. The order in which the latent predictors was entered into the analyses (i.e. the order in which the dependent factor was regressed onto the latent predictors) was determined by the specific pattern of loadings of the first-order onto the second-order factors. In this type of model, the path coefficient linking a second-order factor to the learning construct can be interpreted as the square root of the proportion of variance that the predictor explains in the outcome after the previous latent predictors have been taken into account. As an illustrative example the structural part of a model with three predictors (fluid intelligence, STM, and WM) is represented in Figure 5.4. The pattern of loadings of the original predictors on the newly created predictors (i.e. second-order factors) specifies a hierarchical regression analysis in which fluid intelligence is entered first, STM is entered next, and WM is entered last.

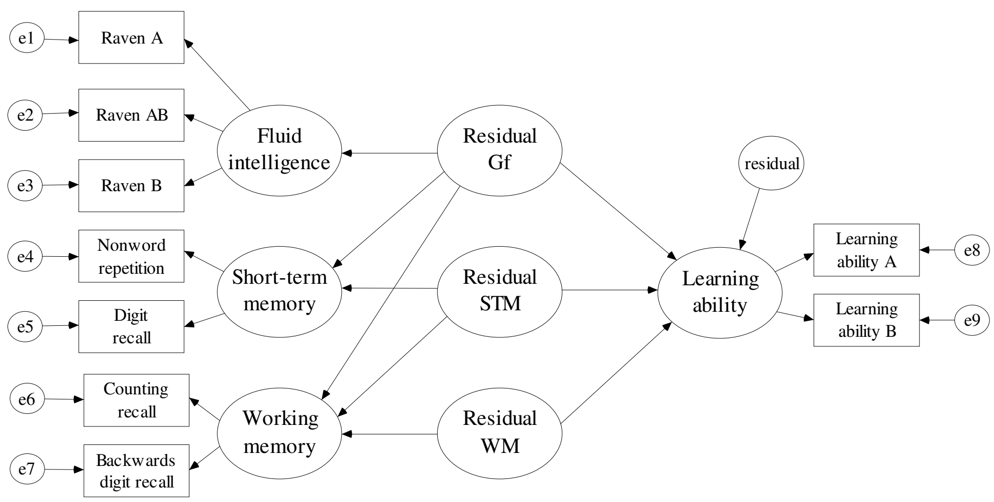

FIGURE 5.4.
Hierarchical regression model
Gf: fluid intelligence; STM: short-term memory; WM: working memory

It is worth pointing out that, although the approaches are not mathematically equivalent, the nested model approach adopted in the previous section carries the same interpretation as the hierarchical regression model described above. The main difference is that in the nested factor models the general factor had direct effects on all manifest variables, whereas in the hierarchical regression models the second order factors have only indirect effects on the manifest variables (see de Jong, 1999; Gustafsson & Balke, 1993 for further details). For clarification, Figure 5.5. displays the path structure of a nested factor model and Figure 5.6. represents an equivalent hierarchical regression model, with WM and STM as predictors in both cases.

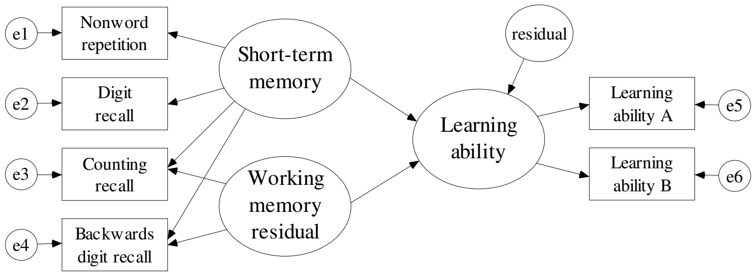

FIGURE 5.5.
Nested factor model with STM and WM as predictors

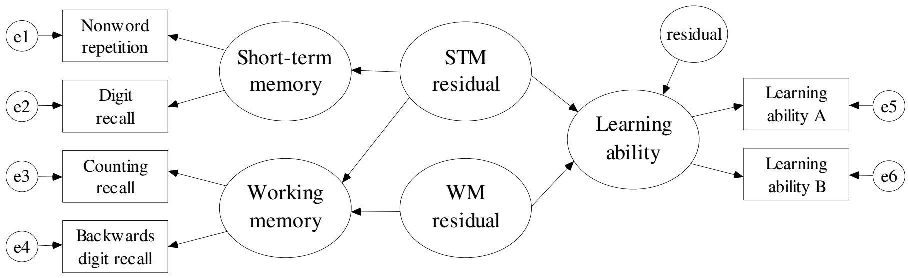

FIGURE 5.6.
Hierarchical regression model with STM and WM as predictors

In a first part of the analyses fluid intelligence and phonological awareness were integrated into the analyses. A second set of models included the latent vocabulary construct as additional covariate.

5.2.1. Fluid intelligence and phonological awareness as covariates

In all the analyses the factor loadings were fixed to the values obtained from the measurement models outlined in chapter 4. Multivariate outliers were detected for two sets of models in second grade. Two children were excluded from the analyses with the vocabulary factor, and one child was excluded from the analyses with the mathematical abilities factor. After removal of these children the distribution of scores for all of the analyses manifested multivariate normality, and no further multivariate outliers were detected. [18]

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[18] The analyses were repeated without constraining any of the estimates and the results remained nearly identical. On average correlation coefficients between the cognitive factors and learning changed by .00 for fluid intelligence, .07 for phonological awareness, .06 for verbal STM, and .07 for WM.

In a first step, CFA models were performed for each learning construct in each study wave. The basic path model used for all of the analyses is depicted in Figure 5.7.

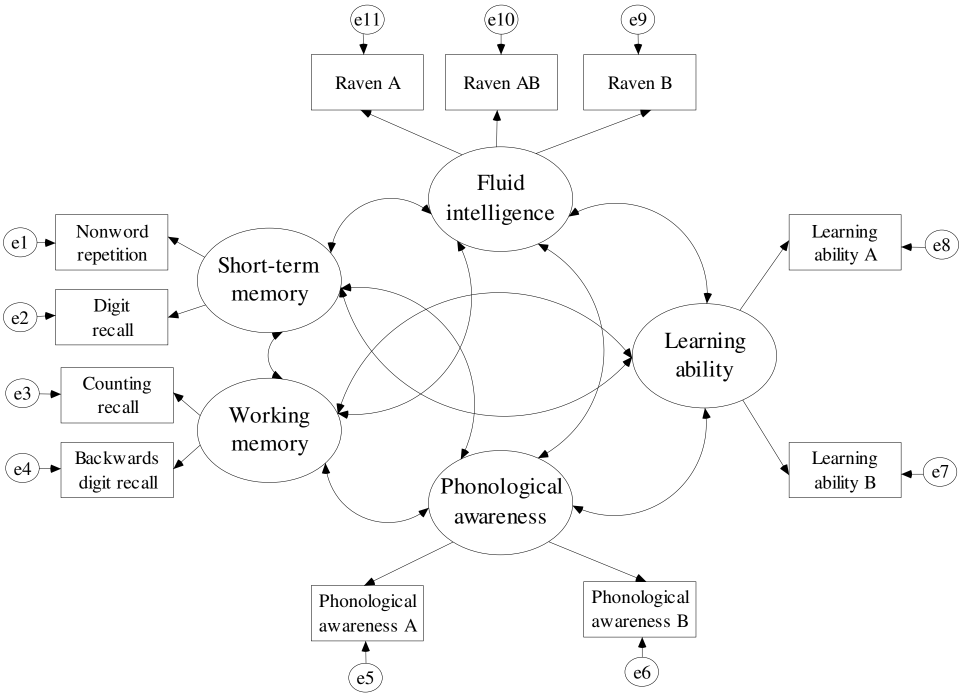

FIGURE 5.7.
Basic path model for confirmatory factor analysis

Fit statistics in Table 5.10. indicate that all of the tested models provided a good account of the data: All of the χ^2 statistics were non-significant, CFI and IFI values ranged from .96 to 1.06, and none of the RMSEA indexes exceeded .05.

TABLE 5.10.
Fit Indices for Confirmatory Factor Analysis Including WM, STM, Phonological Awareness, Fluid Intelligence, and Learning for the Different Study Waves

Study wave	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
			Vocabulary				
Kindergarten	43.26	51	.77	1.00	1.02	.00	73.26
First grade	51.67	51	.45	1.00	1.00	.01	81.67
Second grade[1]	61.26	51	.15	.97	.97	.04	91.26
			Comprehension				
Kindergarten	31.30	40	.84	1.00	1.03	.00	61.30
First grade	43.36	51	.77	1.00	1.03	.00	73.36
Second grade	50.96	63	.86	1.00	1.03	.00	80.96
			Reading				
Kindergarten	34.67	51	.96	1.00	1.06	.00	64.67
First grade	54.66	51	.34	.99	.99	.02	84.60
Second grade	63.26	63	.47	1.00	1.00	.00	93.26
			Spelling				
Second grade	45.61	51	.69	1.00	1.02	.00	75.61
			French				
Second grade	65.06	63	.40	.99	.99	.02	95.06
			Mathematical abilities				
Second grade[2]	85.12	63	.03	.96	.96	.05	115.12

Note. [1]N = 117; [2]N = 118

Table 5.11. displays the correlations among the basic cognitive ability factors for each study wave. Fluid intelligence was strongly linked to WM across the three study waves and also to phonological awareness in first and second grade. As described in more detail in chapter 4, STM and WM were significantly associated in all three studies and also manifested significant links with phonological awareness.

TABLE 5.11.
Correlations Between the Latent Cognitive Ability Factors in Each Study Wave

	Fluid intelligence			Phonological awareness			Short-term memory		
Factors	K	Gr1	Gr2	K	Gr1	Gr2	K	Gr1	Gr2
Fluid intelligence	--	--	--	--	--	--	--	--	--
Phonological awareness	.18	**.34**	**.40**	--	--	--	--	--	--
Short-term memory	.18	**.25**	**.28**	**.27**	**.44**	**.42**	--	--	--
Working memory	**.54**	**.43**	**.42**	**.35**	**.43**	**.38**	**.64**	**.29**	**.43**

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; significant values marked in boldface, $p < .05$

The correlations of the cognitive ability factors with the learning factors on each occasion are presented in Table 5.12. It is worth mentioning that the structural coefficients represent the relationship of the basic cognitive ability factors with the given learning construct without controlling for their intercorrelations.

TABLE 5.12.
Correlations of the Latent Cognitive Ability Factors With the Different Learning Constructs in Each Study Wave

	Vocabulary			Comprehension			Reading			Spelling	French	Math.
Factors	K	Gr1	Gr2 [1]	K	Gr1	Gr2	K	Gr1	Gr2	Gr2	Gr2	Gr2 [2]
Fluid intelligence	.16	**.32**	**.30**	**.51**	**.58**	**.51**	**.33**	.15	.11	.07	.06	**.36**
Phonological awareness	**.24**	**.31**	**.25**	**.36**	**.58**	**.50**	.23	**.57**	**.44**	**.57**	**.33**	**.46**
STM	**.51**	**.40**	**.40**	**.55**	**.55**	**.42**	**.29**	**.30**	**.24**	**.27**	**.24**	.18
WM	**.31**	**.27**	.13	**.55**	**.36**	**.46**	**.40**	.21	**.33**	**.38**	.18	**.30**

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; [1]N = 117; [2]N = 118; significant values marked in boldface, $p < .05$

The results in Table 5.12. show that phonological awareness and verbal STM manifested medium to large associations with all the assessed learning constructs (with exception of phonological awareness and reading in kindergarten and STM and mathematics in second grade). Verbal STM correlated highest with vocabulary and comprehension, whereas phonological awareness manifested the largest correlations with comprehension and reading in first and second grade, and spelling and mathematical abilities in second grade. WM manifested strong associations with comprehension in all three study waves and weaker, yet significant, links with vocabulary in kindergarten and first grade. Furthermore, WM was significantly associated with pre-reading skills in kindergarten, and reading, spelling, and mathematics in second grade. Finally, fluid intelligence was strongly linked with the comprehension factor across the years and manifested weaker, but significant, associations with vocabulary in first and second grade, reading in kindergarten, and mathematical abilities in second grade.

Next, two sets of hierarchical regression analyses were performed to examine the specific effects of WM and STM to learning, independent of phonological awareness and fluid intelligence. Separate analyses were conducted for each learning construct. Because Cholesky factoring (described above, p. 165) corresponds to a rearrangement of the factor intercorrelation matrix of the latent predictors, the fits of the hierarchical regression models did not differ from the fits of the CFA models reported in Table 5.10.

In the first set of hierarchical regression analyses, fluid intelligence was entered in the first step, whereas in the second set of models fluid intelligence was omitted (i.e. entered last). The standardized estimates are shown in Table 5.13. with the first set of analyses, incorporating fluid intelligence, displayed in the upper part of the table and the second set of analyses, with fluid intelligence excluded in the bottom part of the table. In each analysis the specific effects of verbal STM and WM were explored by entering these predictors in two different orders. In all of the subsequent tables the total R^2 is provided in italics.

Likelihood ratio tests were performed to evaluate the significance of regression coefficients. This procedure was used because it is invariant to how the model is identified (Gonzalez & Griffin, 2001). In the likelihood ratio test the χ^2 for the full model with all parameters free is first estimated. Next, the χ^2 is estimated with the parameter of interest set to the value of the null hypothesis, 0 in this case, and finally χ^2 difference tests are preformed to determine the significance of the parameter in question (same approach as adopted in section 5.1.2., p. 150). It is important to keep in mind that statistical significance testing of individual effects should not be over-interpreted in a structural equation modelling framework in which evaluation of the entire model has precedence over that of specific details. Results of statistical tests reflect not only the absolute magnitudes of path coefficients but also other factors, such as sample size and intercorrelations among the variables (Kline, 2005). In the present context of a medium sample size it is therefore more likely that large effects can fail to be statistically significant. In addition to assessing significance of regression coefficients the absolute magnitudes of standardized path coefficients were therefore interpreted, following Cohen's (1988) suggestions where an absolute value of .10 represents a small effect,. .30 represents a medium effect, and a value above .50 represents a large effect.

TABLE 5.13.
Standardized Regression Coefficients from Hierarchical Regression Analysis

		Vocabulary			Comprehension			Reading			Spelling	French	Math
Step	Predictor	K	Gr1	Gr2 [1]	K	Gr1	Gr2	K	Gr1	Gr2	Gr2	Gr2	Gr2 [2]
1	Fluid intelligence	.16	.32**	.30**	.51**	.58**	.51**	.33*	.15	.11	.07	.06	.36**
2	Phonol. awareness	.22*	.21†	.15	.27**	.41**	.32**	.17	.55**	.44**	.59**	.34**	.34**
3	STM	.45**	.27*	.29**	.42**	.28*	.19†	.20	.06	.07	.05	.12	-.03
4	WM	-.08	.05	-.15	.00	-.04	.14	.12	-.04	.20†	.24*	.05	.07
3	WM	.22	.08	-.03	.26*	-.02	.19†	.22	-.03	.21*	.25*	.09	.06
4	STM	.40**	.27*	.32**	.33**	.28*	.14	.08	.06	.01	-.02	.10	-.06
	Total R^2	*.28*	*.23*	*.22*	*.51*	*.59*	*.42*	*.19*	*.33*	*.25*	*.41*	*.13*	*.25*
	Without fluid intelligence												
1	Phonol. awareness	.24*	.31**	.25**	.36**	.58**	.50**	.23†	.57**	.44**	.57**	.33**	.46**
2	STM	.46**	.30**	.32**	.48**	.33**	.24*	.24†	.05	.06	.03	.11	-.01
3	WM	-.04	.12	-.10	.21†	.08	.23*	.24	-.05	.16	.18†	.02	.11
2	WM	.25†	.15	.04	.46**	.12	.29**	.34*	-.04	.17†	.18†	.06	.10
3	STM	.39**	.28**	.34**	.25*	.32**	.15	.04	.06	.00	-.03	.09	-.05
	Total R^2	*.27*	*.20*	*.18*	*.40*	*.46*	*.36*	*.17*	*.33*	*.23*	*.35*	*.12*	*.22*

Note. K: kindergarten; Gr1: first grade; Gr2: second grade; [1]N = 117; [2]N = 118; †$p < .10$. *$p < .05$. **$p < .01$ (approximate values)

Results on vocabulary were very clear: After the effects of fluid intelligence and phonological awareness were controlled (upper part of Table 5.13.), verbal STM described additional variance in vocabulary in all three study waves, even after the common variance with WM was taken into account. Interestingly, the association was strongest in kindergarten, with verbal STM accounting for 16% of additional variance in vocabulary (in contrast to 7% in first grade and 10% in second grade). WM did not make any specific contributions to vocabulary after controlling for the three remaining predictors.

For language comprehension the data showed that after fluid intelligence, phonological awareness, and WM were controlled, verbal STM accounted for a significant 11% and 8% of extra variance in comprehension in kindergarten and first grade respectively. Verbal STM did, however, not explain additional variance in second grade comprehension. Importantly, the link between verbal STM and language comprehension appeared to decrease over the years. WM manifested no specific associations with comprehension after controlling for fluid intelligence, phonological awareness, and verbal STM. It is, however, important to point out that

WM described a significant 5% of extra variance in second grade comprehension when fluid intelligence was not taken into account (bottom part of Table 5.13).

For the reading measures, the results in the lower and the upper part of Table 5.13. show that in first and second grade phonological awareness accounted for the major part of the variance in reading. Verbal STM did not add any extra variance above the one explained by phonological awareness. In the same vein, WM did not make specific contribution to reading in kindergarten and first grade once the common variance with phonological awareness, verbal STM, and fluid intelligence was considered. In second grade, however, specific links between WM and reading emerged, with WM accounting for a significant 4% of extra variance in reading. A similar pattern was observed for spelling in second grade: WM described a significant 6% of the variance in spelling, above the variance explained by phonological awareness, fluid intelligence, and verbal STM. STM did not manifest an additional effect on spelling after all other predicators were controlled.

Finally, findings on the French and mathematical ability measures showed that in both cases verbal STM and WM did not account for additional variance, after controlling for phonological awareness alone and after controlling for both phonological awareness and fluid intelligence.

5.2.2. Vocabulary knowledge as covariate

To investigate whether links between WM and STM with learning were not subsumed by the more general contribution of verbal ability, a second part of the analysis included the latent vocabulary construct as an additional covariate. The hierarchical regression analyses were performed in the same way as described above with six latent factors included in each model: STM, WM, phonological awareness, fluid intelligence, vocabulary knowledge, and the given learning construct. Multivariate outliers were detected for four sets of models in second grade. Two children were therefore excluded from the analyses involving comprehension, spelling, French, and mathematical abilities. After removal of these cases, no further multivariate outliers were detected. The distribution of scores for all of the analyses manifested multivariate normality.

TABLE 5.14.
Fit Indices for Confirmatory Factor Analysis Including WM, STM, Phonological Awareness, Fluid Intelligence, Vocabulary, and the Learning Measures

Study wave	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
			Comprehension				
Kindergarten	48.34	57	.79	1.00	1.02	.00	90.34
First grade	63.34	70	.70	1.00	1.01	.00	105.34
Second grade[1]	84.12	84	.48	1.00	1.00	.00	126.11
			Reading				
Kindergarten	54.69	70	.91	1.00	1.04	.00	96.69
First grade	76.98	70	.26	.99	.99	.03	118.97
Second grade	103.46	84	.07	.97	.98	.04	145.45
			Spelling				
Second grade[1]	99.74	70	.01	.95	.95	.06	141.74
			French				
Second grade[1]	108.23	84	.04	.96	.96	.05	150.23
			Mathematical abilities				
Second grade[1]	113.96	84	.02	.96	.96	.05	155.96

Note . [1]N = 117

Fit statistics of the CFA models in Table 5.14. indicate that all of the models tested provided a reasonable account of the data. Although for some of the models the χ^2 statistic was significant (spelling, French, and mathematical abilities), the CFI and IFI values for all of the models tested were above .94, and the RMSEAs were below .07. Table 5.15. displays the correlations of the cognitive ability factors with the learning outcome factors on each occasion. Table 5.15. does not differ fundamentally from Table 5.12. (p. 170) with the exception that the latent vocabulary factor was added into the analysis.

TABLE 5.15.
Correlations of the Latent Cognitive Ability and Vocabulary Factors With the Different Learning Constructs in Each Study Wave

	Comprehension			Reading			Spelling	French	Math
Factors	K	Gr1	Gr2[1]	K	Gr1	Gr2	Gr2[1]	Gr2[1]	Gr2[1]
Fluid intelligence	**.51**	**.58**	**.48**	**.33**	.15	.11	.03	.02	**.31**
Phonol. awareness	**.36**	**.58**	**.47**	.23	**.57**	**.44**	**.55**	**.31**	**.45**
STM	**.55**	**.55**	**.44**	**.29**	**.30**	**.24**	**.27**	**.25**	**.21**
WM	**.55**	**.36**	**.45**	**.40**	.21	**.33**	**.38**	.15	**.23**
Vocabulary	**.56**	**.82**	**.76**	.04	**.30**	**.27**	**.27**	.14	**.33**

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; [1]N = 117; significant values marked in boldface, $p < .05$

Correlation coefficients in Table 5.15. show that vocabulary manifested strong links with language comprehension and medium associations with reading in first grade and reading, spelling, and mathematical abilities in second grade. Interestingly, vocabulary (Luxembourgish and German) did not manifest a significant association with French language in second grade.

In the hierarchical regression models all of the covariates were entered into the analyses before the memory factors: Fluid intelligence was entered first; vocabulary second; and phonological awareness third. Verbal STM and WM were entering in two different orders. The results of the regression analysis are shown in Table 5.16., with the total R^2 of each model provided in italics. Significance of regression coefficients were tested via likelihood ratio tests (Gonzalez & Griffin, 2001).

TABLE 5.16.
Standardized Regression Coefficients from Hierarchical Regression Analysis

		Comprehension			Reading			Spelling	French	Math
Step	Predictor	K	Gr1	Gr2 [1]	K	Gr1	Gr2	Gr2 [1]	Gr2 [1]	Gr2 [1]
1	Fluid intelligence	.51**	.58**	.48**	.33**	.15	.11	.03	.02	.31**
2	Vocabulary	.49**	.66**	.65**	-.01	.27**	.25*	.27*	.14	.25*
3	Phonol. awareness	.16*	.27**	.21**	.18	.50**	.39**	.54**	.30**	.33**
4	STM	.24*	.11	.02	.25†	.02	.03	.00	.12	-.08
5	WM	.02	-.07	.25**	.10	-.05	.22*	.29*	.04	.07
4	WM	.17	-.06	.24**	.24	-.05	.22*	.27*	.08	.04
5	STM	.18	.12	-.08	.13	.02	-.03	-.12	.10	-.10
	Total R^2	*.59*	*.87*	*.76*	*.21*	*.35*	*.28*	*.45*	*.13*	*.27*

Note. K: kindergarten; Gr1: first grade; Gr2: second grade; [1]N = 117; $^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$ (approximate values)

For comprehension the results showed that when controlling for vocabulary, fluid intelligence, and phonological awareness, verbal STM accounted for a significant 6% of extra variance in comprehension in kindergarten. As noted before, the strength of this association appeared to weaken over the years, with verbal STM accounting for a negligible amount of variance in comprehension in first and second grade. WM manifested the opposite pattern of associations, with negligible links with comprehension in kindergarten and in first grade but a significant association in second grade. In second grade WM accounted for 6% of extra variance in comprehension that was independent of vocabulary, fluid intelligence, phonological awareness, and verbal STM.

For the remaining learning outcomes (i.e. reading, French, spelling, and mathematical abilities), the overall pattern of results did not change considerably from the previous analyses involving only fluid intelligence and phonological awareness as covariates. Most notably, links between WM with reading and spelling in second grade remained significant even after controlling for vocabulary and all other predictors.

5.2.3. Phonological awareness and learning

A final set of analyses explored the specific contributions of phonological awareness to learning. For this purpose the phonological awareness factor was entered last into the hierarchical regression analysis, after fluid intelligence, verbal abilities, WM, and verbal STM. The standardized regression weights of these analyses are summarized in Table 5.17., with the total R^2 of each analysis in italics.

TABLE 5.17.
Standardized Regression Coefficients from Hierarchical Regression Analysis

		Vocabulary			Comprehension			Reading			Spelling	French	Math
Step	Predictor	K	Gr1	Gr2	K	Gr1	Gr2 [1]	K	Gr1	Gr2	Gr2 [1]	Gr2 [1]	Gr2 [1]
1	Fluid intelligence	.16	.32**	.30**	.51**	.58**	.48**	.33*	.15	.11	.03	.02	.31**
2	Vocabulary	--	--	--	.49**	.66**	.65**	-.01	.27**	.25*	.27*	.14	.25*
3	STM	.49**	.33**	.33**	.26**	.20*	.09	.27†	.19	.16	.19	.22	.04
4	WM	-.06	.08	-.14	.05	-.01	.27**	.13	.09	.27**	.35**	.06	.11
3	WM	.27†	.14	.01	.20†	.03	.28**	.27	.12	.31**	.39**	.16	.12
4	STM	.40**	.31**	.36**	.18	.20*	-.04	.13	.17	.05	.01	.17	-.01
5	Phonol. awareness	.12	.07	.05	.11	.23*	.16*	.11	.46**	.32**	.47**	.23*	.32**
	Total R^2	*.28*	*.23*	*.22*	*.59*	*.87*	*.76*	*.21*	*.35*	*.28*	*.45*	*.13*	*.27*

Note. K: kindergarten; Gr1: first grade; Gr2: second grade; [1]N = 117; †$p < .10$. *$p < .05$. **$p < .01$ (approximate values)

When controlling for all other predictors, phonological awareness remained strongly related to reading in first grade and spelling in second grade, and manifested medium associations with reading, French, and mathematical skills in second grade. The data further showed that phonological awareness was significantly linked to comprehension in first grade, accounting for 5% of its variance. This association reduced over the year, with phonological awareness accounting for only 2.5% of extra variance in comprehension in second grade.

5.2.4. Summary

The specific links between verbal STM and WM with learning, controlling for fluid intelligence, vocabulary, and phonological awareness are summarized in Figure 5.8. Lines in boldface indicate the links that remained significant after controlling for either STM or WM in addition to the three other covariates (two covariates in the case of vocabulary). Taken together, the data showed that verbal STM manifested significant and highly specific links with vocabulary in the three study waves. The association was strongest in kindergarten. Furthermore, verbal STM was significantly associated with language comprehension in kindergarten; this link disappeared, however, in subsequent years. WM did not manifest strong specific associations with any of the learning constructs in kindergarten and in first grade. Specific links emerged, however, in second grade with WM manifesting significant associations with comprehension, reading, and spelling.

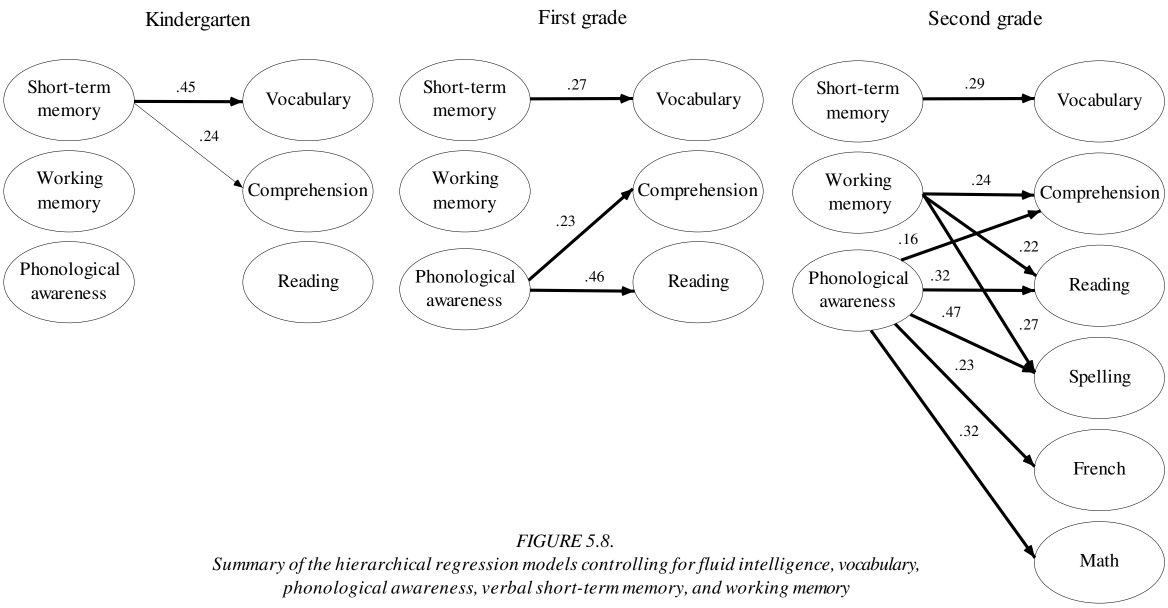

FIGURE 5.8.
Summary of the hierarchical regression models controlling for fluid intelligence, vocabulary, phonological awareness, verbal short-term memory, and working memory

Figure 5.8. further represents the specific association of phonological awareness with learning after controlling for the common variance with fluid intelligence, vocabulary, verbal STM, and WM. It is important to bear in mind that phonological

awareness in kindergarten was indexed by a rhyme detection task, whereas in subsequent years measures involving the manipulation of phonemes were included in the analyses. Rhyme detection did not seem to be related to any of the learning constructs in kindergarten. Furthermore, phonological awareness did not manifest significant associations with vocabulary in any of the three studies. Links between phonological awareness with reading and comprehension started to emerge in first grade; these associations remained significant one year later; reduced, however, in magnitude. With the exception of vocabulary knowledge, phonological awareness was significantly linked to all of the learning constructs in second grade.

5.3. Discussion

The present chapter explored cross-sectional links between STM and WM with learning at the level of latent variables in the same sample of Luxembourgish children, followed from kindergarten to second grade. The first part of the analysis focused on the relations between learning and memory, whereas in the second part related cognitive abilities (i.e. fluid intelligence, phonological awareness, and verbal abilities) were entered into the analysis as covariates. The main objective was to explore whether or not significant links between WM and verbal STM with learning would emerge and more specifically, which aspect of the WM model - short-term storage or controlled attention - would mediate the relationships. Furthermore, the analyses aimed to investigate if observed associations between WM and STM with learning were independent of other plausible known causes. In total six learning abilities were considered: vocabulary knowledge in native and in a highly familiar second langue; language comprehension; reading; spelling; linguistic abilities in the unfamiliar second language French; and mathematical skills. The general and specific contribution of WM and STM to each of these abilities will be discussed in turn.

5.3.1. Vocabulary knowledge

Vocabulary knowledge in the native and the highly familiar second language German was strongly related to verbal STM in all three study waves. These findings are consistent with previous evidence suggesting that verbal STM might be the driving force behind both native and foreign vocabulary acquisition, by supporting the formation of stable phonological representations of new words in long-term memory (Cheung, 1996; Gathercole et al., 1992; Jarrold et al., 2009; Masoura & Gathercole, 2005; Service, 1992). The finding that the association was independent of WM, phonological awareness, and fluid intelligence suggests that the link between verbal STM and vocabulary is highly specific, in line with the view that it is the short-term storage component of working memory that underpins language development (Baddeley et al., 1998; Gathercole, 2006). Notably, neither WM nor phonological awareness had specific effects on vocabulary, providing further support for the highly specific contribution of verbal STM to vocabulary acquisition. These findings also clearly reject the hypothesis put forward by Bowey (1996, 2001, 2006; see also Metsala, 1999; Snowling et al., 1991) that the relationship between vocabulary and verbal STM is mediated by an individual's phonological awareness. Instead, the data are consistent with recent evidence by Jarrold and colleagues (2009) indicating that in children, new word learning is more closely related to verbal STM than to phonological awareness.

Although the path coefficients across models were not statistically compared, the overall pattern of findings suggests that the association between STM and vocabulary was strongest in kindergarten, in line with previous evidence suggesting that the contribution of verbal STM to vocabulary development is most important in the initial stages of language acquisition (Gathercole et al., 1992). Several reasons for the reduced strength of association in first and second grade can be proposed. One possibility is that as children develop, top down influences of linguistic knowledge on STM performance might become more important and mask the relationship between verbal STM and vocabulary (Cheung, 1996; Jarrold et al., 2004). Alternatively, the nature of vocabulary learning might change with development, with semantic or lexical coding strategies becoming increasingly important in older ages (Duyck et al., 2003; Gathercole et al., 1992; Jarrold et al., 2009).

5.3.2. Language comprehension

Language comprehension was strongly associated with verbal STM in kindergarten (see also Dufva et al., 2001; van Daal, Verhoeven, van Leeuwe, & van Balkom, 2008). Importantly, links were independent of fluid intelligence, phonological awareness, and WM. Furthermore, it can be ruled out that vocabulary knowledge was mediating the STM-language comprehension association as the relationship persisted even after vocabulary had been taken into account.

As for vocabulary knowledge, the overall pattern of findings suggests that the link between STM and comprehension was strongest in kindergarten and reduced over the years. This decrease might be related to the fact that the phonological awareness tasks in kindergarten did not involve the explicit manipulation of phonemes (as they did in first and second grade). The weaker links between STM and comprehension in first and second grade, in contrast to kindergarten, might therefore not be due to a reduced importance of verbal STM to language comprehension per se, but to the fact that the covariate phonological awareness might have reflected a slightly different construct in kindergarten then in first and second grade. Two arguments against this position can be put forward: First, the strengths of the association between STM and comprehension reduced further from first to second grade, although the observed measures indexing phonological awareness were highly similar in both study waves (both involving the manipulation of phonemes); second, when only vocabulary and fluid intelligence were considered as covariates, the same pattern of results was observed.

The data therefore indicates that verbal STM plays a direct role in the syntactic processing of sentences in very young children, possibly serving as buffer storage whilst the child applies syntactic and semantic processing to arrive at an interpretation of its meaning. Another interesting aspect of the data was the highly specific link between WM and language comprehension in second grade that was independent of vocabulary knowledge, fluid intelligence, verbal STM, and phonological awareness. Importantly, corresponding associations were not observed in kindergarten or in first grade.

When interpreting these findings - specific links between STM and comprehension in kindergarten; and specific associations between WM and comprehension in second grade - it is important to bear in mind that comprehension was assessed by a native language listening comprehension task in kindergarten, whereas in second grade more complex language comprehension measures, involving the foreign language German (listening and reading comprehension), were included in the analysis. It is therefore possible that the observed pattern of associations with verbal STM (i.e. decrease over time) and WM (i.e. increase over time) reflected the increased complexity of the language comprehension construct. From this perspective, verbal STM might be involved in the comprehension of simple native language sentences structures, such as “the sheep is running” (TROG-2, Bishop, 2003), that require the maintenance of several elements in a simple linear order. WM, in contrast, might be involved in the processing of more complex sentence structures and the lexical semantic understanding of longer text. Understanding sentences in a foreign language or processing text paragraphs for meaning might place heavy demands on the central executive component of WM since task-relevant information needs to be kept active while other cognitively demanding activities are performed (e.g. processing a foreign language for meaning, transforming a linear sequence of words into a hierarchical structure). Consistent with this view, findings reported by Daneman and Blennerhassett (1984) indicate that understanding narrative story segments that involve the integration of information from different sentences, place high demands on the central executive in young children. Importantly, the strongest associations were observed with items that particularly taxed the integration processes, suggesting that the main role of the central executive in language comprehension might lie in the integration of various ideas into a coherent representation.

5.3.3. Reading

The data on the reading measures showed that both memory constructs made significant contributions to word decoding when considered in isolation. For pre-reading skills in kindergarten, these links appeared to be largely mediated by common associations with fluid intelligence. In first and second grade, the association of verbal STM with reading could be fully accounted for by its relation with phonological awareness. These findings are consistent with the position of Wagner et al. (1994) and de Jong and van der Leij (1999), suggesting that the role of verbal STM in reading acquisition might be as part of a general phonological processing construct related to literacy development rather than representing a causal factor per se (see also Dufva et al., 2001).

The data further showed that significant links between WM and reading emerged in second grade. Most notably, this association was highly specific and persisted even after phonological awareness, fluid intelligence, verbal STM, and verbal abilities were controlled. These findings contradict recent research efforts by Swanson (2008), failing to establish a significant association between the central executive and reading in 6- to 9-year-olds, but are in line with other developmental studies in which WM was found to account for significant unique variance in reading (Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Bayliss et al., 2003; Gathercole & Pickering, 2000a; Kail & Hall, 2001; Leather & Henry, 1994). In the early stages of literacy development, word decoding involves the sequential translation of letters into sounds and the blending of these sounds into spoken word forms. As these phonological recoding processes are less automatic in young children without extensive reading experience, they are likely to be attention demanding and might therefore draw on resources from the central executive. This view fits well with the observed links between WM and reading in second grade; it does, however, not account for the absence of an association in first grade. An alternative explanation is that literacy classroom activities impose heavy demands on WM, the capacity of which therefore has a direct effect on the frequency of task failure or success in these classroom activities which consequently influences the rate of learning (Alloway & Gathercole, 2006; Gathercole & Alloway, 2008; Gathercole, Lamont et al., 2006). As new learning builds on already acquired knowledge and skills, the effects of poor WM capacity on reading development might be particularly marked in more advanced stages of learning.

5.3.4. Spelling

For spelling skills in second grade the findings were very clear: Strong links were observed between WM and spelling that were independent of fluid intelligence, STM, verbal ability, and phonological awareness. Verbal STM, in contrast, did not manifest significant associations with spelling. These findings extend previous evidence on adults (Ormrod & Cochran, 1988) and on young children (Alloway et al., 2005). It is worth pointing out that Alloway and colleagues (2005) evaluated early writing skills via teacher-based assessments, whereas the present study adopted a more objective approach of assessing spelling abilities. Importantly, both studies reached the same conclusion: early writing scores were uniquely associated with WM and phonological awareness performance but not with verbal STM skills.

These findings are particularly important as the cognitive skills underpinning early spelling abilities are less well understood then for reading that has been studied more extensively. The present study provides some preliminary evidence suggesting that WM abilities might be underlying the development of both abilities. These findings are plausible given that the cognitive demands involved in reading and spelling are very similar. In young children both abilities entail phonological recoding, with the main difference that in the case of reading graphemes need to be converted into phonemes, whereas for spelling phonemes need to be translated into their graphemic form. Importantly, the study has shown that although the two abilities are strongly related and both are associated with WM, they are not isomorphic constructs suggesting that there might be some underlying difference in the cognitive processes associated with reading and spelling.

One possibility is that WM might make stronger contributions to early writing abilities than to reading because in addition to phonological recoding processes, spelling also involves the manual production of written symbols. In contrast to experienced writers, handwriting is a less automated activities in children and therefore likely to require conscious control (Bourdin & Fayol, 1994). Consistent with this hypothesis stronger links between spelling and WM then between WM and reading were found. An alternative hypothesis regarding the potential role of WM in spelling has been proposed by Ormrod and Cochran (1988), suggesting that during the reading process individuals with larger WM capacities might be able to draw there attention to the individual letters within words as well as comprehending the reading passage. Low WM individuals, in contrast, might devote most of the available WM capacity to reading comprehension and might therefore not learn the spelling of words through the reading process alone. Others suggest that it might be the heavy WM demands of many literacy classroom activities that may account for the observed association between WM capacities and early spelling skills (Gathercole, Lamont et al., 2006).

Taken together spelling is likely to be a resource demanding task in young children, requiring the successful management of a number of processes (e.g. phonological recoding, graphic execution of the message, keeping track of the place in the task) which could explain the observed strong links with the central executive component of WM.

5.3.5. Linguistic knowledge in French

The study showed that, as expected, verbal STM but not WM made significant contributions to the acquisition of the foreign language French, involving French vocabulary knowledge and the understanding of simple sentences in French. This result is in line with the previously described finding of a relationship between verbal STM with vocabulary development and early comprehension skills and also with other studies on foreign language learning in children (Masoura & Gathercole, 1999; Service, 1992). The link was, however, lower then expected and disappeared once phonological awareness was taken into account. In contrast, if verbal STM was controlled the association between French and phonological awareness was maintained. These findings seem to suggest that the relationship between verbal STM and French language primarily reflects the processes in common with phonological awareness.

One potential unitary trait of verbal STM and phonological awareness tasks might be the quality of phonological representations (Boada & Pennington, 2006; Gathercole et al., 1992; Service et al., 2007). The ability to construct well defined representations of unfamiliar speech sounds might be particularity important in the early stages of acquiring new words in a foreign language with an unfamiliar phonology. Whereas both Luxembourgish and German are Germanic languages, French belongs to the family of Romantic languages with a phonological structure that is substantially different from either Luxembourgish or German. As children were assessed after only five month of French instruction, it is likely that they had not yet created stable representations of the different sound units in the French language which might have shadowed the contribution of verbal STM to new word learning in French. It is, however, possible that in later stages of French learning, after being familiar with the French phonology, significant links between French and verbal STM would have been observed.

An alternative explanation for the lower then expected relationship between verbal STM and French is that long-term lexical and sublexical knowledge might have made a significant contribution to children's STM performance in second grade. This might have masked the contribution of STM to new word learning in the French language for which long-term memory support is supposed to be minimal.

5.3.6. Mathematical abilities

Finally the data showed that WM accounted for significant variance in mathematical abilities of 8-year-olds, over and above the contributions of STM that in turn did not make significant contribution to mathematics in second grade. This finding is consistent with a range of developmental studies (Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Bull & Scerif, 2001; Gathercole & Pickering, 2000a; St Clair-Thompson & Gathercole, 2006; Swanson, 2008) suggesting that the central executive component of WM is of crucial importance for the mathematical performance of children.

The study further showed that fluid intelligence made significant contributions to mathematical skills. Importantly, significant links between mathematics and WM disappeared once fluid intelligence was taken into account, suggesting that it might be the processes that WM and fluid intelligence have in common that account for the connection between WM and mathematics. Engle et al. (1999b) suggest that the link between measures of WM and fluid intelligence is the demand for controlled attention. According to this account, controlled attention might underlie the observed relationship between WM and mathematical abilities in the present population of young children. This hypothesis is consistent with recent research evidence by Swanson (2008), showing that WM capacity (with STM controlled) significantly predicated mathematical abilities in 6-to 9-year-olds, but that this link disappeared when measures of controlled attention were entered into the analysis.

It is worth pointing out that individual differences in phonological awareness made an important contribution to the variance in mathematical abilities even after fluid intelligence, verbal abilities, STM, and WM were considered. Similar findings have been observed by Leather and Henry (1994) in English second grade school children. The nature of the underlying link between phonological awareness skills and mathematical abilities is at present unclear. Leather and Henry (1994) suggest that phonological awareness and mathematics might be related because some of the more complex phonological awareness measures incorporate arithmetic processes, such as subtracting and adding phonological segments (e.g. Spoonerism task in the present context). An alternative explanation is that phonological awareness measures are multifaceted and likely to involve a wide range of cognitive abilities. Links with mathematical abilities are therefore to be expected, given that mathematics is a complex domain with a whole host of cognitive skills contributing to performance (Bull & Espy, 2006). The latter position is favoured in the present context on the basis of the finding that phonological awareness measures were significantly linked to various learning domains - language comprehension, reading, spelling, French, and mathematical - raising doubts about the claimed domain-specificity of phonological awareness tasks (Bryant et al., 1990).

5.3.7. Conclusion

In summary, the present chapter aimed to explore the specific links between verbal STM and WM with vocabulary knowledge, language comprehension, reading, spelling, foreign language learning, and mathematics in young, multilingual children. The data showed that the short-term storage and the central executive components of WM were differentially associated with these learning domains. Whereas verbal STM was more specifically linked to early language development and vocabulary in particular, the central executive appeared to make more general contributions to classroom related learning. WM manifested unique and robust links with language comprehension, reading, and spelling in second grade and weaker associations with mathematical abilities that were shared with fluid intelligence. Importantly, the processing element of the WM tasks (i.e. reversing sequences of digits and counting) did not match the domain of most aptitude test (i.e. reading, spelling, and language comprehension) rejecting the possibility that the observed relationships were due to task specific similarities. There was no evidence for any specific links between verbal STM and either literacy or mathematical ability.

The findings reinforce previous evidence indicating that the capacity to store verbal material for brief periods of time is a crucial factor in supporting developing language abilities (for review, see Baddeley et al., 1998). Furthermore, the findings fit well with the position that the central executive might play an important role in the monitoring and processing of information during complex and demanding activities present in many classroom situations (Gathercole, Lamont et al., 2006).

Although the presented evidence provides valuable insights into the cognitive underpinnings of learning in young children, it is important to bear in mind that the analyses were based on correlational, cross-sectional data; it is therefore improper to draw strong conclusions regarding the causal relationship between WM, STM, and learning or to identify the dynamic nature of the processes under study. These issues will be addressed more directly in the following chapter 6, exploring cross-lagged relations between the constructs of interest.

CHAPTER SIX

Results III - Longitudinal analyses

The main objective of the present chapter was to explore the influences of individual differences in WM and verbal STM on subsequent individual differences in learning. The time periods from kindergarten to first grade, from first grade to second grade, and from kindergarten to second grade were assessed. The chapter consists of five different sections: The first part of the analysis will centre on the general contributions of verbal STM and WM to learning, whereas in a second part more specific links will be explored after controlling for possible associated causes. In a third part potential causal influences of learning on basic cognitive abilities are investigated, and a last set of analyses will focus on the relations of STM and WM with two specific domains of learning - French vocabulary and reading comprehension. The main findings of the analyses are discussed in a final fifth section.

6.1. Influences of individual differences in WM and STM on subsequent individual differences in learning

The following analyses followed the same approach as adopted in the previous chapter 5. In an initial step CFA models were performed, exploring the influences of verbal STM and WM on learning when considered in isolation. Next, SR models were fitted to the data investigating the specific contributions of STM and WM to learning. The statistical procedures were identical to the ones described in chapter 5; the following sections will therefore only focus on the results (for a detailed description of the statistical procedures see chapter 5).

6.1.1. Confirmatory factor analysis

Separate CFA models were performed for each learning construct for each time period, with a gap of one year from kindergarten to first grade and from first grade to second grade, and a gap of two years from kindergarten to second grade. In total 15 models were tested, with three models (one for each time period) for vocabulary, for comprehension, and for reading, and two models for spelling, French language, and mathematical abilities (first-second grade and kindergarten-second grade). All of the models were composed of three latent factors: STM, WM, and the subsequent learning construct in question. An example of the basic CFA model with a one year time interval is represented in Figure 6.1. Factor loadings and error variances were fixed to the values obtained from the measurement models outlined in chapter 4. For none of the models multivariate outliers were detected, and the data manifested multivariate normality with standardized Mardia's coefficient ranging from .09 to 2.63.

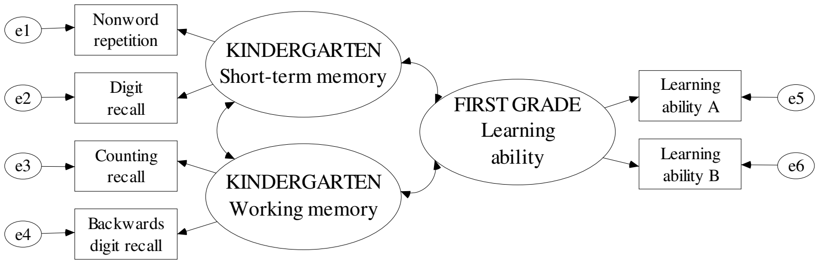

FIGURE 6.1.
Three-factor CFA model with one year time interval

Fit statistics of the different CFA models are presented in Table 6.1. All of the tested models fitted the data well with significant χ^2 values, CFI and IFI indices above .95, and RMSEA values below .08.

TABLE 6.1.
Fit Indices for Confirmatory Factor Analysis (With One and Two Year Time Gaps) With WM and STM (Kindergarten and First Grade) and Subsequent Learning Abilities (First and Second Grade)

Time period	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Vocabulary dependent factor							
K to Gr1	24.30	15	.06	.96	.96	.07	36.30
Gr1 to Gr2	12.70	15	.63	1.00	1.01	.00	24.70
K to Gr2	22.74	15	.09	.97	.97	.07	34.74
Comprehension dependent factor							
K to Gr1	18.81	15	.22	.97	.97	.05	30.81
Gr1 to Gr2	18.15	22	.70	1.00	1.03	.00	30.15
K to Gr2	26.20	22	.24	.98	.98	.04	38.20
Reading dependent factor							
K to Gr1	10.92	15	.76	1.00	1.01	.00	22.92
Gr1 to Gr2	19.22	22	.63	1.00	1.00	.00	31.22
K to Gr2	11.90	22	.96	1.00	1.02	.00	23.90
Spelling dependent factor							
Gr1 to Gr2	8.63	15	.90	1.00	1.05	.00	20.63
K to Gr2	14.48	15	.49	1.00	1.00	.00	26.48
French language dependent factor							
Gr1 to Gr2	14.61	22	.88	1.00	1.04	.00	26.61
K to Gr2	17.97	22	.71	1.00	1.02	.00	29.97
Mathematical abilities dependent factor							
Gr1 to Gr2	18.61	22	.67	1.00	1.01	.00	30.61
K to Gr2	22.15	22	.45	1.00	1.00	.01	34.15

Note . K: kindergarten; Gr1: first grade; Gr2: second grade

The correlations between the WM and verbal STM constructs in kindergarten and first grade with the subsequent learning constructs in first and second grade are presented in Table 6.2.[19]

[19] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average correlation coefficients between STM and learning changed by .09 for kindergarten-first grade, .01 for first grade-second grade, and .04 for kindergarten-second grade. For WM and learning, correlation coefficients changed on average by .04 for kindergarten-first grade, .01 for first grade-second grade, and .03 for kindergarten-second grade.

TABLE 6.2.
Correlations of the STM and WM Factors (Kindergarten and First Grade) With Subsequent Learning Factors (First and Second Grade)

	Time period		
Latent predictor	K to Gr1	Gr1 to Gr2	K to Gr2
Vocabulary dependent factor			
STM	**.33**	**.41**	**.37**
WM	.22	**.35**	**.28**
Comprehension dependent factor			
STM	**.46**	**.45**	**.47**
WM	**.49**	**.40**	**.49**
Reading dependent factor			
STM	**.26**	**.34**	**.34**
WM	**.42**	.22	**.30**
Spelling dependent factor			
STM	--	**.33**	**.30**
WM	--	**.32**	**.43**
French language dependent factor			
STM	--	**.22**	**.28**
WM	--	.22	**.27**
Mathematical abilities dependent factor			
STM	--	**.23**	**.23**
WM	--	**.27**	**.38**

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; significant coefficients marked in boldface, $p < .05$

The results showed that verbal STM in kindergarten and in first grade significantly predicted all of the learning outcomes one and two years later. The strongest associations were observed with vocabulary and comprehension (*r*'s ranging from .33 to .47) and the weakest with French and mathematics (*r*'s ranging from .22 to .28). With the exception of WM in first grade not manifesting significant links with reading and French in second grade, the WM construct was significantly associated with all of the learning outcomes. The strongest links were observed with comprehension (*r*'s ranging from .40 to .49), early reading development (WM kindergarten to first grade reading: $r = .42$) and spelling (WM kindergarten and second grade spelling: $r = .43$).

6.1.2. Structural regression models

In a next step, nested factor SR models (Gustafsson & Balke, 1993) were performed to explore the specific contributions of STM and WM to subsequent learning. As in chapter 5, the four memory tasks were loading onto a general factor. In model A, counting recall and backwards digit recall were specified as indicators of a specific WM factor (Figure 6.2.), whereas in model B nonword repetition and digit recall were specified to load onto a specific verbal STM construct (Figure 6.3.). Cross-factor loadings were freely estimated, whereas factor loadings and error variances were fixed to the values obtained from the measurement models.

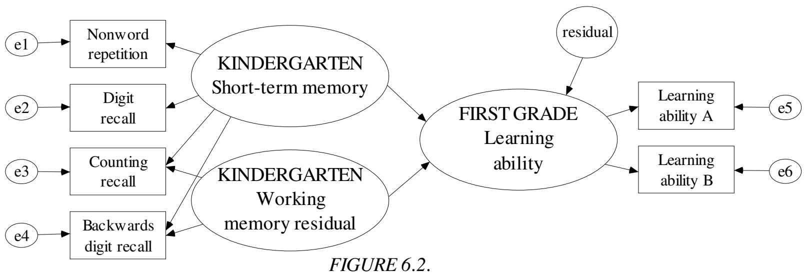

FIGURE 6.2.
Model A: nested factor model
Kindergarten WM and STM predicting learning in first grade

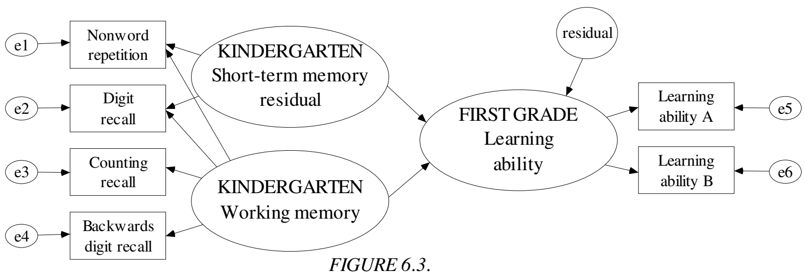

FIGURE 6.3.
Model B: nested factor model
Kindergarten WM and STM predicting learning in first grade

For each learning ability four sets of models were compared: The "full model", with both memory constructs linked to the given learning construct; two "reduced models", with paths from either verbal STM or WM to the subsequent learning construct; and a "no path" model, with no links between verbal STM and WM and subsequent learning. Models were compared by χ^2 difference tests or by comparing the AIC statistics in the case of non-hierarchical factor models. In all of the subsequent tables the total R^2 is provided in italics.

Kindergarten WM and STM predicting first grade learning

Different sets of SR models were tested linking WM and verbal STM in kindergarten to vocabulary, comprehension, and reading skills in first grade in separate analyses.

Fit statistics of model A, exploring the relationship between WM and learning after controlling for STM, are presented in Table 6.3. The χ^2 difference tests indicated that for vocabulary and comprehension the reduced model 2, with a single path from verbal STM, did not worsen model fit compared to the full model 1 [vocabulary: $\Delta\chi^2(1) = 0.0$; comprehension: $\Delta\chi^2(1) = 2.78$; $p > .10$ in both cases]. The same was not the case for the reduced model 3: Eliminating the path from STM to vocabulary or comprehension significantly worsened model fit [vocabulary: $\Delta\chi^2(1) = 9.8$; comprehension: $\Delta\chi^2(1) = 14.57$; $p < .01$ in both cases]. In both cases, model 2 provided a better account of the data than the no-path model 4 [vocabulary: $\Delta\chi^2(1) = 10.03$; comprehension: $\Delta\chi^2(1) = 16.48$; $p < .01$ in both cases]. For reading, the full model 1 provided the best account of the data and was significantly better than any of the reduced models [model 2: $\Delta\chi^2(1) = 5.67$, $p < .05$; model 3: $\Delta\chi^2(1) = 6.44$, $p < .01$; model 4: $\Delta\chi^2(2) = 13.95$, $p < .01$].

TABLE 6.3.
Fit Statistics and Standardized Regression Coefficients for Model A (Controlling for Verbal STM) Linking Kindergarten STM and WM to Learning in First Grade

								Path coefficients	
Models	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	STM	WM
				Vocabulary first grade					
Model 1: WM and STM	24.21	14	.05	.96	.96	.08	38.21	.33	.01
Model 2: STM only	**24.21**	**15**	**.06**	**.96**	**.96**	**.07**	**36.21**	**.33**	--
Model 3: WM only	34.01	15	.00	.92	.92	.10	46.01	--	.07
Model 4: No path	34.24	16	.00	.93	.93	.10	44.24	--	--
Total R^2 model 1	*.11*								
				Comprehension first grade					
Model 1: WM and STM	18.72	14	.18	.97	.97	.05	32.72	.46	.25
Model 2: STM only	**21.50**	**15**	**.12**	**.96**	**.96**	**.06**	**33.37**	**.49**	--
Model 3: WM only	33.29	15	.00	.88	.88	.10	45.29	--	.37
Model 4: No path	37.98	16	.00	.85	.85	.11	47.98	--	--
Total R^2 model 1	*.28*								
				Reading first grade					
Model 1: WM and STM	**10.86**	**14**	**.70**	**1.00**	**1.01**	**.00**	**24.86**	**.27**	**.32**
Model 2: STM only	16.53	15	.35	.99	.99	.03	28.53	.30	--
Model 3: WM only	17.30	15	.30	.99	.99	.04	29.30	--	.38
Model 4: No path	24.81	16	.07	.97	.97	.07	34.81	--	--
Total R^2 model 1	*.17*								

Note . The endorsed model is marked in boldface.

For model B (Table 6.4.), the results showed that for both comprehension and reading the reduced model 3, linking only the general WM construct to the given outcome factor, was preferred over the full model 1 [comprehension: $\Delta\chi^2(1) = 1.48$;

reading: $\Delta\chi^2(1) = .00$; $p > .10$ in both cases], the no-path model 4 [comprehension: $\Delta\chi^2(1) = 18.21$; reading: $\Delta\chi^2(1) = 14.29$; $p < .05$ in all cases], and the reduced model 2 [comprehension: ΔAIC = 11.83; reading: ΔAIC = 13.12]. For vocabulary, none of the reduced single path models worsen model fit considerably in comparison to the full model 1 [model 2: $\Delta\chi^2(1) = 3.52$; model 3: $\Delta\chi^2(1) = 3.36$; $p > .05$ in both cases]. Constraining both paths to 0 (model 4) resulted, however, in a significant decrease in model fit over the full model 1 [$\Delta\chi^2(2) = 10.11$, $p < .01$] suggesting that both path are necessary in the model.

TABLE 6.4.
Fit Statistics and Standardized Regression Coefficients for Model B (Controlling for WM) Linking Kindergarten STM and WM to Learning in First Grade

								Path coefficients	
Models	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	STM	WM
Vocabulary first grade									
Model 1: WM and STM	**24.01**	**14**	**.05**	**.96**	**.96**	**.08**	**38.01**	**.24**	**.23**
Model 2: STM only	27.53	15	.02	.95	.95	.08	39.53	.32	--
Model 3: WM only	27.37	15	.03	.95	.95	.08	39.37	--	.30
Model 4: No path	34.12	16	.00	.93	.93	.10	44.12	--	--
Total R^2 model 1	*.11*								
Comprehension first grade									
Model 1: WM and STM	18.17	14	.20	.97	.97	.05	32.17	.18	.51
Model 2: STM only	31.48	15	.00	.89	.89	.10	43.48	.37	--
Model 3: WM only	**19.65**	**15**	**.19**	**.97**	**.97**	**.05**	**31.65**	--	**.56**
Model 4: No path	37.86	16	.00	.85	.85	.11	47.86	--	--
Total R^2 model 1	*.28*								
Reading first grade									
Model 1: WM and STM	10.40	14	.73	1.00	1.01	.00	24.40	-.01	.42
Model 2: STM only	23.52	15	.07	.97	.97	.07	35.52	.14	--
Model 3: WM only	**10.40**	**15**	**.79**	**1.00**	**1.02**	**.00**	**22.40**	--	**.42**
Model 4: No path	24.69	16	.07	.97	.97	.07	34.69	--	--
Total R^2 model 1	.17								

Note . The endorsed model is marked in boldface.

In summary, the results suggest that when considered independently both verbal STM and WM in kindergarten significantly predicted vocabulary and reading one year later. The general verbal STM factor explained 11% of the variance in vocabulary, and 7% of the variance in reading in first grade. The general WM construct accounted for a significant 5% and 17% of the respective variances in first grade vocabulary and reading. When the specific contributions of verbal STM and WM were considered, the results showed that STM accounted for a significant 5% of extra variance in vocabulary, whereas the specific WM factor did not make significant contributions to vocabulary above the variance explained by STM. The opposite pattern of results was observed for reading: The specific WM construct was significantly associated with reading in first grade, accounting for 10% of its variance. The link between STM and reading disappeared once WM was controlled. For comprehension, the data showed that the general STM and WM constructs respectively explained a significant 21% and 26% of the variance in comprehension one year later. When STM was considered, WM maintained a medium association with comprehension (accounting for 6% of its variance) that failed, however, to reach significance. In the same vein, the specific STM factor explained a negligible 3% of extra variance in comprehension once WM was controlled.[20]

First grade WM and STM predicting second grade learning

The following SR models explored the relations between verbal STM and WM in first grade with vocabulary, comprehension, French, reading, spelling, and mathematical abilities in second grade in six separate set of analyses. The results of model A are summarized in Table 6.5. and of model B in Table 6.6.

For model A (Table 6.5.) the results indicated that for none of the models eliminating the link of the specific WM factor with the given learning construct (model 2) significantly worsen model fit in relation to the full two-path model 1 [vocabulary: $\Delta\chi^2(1) = 2.98$; comprehension: $\Delta\chi^2(1) = 3.76$; French: $\Delta\chi^2(1) = 1.23$; reading: $\Delta\chi^2(1) = .84$; spelling: $\Delta\chi^2(1) = 2.71$; mathematics: $\Delta\chi^2(1) = 2.17$; $p = > .05$ in all cases]. Furthermore, in all the analyses model 2 was significantly better than the no-path model 4 [vocabulary: $\Delta\chi^2(1) = 15.56$; comprehension: $\Delta\chi^2(1) = 16.77$; French: $\Delta\chi^2(1) = 4.11$; reading: $\Delta\chi^2(1) = 11.41$; spelling: $\Delta\chi^2(1) = 8.63$; mathematics: $\Delta\chi^2(1) = 4.99$; $p = < .05$ in all cases] and the reduced model 3 [vocabulary: ΔAIC = 11.85; comprehension: ΔAIC = 12.15; French: ΔAIC = 2.65; reading: ΔAIC = 10.24; spelling: ΔAIC = 5.92; mathematics: ΔAIC = 2.49].

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[20] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average standardized regression coefficients between STM and learning changed by .01 for model A and by .05 for model B. For WM and learning, standardized regression coefficients changed on average by .05 for model A and by .04 for model B.

TABLE 6.5.
Fit Statistics and Standardized Regression Coefficients for Model A (Controlling for Verbal STM) Linking First Grade STM and WM to Learning in Second Grade

Models	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients STM	Path coefficients WM
Vocabulary second grade									
Model 1: WM and STM	12.63	14	.56	1.00	1.00	.00	26.63	.41	.24
Model 2: STM only	**15.61**	**15**	**.41**	**1.00**	**1.00**	**.02**	**27.61**	**.42**	--
Model 3: WM only	27.46	15	.02	.94	.94	.08	39.46	--	.30
Model 4: No path	31.17	16	.01	.93	.93	.09	41.17	--	--
Total R^2 model 1	*.22*								
Comprehension second grade									
Model 1: WM and STM	18.13	21	.64	1.00	1.02	.00	32.13	.45	.29
Model 2: STM only	**21.89**	**22**	**.47**	**1.00**	**1.00**	**.00**	**33.89**	**.46**	--
Model 3: WM only	34.04	22	.05	.92	.92	.07	46.04	--	.36
Model 4: No path	38.66	23	.02	.89	.89	.08	48.66	--	--
Total R^2 model 1	*.29*								
French language second grade									
Model 1: WM and STM	14.54	21	.84	1.00	1.03	.00	28.54	.22	.17
Model 2: STM only	**15.77**	**22**	**.83**	**1.00**	**1.03**	**.00**	**27.77**	**.23**	--
Model 3: WM only	18.42	22.0	0.7	1.00	1.02	.00	30.42	--	.19
Model 4: No path	19.88	23.0	0.7	1.00	1.02	.00	29.88	--	--
Total R^2 model 1	*.08*								
Reading second grade									
Model 1: WM and STM	19.18	21	.57	1.00	1.00	.00	33.18	.34	.13
Model 2: STM only	**20.02**	**22**	**.58**	**1.00**	**1.00**	**.00**	**32.02**	**.35**	--
Model 3: WM only	30.26	22	.11	.98	.98	.06	42.26	--	.16
Model 4: No path	31.43	23	.11	.98	.98	.06	41.43	--	--
Total R^2 model 1	*.13*								
Spelling second grade									
Model 1: WM and STM	8.54	14	.86	1.00	1.04	.00	22.54	.33	.24
Model 2: STM only	**11.25**	**15**	**.73**	**1.00**	**1.03**	**.00**	**23.01**	**.34**	--
Model 3: WM only	16.93	15	.32	.98	.98	.03	28.93	--	.27
Model 4: No path	19.88	16	.23	.97	.97	.04	29.88	--	--
Total R^2 model 1	*.16*								
Mathematical abilities second grade									
Model 1: WM and STM	18.59	21	.61	1.00	1.00	.00	32.59	.23	.21
Model 2: STM only	**20.76**	**22**	**.54**	**1.00**	**1.00**	**.00**	**32.76**	**.24**	--
Model 3: WM only	23.25	22	.38	1.00	1.00	.02	35.25	--	.24
Model 4: No path	25.75	23	.31	.99	.99	.03	35.75	--	--
Total R^2 model 1	*.10*								

Note . The endorsed model is marked in boldface.

Fit indices of model B are represented in Table 6.6. and show that for vocabulary, comprehension, and spelling the full model 1 provided a significantly better account of the data than any of the reduced models [model 2 and 3: $\Delta\chi^2(1)$ ranging from 3.87 to 7.51, $p < .05$; model 4: vocabulary: $\Delta\chi^2(2) = 19.11$, comprehension: $\Delta\chi^2(2) = 21.03$, spelling: $\Delta\chi^2(2) = 11.66$; $p < .01$ in all cases]. For reading, the preferred model was the reduced model 2 with a single path from the specific STM factor to reading. Model 2 produced as good of a fit to the data as the full 2-path model 1 [$\Delta\chi^2(1) = 2.49$, $p > .05$] and provided a better account of the data than the no-path model 4 [$\Delta\chi^2(1) = 9.82$, $p < .01$] or the reduced model 3 [ΔAIC = 4.49]. For French, the preferred model was the no-path model 4 that fitted the data as good as any of the more complex models [model 1: $\Delta\chi^2(2) = 5.35$; model 2: $\Delta\chi^2(1) = 3.09$; model 3: $\Delta\chi^2(1) = 3.45$; $p < .05$]. Finally, for mathematics both of the reduced one-path models provided a significantly better fit to the data then the full model 1 [model 2: $\Delta\chi^2(1) = 3.78$; model 3: $\Delta\chi^2(1) = 1.97$; $p > .05$ in both cases]. The no-path model 4 provided a significantly better account of the data than model 2 [$\Delta\chi^2(1) = 3.60$, $p > .05$] but did not fit the data significantly better than model 3 [$\Delta\chi^2(1) = 5.41$, $p < .05$]. Model 3, with a single path from WM to mathematics, was therefore preferred.

TABLE 6.6.
Fit Statistics and Standardized Regression Coefficients for Model B (Controlling for WM) Linking First Grade STM and WM to Learning in Second Grade

								Path coefficients	
Models	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	STM	WM
				Vocabulary second grade					
Model 1: WM and STM	**11.96**	**14**	**.61**	**1.00**	**1.00**	**.00**	**25.96**	**.32**	**.37**
Model 2: STM only	18.47	15	.24	.98	.98	.04	30.47	.39	--
Model 3: WM only	19.05	15	.21	.98	.98	.05	31.05	--	.52
Model 4: No path	31.07	16	.01	.93	.93	.09	41.07	--	--
Total R^2 model 1	*23.60*								
				Comprehension second grade					
Model 1: WM and STM	**17.52**	**21**	**.68**	**1.00**	**1.02**	**.00**	**31.52**	**.35**	**.42**
Model 2: STM only	25.03	22	.29	.98	.98	.03	37.03	.43	--
Model 3: WM only	24.88	22	.30	.98	.98	.03	36.88	--	.59
Model 4: No path	38.55	23	.02	.89	.89	.08	48.55	--	--
Total R^2 model 1	*29.80*								
				French language second grade					
Model 1: WM and STM	14.42	21	.85	1.00	1.03	.00	28.42	.17	.22
Model 2: STM only	16.68	22	.78	1.00	1.03	.00	28.68	.20	--
Model 3: WM only	16.32	22	0.8	1.00	1.03	.00	28.32	--	.27
Model 4: No path	**19.77**	**23**	**0.7**	**1.00**	**1.02**	**.00**	**29.77**	--	--
Total R^2 model 1	*7.80*								
				Reading second grade					
Model 1: WM and STM	19.01	21	.58	1.00	1.00	.00	33.01	.29	.22
Model 2: STM only	**21.50**	**22**	**.49**	**1.00**	**1.00**	**.00**	**33.50**	**.33**	--
Model 3: WM only	25.99	22	.25	.99	.99	.04	37.99	--	.33
Model 4: No path	31.32	23	.11	.98	.98	.05	41.32	--	--
Total R^2 model 1	*13.50*								
				Spelling second grade					
Model 1: WM and STM	**8.11**	**14**	**.88**	**1.00**	**1.05**	**.00**	**22.11**	**.24**	**.33**
Model 2: STM only	13.00	15	.60	1.00	1.02	.00	25.00	.30	--
Model 3: WM only	11.98	15	.68	1.00	1.02	.00	23.98	--	.42
Model 4: No path	19.77	16	.23	.97	.97	.04	29.77	--	--
Total R^2 model 1	*17.00*								
				Mathematical abilities second grade					
Model 1: WM and STM	18.26	21	0.6	1.00	1.00	.00	32.26	.16	.28
Model 2: STM only	22.04	22	0.5	1.00	1.00	.00	34.04	.21	--
Model 3: WM only	**20.23**	**22**	**0.6**	**1.00**	**1.00**	**.00**	**32.23**	--	**.33**
Model 4: No path	25.64	23	0.3	.99	.99	.03	35.64	--	--
Total R^2 model 1	*10.20*								

Note . The endorsed model is marked in boldface.

Taken together, the data showed that the general STM factor in first grade was significantly associated with all of the learning constructs one year later. More particularly, verbal STM accounted for 17% of the variance in vocabulary, 20% of the variance in comprehension, 12% of the variance in reading, 11% of the variance in spelling, and finally 5% of the variance in French and in mathematics. When the common variance with WM was controlled, STM still explained a significant amount of variance in vocabulary (10%), in comprehension (12%), in reading (8%), and in spelling (6%). The associations with French language and mathematics were, however, no longer significant. The data further showed that the general WM construct in first grade significantly predicted vocabulary (14%), comprehension (18%), spelling (11%), and mathematics (8%) in second grade. Once verbal STM was taken into account none of these associations remained significant. [21]

Kindergarten WM and STM predicting second grade learning

The following set of analyses explored the two-year time period from kindergarten to second grade with verbal STM and WM in kindergarten predicting vocabulary, comprehension, French, reading, spelling, and mathematics in second grade. Six separate set of analyses were performed. The results are summarized in Table 6.7. for model A and in Table 6.8. for model B.

For model A (Table 6.7.), the data showed that for vocabulary, comprehension, French, and reading the reduced model 2, with a single path from STM, provided the best account of the data. In each case model 2 was not significantly worse than the full model 1 [vocabulary: $\Delta\chi^2(1) = .15$; comprehension: $\Delta\chi^2(1) = .2.83$; French: $\Delta\chi^2(1) = .65$; reading: $\Delta\chi^2(1) = .62$; $p > .05$ in all cases] and provided a significantly better account of the data than the no-path model 4 [vocabulary: $\Delta\chi^2(2) = 12.88$; comprehension: $\Delta\chi^2(2) = .20.13$; French: $\Delta\chi^2(2) = 7.10$; reading: $\Delta\chi^2(2) = 11.87$; $p <$ .05 in all cases] or the reduced model 3 [vocabulary: ΔAIC = 12.13; comprehension: ΔAIC = 14.92; French: ΔAIC = 5.77; reading :ΔAIC = 10.34]. For spelling and mathematics, the full model 1 produced a significantly better account of the data than the no-path model 4 [spelling: $\Delta\chi^2(2) = 13.50$; mathematics: $\Delta\chi^2(2) = 10.67$; $p = <$ .01 in both cases] and both of the reduced one-path models [spelling: model 2: $\Delta\chi^2(1)$ = 4.38, model 3: $\Delta\chi^2(1) = 7.38$, $p < .05$ in both cases; mathematics: model 2: $\Delta\chi^2(1)$ = 4.71, model 3 $\Delta\chi^2(1) = 4.55$, $p < .05$ in both cases].

[21] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average standardized regression coefficients between STM and learning changed by .00 for model A and by .06 for model B. For WM and learning, standardized regression coefficients changed on average by .05 for model A and by .04 for model B.

TABLE 6.7.
Fit Statistics and Standardized Regression Coefficients for Model A (Controlling for Verbal STM) Linking Kindergarten STM and WM to Learning in Second Grade

Models	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	Path coefficients STM	Path coefficients WM
				Vocabulary second grade					
Model 1: WM and STM	22.65	14	.07	.97	.97	.07	36.65	.37	.05
Model 2: STM only	**22.80**	**15**	**.09**	**.97**	**.97**	**.07**	**34.80**	**.37**	--
Model 3: WM only	34.93	15	.00	.92	.92	.11	46.93	--	.13
Model 4: No path	35.68	16	.00	.92	.92	.10	45.68	--	--
Total R^2 model 1	*.14*								
				Comprehension second grade					
Model 1: WM and STM	26.11	21	.20	.97	.97	.04	40.11	.47	.24
Model 2: STM only	**28.94**	**22**	**.15**	**.96**	**.96**	**.05**	**40.94**	**.50**	--
Model 3: WM only	43.86	22	.00	.89	.89	.09	55.86	--	.36
Model 4: No path	49.07	23	.00	.87	.86	.10	59.07	--	--
Total R^2 model 1	*.28*								
				French language second grade					
Model 1: WM and STM	17.91	21	.65	1.00	1.01	.00	31.91	.28	.12
Model 2: STM only	**18.56**	**22**	**.67**	**1.00**	**1.01**	**.00**	**30.56**	**.29**	--
Model 3: WM only	24.33	22	0.3	.99	.99	.03	36.33	--	.17
Model 4: No path	25.66	23	0.3	.99	.99	.03	35.66	--	--
Total R^2 model 1	*.09*								
				Reading second grade					
Model 1: WM and STM	11.85	21	.94	1.00	1.02	.00	25.85	.34	.10
Model 2: STM only	**12.47**	**22**	**.95**	**1.00**	**1.02**	**.00**	**24.47**	**.35**	--
Model 3: WM only	22.81	22	.41	1.00	1.00	.02	34.81	--	.18
Model 4: No path	24.34	23	.38	1.00	1.00	.02	34.34	--	--
Total R^2 model 1	*.13*								
				Spelling second grade					
Model 1: WM and STM	**14.41**	**14**	**.42**	**1.00**	**1.00**	**.02**	**28.41**	**.30**	**.30**
Model 2: STM only	18.79	15	.22	.98	.98	.05	30.79	.33	--
Model 3: WM only	21.79	15	.11	.96	.96	.06	33.79	--	.37
Model 4: No path	27.91	16	.03	.93	.93	.08	37.91	--	--
Total R^2 model 1	*.18*								
				Mathematical abilities second grade					
Model 1: WM and STM	**22.10**	**21**	**.39**	**1.00**	**1.00**	**.02**	**36.10**	**.23**	**.30**
Model 2: STM only	26.81	22	.22	.99	.99	.04	38.81	.26	--
Model 3: WM only	26.65	22	.22	.99	.99	.04	38.65	--	.35
Model 4: No path	32.77	23	.08	.97	.97	.06	42.77	--	--
Total R^2 model 1	*.14*								

Note . The endorsed model is marked in boldface.

For model B (Table 6.8.) the preferred model in all cases was model 3, with a single path from the general WM construct to the given learning ability [model 1: $\Delta\chi^2(1)$ ranging from .05 to 3.34, $p > .05$; model 4: $\Delta\chi^2(1)$ ranging from 6.83 to 21.0, $p < .01$; model 2: ΔAIC ranging from 2.32 to 12.75].

TABLE 6.8.
Fit Statistics and Standardized Regression Coefficients for Model B (Controlling for WM) Linking Kindergarten STM and WM to Learning in Second Grade

								Path coefficients	
Models	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*	STM	WM
Vocabulary second grade									
Model 1: WM and STM	22.37	14	.07	.97	.97	.07	36.37	.24	.29
Model 2: STM only	28.03	15	.02	.95	.95	.09	40.03	.34	--
Model 3: WM only	**25.71**	**15**	**.04**	**.96**	**.96**	**.08**	**37.71**	--	**.36**
Model 4: No path	35.56	16	.00	.92	.92	.10	45.56	--	--
Total R^2 model 1	*.14*								
Comprehension second grade									
Model 1: WM and STM	25.77	21	.21	.98	.98	.04	39.77	.20	.49
Model 2: STM only	40.70	22	.00	.90	.90	.08	52.70	.39	--
Model 3: WM only	**27.95**	**22**	**.18**	**.97**	**.97**	**.05**	**39.95**	--	**.55**
Model 4: No path	48.95	23	.00	.87	.86	.10	58.95	--	--
Total R^2 model 1	*.28*								
French language second grade									
Model 1: WM and STM	17.69	21	.67	1.00	1.01	.00	31.69	.14	.28
Model 2: STM only	22.46	22	.43	1.00	1.00	.01	34.46	.23	--
Model 3: WM only	**18.71**	**22**	**0.7**	**1.00**	**1.01**	**.00**	**30.71**	--	**.31**
Model 4: No path	25.54	23	0.3	.99	.99	.03	35.54	--	--
Total R^2 model 1	*.09*								
Reading second grade									
Model 1: WM and STM	11.57	21	.95	1.00	1.02	.00	25.57	.19	.30
Model 2: STM only	18.30	22	.69	1.00	1.00	.00	30.30	.29	--
Model 3: WM only	**13.83**	**22**	**.91**	**1.00**	**1.02**	**.00**	**25.83**	--	**.36**
Model 4: No path	24.22	23	.39	1.00	1.00	.02	34.22	--	--
Total R^2 model 1	*.13*								
Spelling second grade									
Model 1: WM and STM	13.91	14	.46	1.00	1.00	.00	27.91	.03	.44
Model 2: STM only	25.94	15	.04	.94	.94	.08	37.94	.18	--
Model 3: WM only	**13.96**	**15**	**.53**	**1.00**	**1.00**	**.00**	**25.96**	--	**.45**
Model 4: No path	27.79	16	.03	.93	.93	.08	37.79	--	--
Total R^2 model 1	*.19*								
Mathematical abilities second grade									
Model 1: WM and STM	21.67	21	0.4	1.00	1.00	.02	35.67	-.02	.38
Model 2: STM only	31.98	22	0.1	.97	.97	.06	43.98	.11	--
Model 3: WM only	**21.70**	**22**	**0.5**	**1.00**	**1.00**	**.00**	**33.70**	--	**.38**
Model 4: No path	32.65	23	0.1	.97	.97	.06	42.65	--	--
Total R^2 model 1	*.15*								

Note . The endorsed model is marked in boldface.

In summary, the results showed that the general STM and WM factors in kindergarten significantly predicted all of the learning constructs two years later. More specifically, verbal STM and WM accounted for 14% and 8% of the respective variances in vocabulary, 22% and 24% of the respective variances in comprehension, 11% and 9% of the respective variances in reading, 9% and 19% of the respective variances in spelling, 8% of the respective variances in French, and 5% and 14% of the respective variances in mathematics. The specific factors did not appear to make significant contributions to learning with the exception of spelling and mathematics; in both cases the specific WM factor accounted for a significant 9% of extra variance. [22]

6.1.3. Summary

Table 6.9. provides a summary of the standardized path coefficients for the three time periods, with WM and STM in kindergarten and first grade predicting learning one and two years later. Most notably, the results showed that WM and verbal STM made differential contributions to learning over the years. The overall pattern of findings is summarized below.

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[22] All the models were fitted again without fixing any of the values derived from the measurement models and the results were almost identical. On average standardized regression coefficients between STM and learning changed by .05 for model A and by .09 for model B. For WM and learning, standardized regression coefficients changed on average by .02 for model A and by .03 for model B.

TABLE 6.9.
Summary of the Standardized Path Coefficients With STM and WM in Kindergarten and First Grade as Predictors and Subsequent Learning in First and Second Grade as Outcome

	Model A		Model B	
Time period	STM	WM residual	STM residual	WM
Vocabulary dependent factor				
K to Gr1	.33**	.01	.24†	.23†
Gr1 to Gr2	.41**	.24†	.32**	.37**
K to Gr2	.37**	.05	.24†	.29*
Comprehension dependent factor				
K to Gr1	.46**	.25†	.18	.51**
Gr1 to Gr2	.45**	.29†	.35**	.42**
K to Gr2	.47**	.24†	.20	.49**
Reading dependent factor				
K to Gr1	.27*	.32*	-.01	.42**
Gr1 to Gr2	.34**	.13	.29**	.22
K to Gr2	.34**	.10	.19	.30**
Spelling dependent factor				
Gr1 to Gr2	.33**	.24†	.24*	.33*
K to Gr2	.30**	.30*	.03	.44**
French language dependent factor				
Gr1 to Gr2	.22*	.17	.17	.22
K to Gr2	.28*	.12	.14	.28*
Mathematics dependent factor				
Gr1 to Gr2	.23*	.21	.16	.28*
K to Gr2	.23*	.30*	-.02	.38**

Note. K: kindergarten; Gr1: first grade; Gr2: second grade; $^{\dagger}p < .10$; $^{*}p < .05$; $^{**}p < .01$

Verbal STM significantly predicted vocabulary over the three time periods. These links were maintained even after the variance shared with WM was taken into account. For WM the links with subsequent vocabulary knowledge appeared to be driven by verbal STM. The opposite seemed to be the case for comprehension: Whereas WM made specific contributions to comprehension over the years, the link between verbal STM and comprehension seemed to be mediated by WM (with the exception of first grade STM predicting comprehension in second grade). Both memory constructs predicted reading when considered as general factors. Once controlling for their common variance no clear pattern emerges. Most notably, WM in kindergarten significantly predicted reading in first grade, independently of verbal STM. From first to second grade verbal STM seemed to be driving the relationship, and from kindergarten to second grade none of the memory constructs appeared to make strong independent contributions to reading.

Spelling, French, and mathematical abilities were only assessed in second grade. Strong and specific links between WM and spelling emerged. Verbal STM in kindergarten did not seem to make specific contributions to spelling two years later. Specific links were, however, observed between STM in first grade and spelling in second grade. The results further showed that STM in kindergarten and first grade significantly predicted French in second grade. Once WM was controlled, these associations dropped to a non-significant level. Finally, the data showed that both the general WM and the general STM factors significantly predicted mathematical skills. When controlling for STM, the link between WM in kindergarten and mathematical skills two years later remained significant; the opposite (STM predicting mathematics after controlling for WM) was not the case. No specific links between WM or STM in first grade and mathematical abilities in second grade were observed.

6.2. Influences of individual differences in WM and STM on subsequent individual differences in learning when controlling for covariates

In the next section hierarchical regression analyses were conducted in order to examine causal relations between STM and WM with subsequent learning, independent of related cognitive abilities - phonological awareness, fluid intelligence, verbal abilities, and the autoregressive effect. The statistical procedure followed the same logic as described in the previous chapter 5, with a Cholesky factoring applied to the latent predictors (Loehlin, 1996). An illustrative example of the structural part of a model with three predictor factors (fluid intelligence, STM, and WM) is represented in Figure 6.4.

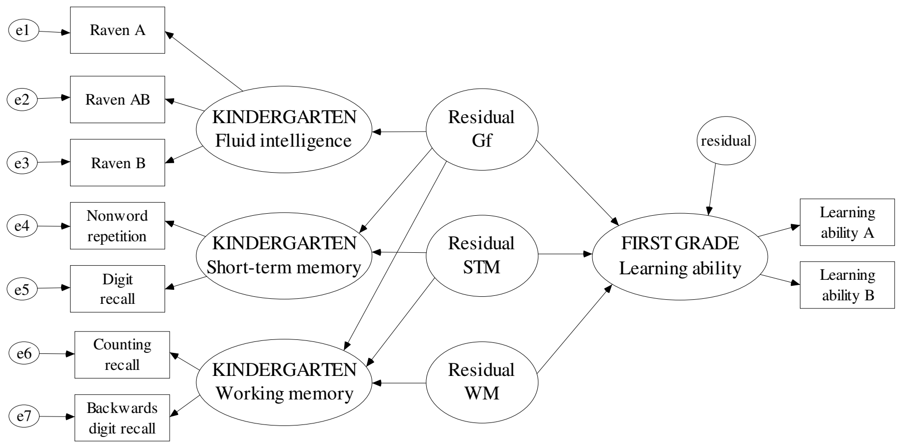

FIGURE 6.4.
Hierarchical regression model of basic cognitive ability measures in kindergarten predicting learning in first grade
Gf: fluid intelligence; STM: short-term memory; WM: working memory

Different sets of analysis were performed: In the first set, fluid intelligence and phonological awareness were included in the analysis; a second set of models explored the contributions of WM and STM to learning after controlling for verbal abilities; and in a last set of models the autoregressive effect of each learning construct on itself was included. A final part of the analyses focused on possible mediation effects and the contributions of phonological awareness to learning. No multivariate outliers were detected for any of the tested models so all the analyses were performed on the full sample of 119 cases. The distribution of scores in all of the analyses manifested multivariate normality.

6.2.1. Fluid intelligence and phonological awareness as covariates

Fluid intelligence and phonological awareness were included into the analyses together with verbal STM and WM. Structural estimates were fixed to the values obtained from the measurement models[23]. For each learning construct separate CFA models were performed. Each model containing five factors: STM, WM, phonological awareness, fluid intelligence, and the respective learning construct assessed one or two years later. All the tested models provided an excellent account

[23] The analyses were repeated without constraining any of the estimates and the results remained nearly identical. On average correlation coefficients between the cognitive factors and learning changed by .00 for fluid intelligence, .03 for phonological awareness, .05 for verbal STM, and .01 for WM.

of the data as indicated by the fit indices in Table 6.10. The χ^2 statistics of all the models were non-significant, CFI and IFI values ranged from .98 to 1.00, and none of the RMSEA indices exceeded .03.

TABLE 6.10.
Fit Indices for Confirmatory Factor Analysis (With One and Two Year Time Gaps) With WM, STM, Phonological Awareness, and Fluid Intelligence (Kindergarten and First Grade) and Subsequent Learning Abilities (First and Second Grade)

Time period	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Vocabulary dependent factor							
K to Gr1	47.22	51	.62	1.00	1.01	.00	77.22
Gr1 to Gr2	56.13	51	.29	.98	.98	.03	86.13
K to Gr2	55.19	51	.32	.99	.99	.03	85.19
Comprehension dependent factor							
K to Gr1	42.03	51	.81	1.00	1.03	.00	72.03
Gr1 to Gr2	68.15	63	.31	.98	.98	.03	98.15
K to Gr2	59.24	63	.61	1.00	1.01	.00	89.24
Reading dependent factor							
K to Gr1	38.64	51	.90	1.00	1.03	.00	68.64
Gr1 to Gr2	69.11	63	.28	.99	.99	.03	99.11
K to Gr2	53.76	63	.79	1.00	1.01	.00	83.76
Spelling dependent factor							
Gr1 to Gr2	42.32	51	.80	1.00	1.03	.00	72.32
K to Gr2	39.71	51	.87	1.00	1.04	.00	69.71
French language dependent factor							
Gr1 to Gr2	51.15	63	.86	1.00	1.04	.00	81.15
K to Gr2	54.32	63	.77	1.00	1.02	.00	84.32
Mathematical abilities dependent factor							
Gr1 to Gr2	61.30	63	.54	1.00	1.00	.00	91.30
K to Gr2	47.37	63	.93	1.00	1.03	.00	77.37

Note . K: kindergarten; Gr1: first grade; Gr2: second grade

As the correlations among the predictors for each time period are identical to the ones outlined in chapter 5 (Table 5.11., p. 169), Table 6.11. only summarizes the correlations of the basic cognitive ability factors (kindergarten and first grade) with the learning factors on subsequent years (first and second grade). The coefficients of the verbal STM and WM constructs with learning are identical to the previous section (Table 6.2., p. 191). Fluid intelligence manifested strong associations with comprehension and mathematics (*r*'s ranging from .37 to .51) and weaker, but significant, links with vocabulary (*r*'s ranging from .26 to .37) across the different time periods. Phonological awareness in first grade manifested significant links with reading, spelling, French, and mathematical abilities one year later (*r*'s ranging from

.51 to .62). Furthermore, phonological awareness correlated strongly with comprehension (*r*'s ranging from .35 to .50) and manifested medium associations with vocabulary (*r*'s ranging from .20 to .30).

TABLE 6.11.
Correlations of Fluid Intelligence, Phonological Awareness, STM, and WM (Kindergarten and First Grade) with Subsequent Learning Factors (First and Second Grade)

Latent predictors	Time period		
	K to Gr1	Gr1 to Gr2	K to Gr2
Vocabulary dependent factor			
Fluid intelligence	**.26**	**.37**	**.28**
Phonological awareness	**.20**	**.30**	**.24**
STM	**.33**	**.41**	**.37**
WM	.22	**.35**	**.28**
Comprehension dependent factor			
Fluid intelligence	**.51**	**.48**	**.44**
Phonological awareness	**.35**	**.50**	**.41**
STM	**.46**	**.45**	**.47**
WM	**.49**	**.40**	**.49**
Reading dependent factor			
Fluid intelligence	.17	.17	.12
Phonological awareness	.16	**.55**	.11
STM	**.26**	**.34**	**.34**
WM	**.42**	.22	**.30**
Spelling dependent factor			
Fluid intelligence	--	.22	.21
Phonological awareness	--	**.56**	.10
STM	--	**.33**	**.30**
WM	--	**.32**	**.43**
French language dependent factor			
Fluid intelligence	--	-.07	.12
Phonological awareness	--	**.51**	.09
STM	--	**.22**	**.28**
WM	--	.22	**.27**
Mathematical abilities dependent factor			
Fluid intelligence	--	**.44**	**.37**
Phonological awareness	--	**.62**	.18
STM	--	**.23**	**.23**
WM	--	**.27**	**.38**

Note. K: kindergarten; Gr1: first grade; Gr2: second grade; significant coefficients marked in boldface, $p < .05$

Next, two sets of hierarchical regression analyses were performed: In the first set fluid intelligence was entered in the first step, and in the second set of analyses fluid intelligence was omitted (i.e. entered last). Separate regression analyses were performed for each learning outcome. The fits of the hierarchical regression models did not differ from the fits of the CFA models reported in Table 6.10.

The results of the regression analysis are reported in Table 6.12. with the first set of analyses, incorporating fluid intelligence, displayed in the upper part of the table and the second set of analysis, with fluid intelligence excluded, in the bottom part of the table. The specific effects of verbal STM and WM on subsequent learning were explored by entering these predictors in two different orders into the regression analysis. Significance of regression coefficients were assessed by likelihood ratio tests (Gonzalez & Griffin, 2001). In addition, the absolute magnitudes of standardized path coefficients were considered following Cohen's (1988) suggestions. The total R^2 for each model is provided in italics.

TABLE 6.12.

Standardized Regression Coefficients from Hierarchical Regression Analysis With Fluid Intelligence, Phonological Awareness, STM, and WM in Kindergarten and First Grade Predicting Subsequent Learning in First and Second Grade

		Vocabulary			Comprehension			Reading			Spelling		French		Math	
Step	Latent predictor	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2
1	Fluid intelligence	.26*	.37**	.28*	.51**	.48**	.44**	.17	.17	.12	.22†	.21†	-.07	.12	.44**	.37*
2	Phonological awareness	.16	.19†	.19*	.26*	.36**	.33**	.13	.53**	.09	.52**	.07	.56**	.07	.50**	.12
3	STM	.26*	.27*	.29*	.33**	.22*	.33**	.21*	.11	.31**	.09	.26*	.03	.25*	-.08	.14
4	WM	-.15	.13	-.10	-.02	.09	.00	.29*	-.03	.08	.07	.26*	.09	.09	-.08	.12
3	WM	.05	.15	.10	.19	.11	.21	.36**	-.02	.26*	.08	.37**	.09	.23†	-.09	.18
4	STM	.29*	.26*	.29*	.27†	.22*	.26*	-.02	.12	.19	.08	.04	.02	.14	-.07	.03
	Total R^2	*.18*	*.26*	*.21*	*.43*	*.41*	*.41*	*.18*	*.32*	*.13*	*.33*	*.19*	*.33*	*.09*	*.46*	*.19*
	Without fluid intelligence															
1	Phonological awareness	.20*	.30**	.24*	.35**	.50**	.41**	.16†	.55**	.11	.56**	.10	.51**	.09	.62**	.18†
2	STM	.29*	.31**	.32*	.38**	.26*	.38**	.23*	.11	.32**	.09	.29*	.00	.27*	-.05	.18†
3	WM	-.02	.20	.02	.20	.18	.18	.31*	-.04	.10	.07	.31*	.00	.12	.00	.28*
2	WM	.16	.24	.21†	.40**	.21	.37**	.38**	-.02	.28*	.08	.42**	.00	.25*	.00	.33**
3	STM	.24*	.28**	.24*	.18	.24*	.19	.00	.12	.19	.08	.04	.00	.14	-.05	-.02
	Total R^2	*.12*	*.23*	*.16*	*.31*	*.35*	*.34*	*.17*	*.32*	*.13*	*.33*	*.19*	*.26*	*.09*	*.39*	*.14*

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; $^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$ (approximate values)

The results on vocabulary and comprehension showed that after controlling for fluid intelligence, phonological awareness, and WM (upper part of Table 6.12.), verbal STM described extra variance in vocabulary and comprehension across all three time periods. WM in contrast, did not significantly predict vocabulary or comprehension after controlling for the remaining predictors. It is worth pointing out that when fluid intelligence and STM were not taken into account (lower part of Table 6.12.), WM in kindergarten made significant contributions to language comprehension in first and second grade, and WM in first grade manifested medium links with comprehension in second grade.

For reading, the data showed that after controlling for phonological awareness neither WM nor STM in first grade added significant portions of extra variance to the prediction of reading in second grade. The data further showed that WM in kindergarten significantly predicted reading in first grade, even when phonological awareness, fluid intelligence, and STM were considered and explained a significant portion of extra variance in second grade reading if entered before STM into the analysis. Verbal STM in kindergarten did not make specific contributions to reading development once the other three predictors were taken into account, however, when entered into the analysis before WM, kindergarten STM described extra variance in first and second grade reading, independently of fluid intelligence and phonological awareness.

As for reading, the data on spelling showed that phonological awareness in first grade absorbed a considerable proportion of the variation in spelling one year later. Once phonological awareness was taken into account, first grade STM and WM did not make specific contributions to second grade spelling. The data further showed that WM in kindergarten described a significant 7% of extra variance in spelling two years later, independent of phonological awareness, fluid intelligence, and STM. Verbal STM, in contrast, did not have an additional effect on spelling if entered last into the regression analyses, however, when entered before WM, verbal STM in kindergarten predicted a significant 7% of extra variance in second grade spelling.

Finally, findings on the French and mathematics measures showed that phonological awareness in first grade made large contributions to both abilities one year later.

Importantly, after controlling for phonological awareness, first grade STM and WM did not account for additional variance in French and mathematics in second grade. The data further showed that WM in kindergarten described a significant 8% of extra variance in second grade mathematics, independently of phonological awareness and verbal STM; however, once fluid intelligence was taken into account this percentage dropped to a negligible 1%. Verbal STM in kindergarten significantly predicted French language learning in second grade, independently of phonological awareness and fluid intelligence.

6.2.2. Vocabulary knowledge as covariate

A second set of models explored specific link between WM and verbal STM with learning, controlling for verbal abilities in addition to phonological awareness and fluid intelligence. For each hierarchical regression six latent factors were entered into the analysis: fluid intelligence, phonological awareness, vocabulary knowledge, STM, WM, and the respective learning construct assessed one or two years later.

Fit statistics of the CFA models are represented in Table 6.13. and indicate that all of the tested models provided a reasonable account of the data. All of the χ^2 statistics were non-significant, CFI and IFI values were above .96, and the RMSEA indices did not exceed .04.

TABLE 6.13.
Fit Indices for Confirmatory Factor Analysis (With One and Two Year Time Gaps) With WM, STM, Phonological Awareness, Fluid Intelligence, and Verbal Abilities (Kindergarten and First Grade) and Subsequent Learning Abilities (First and Second Grade)

Time period	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
			Comprehension dependent factor				
K to Gr1	56.54	70	.88	1.00	1.03	.00	98.54
Gr1 to Gr2	91.17	84	.28	.98	.98	.03	133.17
K to Gr2	87.84	84	.37	.99	.99	.02	129.84
			Reading dependent factor				
K to Gr1	56.27	70	.88	1.00	1.03	.00	98.27
Gr1 to Gr2	102.69	84	.08	.97	.97	.04	144.69
K to Gr2	77.40	84	.68	1.00	1.01	.00	119.40
			Spelling dependent factor				
Gr1 to Gr2	68.53	70	.53	1.00	1.00	.00	110.53
K to Gr2	66.74	70	.59	1.00	1.00	.00	108.74
			French language dependent factor				
Gr1 to Gr2	79.98	84	.60	1.00	1.00	.00	121.98
K to Gr2	87.32	84	.38	.99	.99	.02	129.32
			Mathematical abilities dependent factor				
Gr1 to Gr2	86.53	84	.40	1.00	1.00	.02	128.53
K to Gr2	79.68	84	.61	1.00	1.00	.00	121.68

Note . K: kindergarten; Gr1: first grade; Gr2: second grade

Table 6.14. displays the correlations of the predictors (kindergarten and first grade) with the subsequent learning factors (first and second grade). Table 6.14. is identical to Table 6.11., with the exception that the latent vocabulary factor was added into the present analyses. Correlation coefficients in Table 6.14. show that vocabulary knowledge manifested strong links with language comprehension (*r*'s ranging from .66 to .81) and medium associations with reading, spelling, and mathematics in subsequent years (*r*'s ranging from .27 and .37). For the French language, the data showed that vocabulary in first grade, but not in kindergarten, was significantly linked to French in second grade ($r = .21$).

TABLE 6.14.
Correlations of Fluid Intelligence, Phonological Awareness, STM, WM, and Vocabulary (Kindergarten and First Grade) With Subsequent Learning Factors (First and Second Grade)

	Time period		
Latent predictor	K to Gr1	Gr1 to Gr2	K to Gr2
Comprehension dependent factor			
Fluid intelligence	**.51**	**.48**	**.44**
Phonological awareness	**.35**	**.50**	**.41**
STM	**.46**	**.45**	**.47**
WM	**.49**	**.40**	**.49**
Vocabulary	**.81**	**.75**	**.66**
Reading dependent factor			
Fluid intelligence	.17	.17	.12
Phonological awareness	.16	**.55**	.11
STM	**.26**	**.34**	**.34**
WM	**.42**	.22	**.30**
Vocabulary	**.37**	**.27**	**.27**
Spelling dependent factor			
Fluid intelligence	--	.22	.21
Phonological awareness	--	**.56**	.10
STM	--	**.33**	**.30**
WM	--	**.32**	**.43**
Vocabulary	--	**.35**	**.33**
French language dependent factor			
Fluid intelligence	--	-.07	.12
Phonological awareness	--	**.51**	.09
STM	--	**.22**	**.28**
WM	--	.22	**.27**
Vocabulary	--	**.21**	.19
Mathematical abilities dependent factor			
Fluid intelligence	--	**.44**	**.37**
Phonological awareness	--	**.62**	.18
STM	--	**.23**	**.23**
WM	--	**.27**	**.38**
Vocabulary	--	**.33**	**.32**

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; significant coefficients marked in boldface, $p < .05$

Two sets of hierarchical regression analyses were performed: In the first set, fluid intelligence was entered first, vocabulary second, and phonological awareness third (upper part of Table 6.15.). In the second set only the vocabulary factor was entered into the analysis as covariate (lower part of Table 6.15.). In all of the analyses verbal STM and WM were entering in two different orders. Separate regression analyses were performed for each learning outcome. The fits of the hierarchical regression models did not differ from the fits of the CFA models reported in Table 6.13. The results of the regression analyses are reported in Table 6.15. Regression coefficients were explored by likelihood ratio tests (Gonzalez & Griffin, 2001) and by considering the absolute magnitudes of the standardized path coefficients following Cohen's (1988) guidelines. The total R^2 for each model tested is provided in italics.

TABLE 6.15.
Standardized Regression Coefficients from Hierarchical Regression Analysis With Fluid Intelligence, Vocabulary, Phonological Awareness, STM, and WM in Kindergarten and First Grade Predicting Subsequent Learning in First and Second Grade

		Comprehension			Reading			Spelling		French		Math	
Step	Latent predictor	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2
1	Fluid intelligence	.51**	.48**	.44**	.17	.17	.12	.22†	.21†	-.07	.12	.44**	.37**
2	Vocabulary	.74**	.62**	.60**	.35**	.23*	.26*	.30**	.30**	.25*	.18	.20*	.27**
3	Phonological awareness	.10	.22*	.20*	.06	.49**	.03	.46**	.00	.52**	.03	.47**	.06
4	STM	.00	.06	.09	-.14	.08	.22*	.03	.14	-.01	.20	-.11	.03
5	WM	.04	.06	.04	.30*	-.04	.09	.06	.28*	.08	.10	-.09	.14
4	WM	.03	.06	.09	.32*	-.03	.21†	.06	.31*	.08	.20	-.10	.13
5	STM	-.02	.06	.05	.07	.09	.12	.03	-.06	-.01	.10	-.10	-.06
	Total R^2	*.82*	*.67*	*.60*	*.26*	*.33*	*.14*	*.35*	*.24*	*.34*	*.10*	*.47*	*.23*
	Without fluid intelligence and phonological awareness as covariates												
1	Vocabulary	.81**	.75**	.66	.37**	.27**	.27**	.35**	.33**	.21*	.19†	.33**	.32**
2	STM	.06	.17	.16	.09	.26**	.23*	.20†	.16	.15	.21†	.11	.08
3	WM	.26*	.18†	.25*	.32*	.10	.11	.20	.30*	.15	.12	.17	.30*
2	WM	.25*	.21†	.29*	.31*	.15	.22†	.23	.34**	.17	.22†	.19	.29*
3	STM	.-11	.13	-.02	-.12	.23*	.13	.16	-.05	.12	.10	.07	-.12
	Total R^2	*.73*	*.62*	*.52*	*.25*	*.15*	*.14*	*.20*	*.23*	*.09*	*.10*	*.15*	*.20*

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; †$p < .10$. *$p < .05$. **$p < .01$ (approximate values)

The results in the upper part of Table 6.15. show that neither verbal STM nor WM significantly predicted comprehension, French, and mathematics once vocabulary, fluid intelligence, and phonological awareness were taken into account. Interestingly, the results in the bottom part of Table 6.15. suggest that WM made significant contributions to comprehension across the three time periods that were independent of STM and verbal abilities. Furthermore, WM in kindergarten described extra variance in mathematical skills two years later, above the variance accounted for by STM and vocabulary.

For reading, the results showed that the link between WM in kindergarten and reading in first grade was maintained, even after controlling for all other four predictors. The data further showed that verbal STM in kindergarten and in first grade significantly predicted reading in second grade, independently of verbal abilities. However, when controlling for fluid intelligence and phonological awareness only the link between kindergarten STM and second grade reading remained significant. For spelling, the most notable finding was the highly specific association between WM skills in kindergarten and spelling in second grade: WM accounted for almost 8% of extra variance in spelling after controlling for verbal STM, fluid intelligence, phonological awareness, and vocabulary.

6.2.3. Autoregressive effects

The following section explores specific links of WM and STM with subsequent learning after controlling for the autoregressive effect of a given learning construct on itself at a later time point. The cross-sectional analyses in chapter 5 have shown that STM and WM were significantly associated with learning in the same year; it is therefore possible that relations between the memory constructs and subsequent learning were mediated by learning at a previous point in time.

For vocabulary and comprehension, assessments on all three occasions were obtained. Reading, involving explicit word decoding, was formally assessed in first and second grade. Measures of reading related knowledge served as autoregressor in kindergarten. In the Luxembourgish school system French is only introduced in second grade. As French is highly distinct from the Luxembourgish language, no prior knowledge of the French language for monolingual Luxembourgish children was assumed. This hypothesis was confirmed by the fact that the children manifested floor effects on the French vocabulary measure administered in kindergarten and in first grade (chapter 3). No autoregressive effect for French could therefore be included in the analyses. Finally, due to time constraints, mathematical abilities and spelling were only assessed in second grade. Given the high correlation between reading and spelling in second grade ($r = .82$), reading in kindergarten and first grade was taken as the autoregressive effect of spelling in second grade.

In summary, four analyses were performed involving vocabulary, comprehension, reading, and spelling. To get accurate estimates of relations among the latent variables, error variances of identical observed measures were allowed to correlate. With the exception of vocabulary, for which only six latent factors were included into the analysis, the rest of the models consisted of seven latent factors with two latent memory constructs; the three covariates (phonological awareness, nonverbal abilities and vocabulary); the autoregressor; and the outcome factor. No multivariate outliers were detected, and the distribution of the scores in all of the analyses manifested multivariate normality. An illustrative example of the structural part of a hierarchical autoregressive model, with vocabulary in first grade as outcome factor, is represented in Figure 6.5.

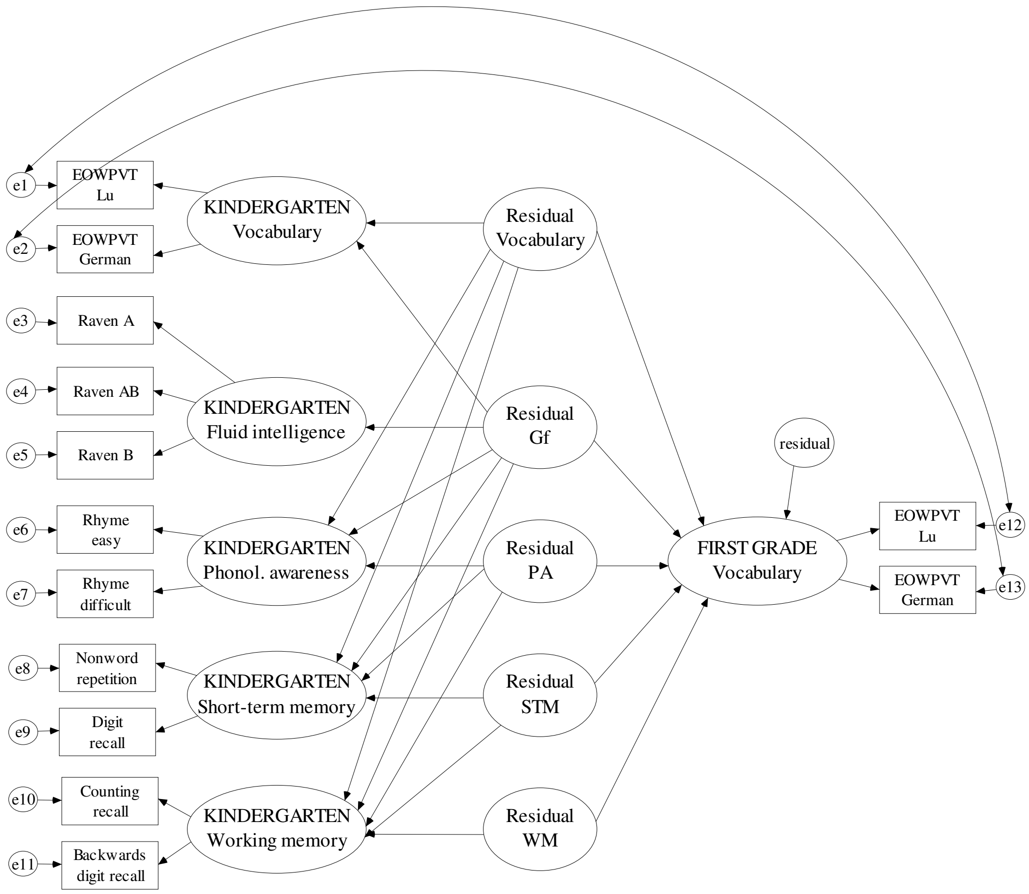

FIGURE 6.5.
Hierarchical regression model of basic cognitive ability measures and autoregressor in kindergarten predicting vocabulary in first grade
EOWPVT: Expressive One Word Picture Vocabulary Test; Lu: Luxembourgish; Gf: fluid intelligence;
PA: phonological awareness; STM: short-term memory; WM: working memory

Table 6.16. provides a summary of the fit statistics of the CFA models. All of the tested models provided a good account of the data: χ^2 statistics were non-significant, CFI and IFI values were above .97, and the RMSEA indices did not exceed .04.

TABLE 6.16.
Fit Indices for Confirmatory Factor Analysis (One and Two Year Time Gaps) with WM, STM, Phonological Awareness, Fluid Intelligence, Verbal Abilities, and Autoregressor (Kindergarten and First Grade) and Subsequent Learning Abilities (First and Second Grade)

Time period	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Vocabulary dependent factor							
K to Gr1[1]	58.64	69	.81	1.00	1.02	.00	102.64
Gr1 to Gr2[2]	81.33	69	.15	.98	.98	.04	125.32
K to Gr2[1]	78.79	69	.20	.98	.98	.03	122.79
Comprehension dependent factor							
K to Gr1[3]	59.73	76	.91	1.00	1.03	.00	117.73
Gr1 to Gr2[3]	104.33	107	.55	1.00	1.00	.00	162.33
K to Gr2[3]	97.08	91	.31	.99	.99	.02	155.08
Reading dependent factor							
K to Gr1	70.94	92	.95	1.00	1.04	.00	126.94
Gr1 to Gr2	130.81	108	.07	.98	.98	.04	186.81
K to Gr2	96.34	108	.78	1.00	1.02	.00	152.34
Spelling dependent factor							
Gr1 to Gr2	99.10	92	.29	.99	.99	.03	155.10
K to Gr2	81.16	92	.78	1.00	1.02	.00	137.16

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; [1]correlated residuals of EOWPVT Luxembourgish; [2]correlated residuals of EOWPVT German; [3]correlated residuals of TROG-Lu

The correlations of the basic cognitive ability factors, verbal ability, and the autoregressor with the subsequent learning factors are represented in Table 6.17. Table 6.17. is identical to Table 6.11. and 6.14 from the previous sections, with the exception that the autoregressive effect was added into the present analyses.

TABLE 6.17.
Correlations of Fluid Intelligence, Phonological Awareness, STM, WM, Vocabulary, and Autoregressor (Kindergarten and First Grade) with Subsequent Learning Factors (First and Second Grade)

	Time period		
Latent predictors	K to Gr1	Gr1 to Gr2	K to Gr2
Vocabulary dependent factor			
Fluid intelligence	**.26**	**.38**	**.27**
Phonological awareness	**.20**	**.32**	**.24**
STM	**.34**	**.40**	**.37**
WM	**.24**	**.36**	**.28**
Autoregressor	**.90**	**.95**	**.91**
Comprehension dependent factor			
Fluid intelligence	**.51**	**.48**	**.44**
Phonological awareness	**.35**	**.50**	**.41**
STM	**.46**	**.45**	**.47**
WM	**.49**	**.40**	**.49**
Vocabulary	**.81**	**.75**	**.66**
Autoregressor	**.59**	**.96**	**.65**
Reading dependent factor			
Fluid intelligence	.17	.17	.12
Phonological awareness	.16	**.55**	.11
STM	**.26**	**.34**	**.34**
WM	**.42**	.22	**.30**
Vocabulary	**.37**	**.27**	**.27**
Autoregressor[1]	**.33**	**.84**	**.30**
Spelling dependent factor			
Fluid intelligence	--	.22	.21
Phonological awareness	--	**.56**	.10
STM	--	**.33**	**.30**
WM	--	**.32**	**.43**
Vocabulary	--	**.35**	**.33**
Autoregressor[2]		**.72**	**.43**

Note . K: kindergarten; Gr1: first grade; Gr2: second grade;
[1]autoregressor in kindergarten = reading related knowledge;
[2]autoregressor in kindergarten = reading related knowledge; autoregressor in first grade = word decoding; significant coefficients marked in boldface, $p < .05$

Correlation coefficients in Table 6.17. indicated a powerful autoregressive effect of previous vocabulary knowledge on itself at later points in time (r's ranging from .90 to .95). Comprehension in first grade correlated almost perfectly with comprehension in second grade (r = .96), and comprehension in kindergarten was strongly associated with itself in subsequent years (r's of .59 and .65). Very high correlations were also observed between reading in first grade and reading and spelling one year later (r's of from .84 and .72). Pre-reading skills in kindergarten manifested medium associations with reading and spelling in subsequent years (*r*'s ranging from .30 and .43).

Next, three sets of regression analyses were performed: In the first, set fluid intelligence was entered first into the regression analyses, followed by vocabulary (for the comprehension, reading, and spelling models), the autoregressive effect, and phonological awareness entered in the fourth step. The second set of analyses explored the autoregressive effect more directly by omitting the other three covariates. Finally, in the last set of analyses the autoregressive effect was included after verbal STM and WM. This approach was taken to explore whether a given learning construct made significant contributions to itself in subsequent years after individual differences in WM and STM of the previous years had been taken into account. In all of the analyses verbal STM and WM were entered in two different orders. Separate regression analyses were performed for each learning outcome. Results of the regression analysis are displayed in Table 6.18. Regression coefficients were explored by likelihood ratio tests (Gonzalez & Griffin, 2001) and by considering the absolute magnitudes of the standardized path coefficients following Cohen's (1988) suggestions. The total R^2 for each model tested is provided in italics.

TABLE 6.18.

Standardized Regression Coefficients from Hierarchical Regression Analysis With Fluid Intelligence, Vocabulary, Autoregressor, Phonological Awareness, STM, and WM in Kindergarten and First Grade Predicting Subsequent Learning in First and Second Grade

		Vocabulary			Comprehension			Reading			Spelling	
Step	Latent predictor	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2
1	Fluid intelligence	.26*	.38**	.27*	.51**	.48**	.44**	.17	.17	.12	.22†	.21†
2	Vocabulary	--	--	--	.74**	.63**	.60**	.35**	.23*	.26*	.30**	.30**
3	Autoregressor	.88**	.88**	.88**	-.05	.57**	.16	.29*	.79**	.28*	.64**	.39**
4	Phonological awareness	-.03	.01	.01	.12	-.14	.17	.00	.08	-.02	.15	-.08
5	STM	-.13	-.01	-.08	.03	-.09	.06	.16	.07	.15	.02	.04
6	WM	-.01	.09	-.06	.05	.16	.05	.29*	.00	.07	.09	.24†
5	WM	-.09	.09	-.02	.06	.15	.07	.23*	.00	.14	.10	.22†
6	STM	-.09	-.01	-.10	-.01	-.11	.01	-.18	.07	.08	.04	-.11
	Total R^2	*.86*	*.92*	*.86*	*.83*	*1.00*	*.61*	*.32*	*.72*	*.19*	*.57*	*.35*
	Without fluid intelligence and phonological awareness as covariates											
1	Autoregressor	.90**	.95**	.91**	.59**	.97**	.66**	.33**	.84**	.30*	.72**	.43**
2	STM	-.11	.00	-.08	.18	-.10	.13	.18†	.10	.26*	.12	.19
3	WM	.08	.11	.06	.11	.06	.12	.26†	.02	.04	.15	.21†
2	WM	-.01	-.02	.00	.18	.06	.17	.31	.05	.19	.17	.28*
3	STM	-.14	.10	-.10	.10	-.10	.05	-.01	.09	.18	.08	.02
	Total R^2	*.83*	*.92*	*.84*	*.39*	*.95*	*.47*	*.21*	*.72*	*.16*	*.56*	*.27*
	Without fluid intelligence and phonological awareness; Autoregressor last											
3	Autoregressor	.85**	.83**	.83**	.34**	.82**	.43**	.18	.76**	.19	.63**	.29*

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; $^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$ (approximate values)

The results showed that after the autoregressive effect was taken into account other predictors did not add significant portions of variance to the prediction of vocabulary and comprehension (upper part of Table 6.18.). Furthermore, the autoregressor remained strongly associated with itself in subsequent years, even after verbal STM and WM were considered (lower part of Table 6.18.). Most probably the absence of a causal influence of WM and verbal STM on subsequent language skills was the year to year stability of individual differences in the vocabulary and comprehension constructs noted earlier.

For reading and spelling, the results showed that the link between WM in kindergarten with reading in first grade and spelling in second grade was maintained even after controlling for all other predictors. The data further showed that after controlling for verbal STM and WM, pre-reading skills in kindergarten did not account for significant portions of extra variance in reading in subsequent years.

6.2.4. Mediator effects

The preceding analyses have shown that verbal STM was significantly related to vocabulary learning in subsequent years. These effects disappeared, however, once the autoregressive effect of prior vocabulary knowledge was taken into account. One possible explanation of these findings is that vocabulary in kindergarten might have acted as a mediator variable; in other words, verbal STM in kindergarten might have exerted an impact on vocabulary in kindergarten which in turn might have influenced vocabulary in first and second grade.

This hypothesis was explored by fitting a three-factor recursive mediation model to the data. To avoid model complexity, only the time period from kindergarten to first grade was explored. The model consisted of the STM factor in kindergarten, vocabulary in kindergarten (representing the mediating factor), and vocabulary in first grade as dependent factor. Both verbal STM and vocabulary in kindergarten directly affected the dependent factor, while verbal STM also directly affected the mediator vocabulary factor in kindergarten. Figure 6.6. summarizes the interrelations in a path diagram. For simplicity only the structural part of the model is depicted.

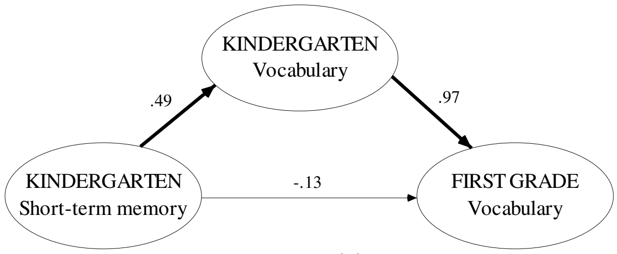

FIGURE 6.6.
Mediator effect of kindergarten STM on first grade vocabulary via kindergarten vocabulary
Lines in boldface indicate coefficients significant at the .05 level

The fit of this model was satisfactory: χ^2 (14) = 24, 33; *p* = .05; CFI = .98; IFI = .98; RMSEA = .08. Standard errors for the indirect effect of kindergarten verbal STM on first grade vocabulary through kindergarten vocabulary were estimated by the method of bootstrapping across 1000 random samples, generated by AMOS from the observed covariance matrix. Table 6.19. provides the standardized estimates and the standard errors of the direct and indirect effects with significant effects marked in boldface.

TABLE 6.19.
Mediator Effect of Kindergarten STM on First Grade Vocabulary Via Kindergarten Vocabulary

	Kindergarten vocabulary		First grade vocabulary	
Kindergarten latent factors	Standardized estimate	Standard error	Standardized estimate	Standard error
		Direct effect		
Vocabulary	--	--	**.97**	**.06**
STM	**.49**	**.09**	-.13	.08
		Indirect effect		
STM	**.47**	**.10**		

significant coefficients marked in boldface, *p* < .05

The results showed that, as expected, the direct effect of verbal STM in kindergarten on vocabulary in second grade was negligible. The indirect effect was, however, highly significant. This pattern of results - statistically significant indirect effect but not direct effect – confirmed the hypothesis that vocabulary in kindergarten played a significant mediating role in second grade vocabulary, assuming correct directionality specification (Kline, 2005). The result suggests that kindergarten verbal STM contributed to vocabulary in kindergarten which then influenced later vocabulary development, rather than verbal STM in kindergarten influencing vocabulary in second grade directly.

The same type of analysis was performed on the comprehension measures with verbal STM in kindergarten as predictor, comprehension in kindergarten as mediating factor, and comprehension in first grade as outcome factor (Figure 6.7.). Model fit was excellent: χ^2 (8) = 10.58; p = .23; CFI = .98; IFI = .98; RMSEA = .05.

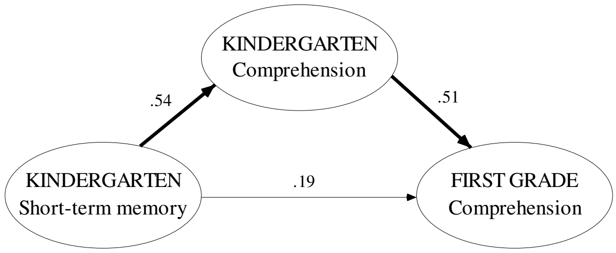

FIGURE 6.7.
Mediator effect of kindergarten STM on first grade comprehension via kindergarten comprehension
Lines in boldface indicate coefficients significant at the .05 level

The results in Table 6.20. suggest that, as for vocabulary knowledge, verbal STM exerted an indirect effect on first grade comprehension via kindergarten comprehension. It is noteworthy that the strength of the indirect effect was considerably lower than in the case of vocabulary.

TABLE 6.20.
Mediator Effect of Kindergarten STM on First Grade Comprehension Via Kindergarten Comprehension

	Kindergarten comprehension		First grade comprehension	
Kindergarten latent factors	Standardized estimate	Standard error	Standardized estimate	Standard error
		Direct effect		
Comprehension	--	--	**.51**	**.17**
STM	**.54**	**.10**	.19	.16
		Indirect effect		
STM	**.28**	**.12**		

significant coefficients marked in boldface, $p < .05$

The analyses in the preceding sections have shown that vocabulary and comprehension were strongly related. Interestingly, the link between kindergarten vocabulary and first grade comprehension was stronger than the corresponding association between the two comprehension constructs (r = .81 versus r = .59). Furthermore, the data showed that significant links between STM and subsequent comprehension dropped to a non-significant level once vocabulary knowledge was considered.

In a final mediation model the possibility was therefore explored that the verbal STM-comprehension link was mediated by vocabulary knowledge. For this purpose a four factor model was fitted to the data. The structural part of the model with standardized path coefficients is represented in Figure 6.8.

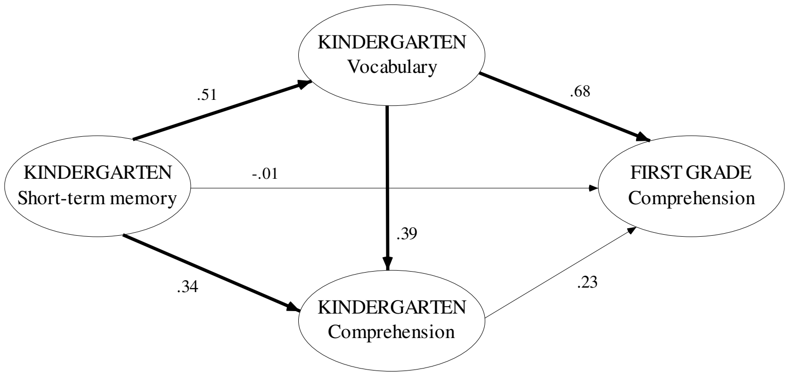

FIGURE 6.8.
Mediator effects of kindergarten STM on first grade comprehension via kindergarten comprehension and vocabulary; Lines in boldface indicate coefficients significant at the .05 level

The analysis showed that the link between STM and comprehension in kindergarten remained significant even after vocabulary knowledge was taken into account (.34). Interestingly, the link between comprehension in kindergarten and comprehension in first grade was non-significant (.23) and appeared to be largely mediated by vocabulary knowledge in kindergarten. The direct effect of kindergarten STM on first grade comprehension was non-significant (-.01); importantly, the indirect effect was highly significant (standardized estimate = .47; *SD* = .11).

Taken together, the data suggests that verbal STM in kindergarten directly influenced the development of early vocabulary knowledge and language comprehension skills; however, in later stages of development the link with language comprehension appeared to be largely driven by vocabulary knowledge.

6.2.5. Phonological awareness and learning

In the final analyses the effect of phonological awareness on learning was explored. Three sets of analyses were performed: In the first set, phonological awareness was entered into the analysis after fluid intelligence, vocabulary, STM, and WM. The second set of analyses included the autoregressive effect in the third step, and finally in the last set of analyses phonological awareness was entered into the analysis after fluid intelligence and the autoregressor. The results of the regression analysis are reported in Table 6.21. with the first set of analyses displayed in the upper part of the table, the second set of analyses in the middle, and the last set of analyses in the bottom of Table 6.21.

The data showed that phonological awareness did not account for additional variance in any of the learning constructs after controlling for fluid intelligence and the autoregressive effect (bottom of Table 6.21.). When the autoregressive effect was not taken into account but all other predicators were held constant (top of Table 6.21), the data showed that phonological awareness in first grade described a significant amount of extra variance in second grade reading (18%), spelling (15%), French (20%), and mathematics (23%).

TABLE 6.21.

Standardized Regression Coefficients from Hierarchical Regression Analysis With Fluid Intelligence, Vocabulary, Phonological Awareness, Autoregressor, STM, and WM in Kindergarten and First Grade Predicting Subsequent Learning in First and Second Grade

		Vocabulary			Comprehension			Reading			Spelling		French		Math	
Step	Latent predictor	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2	Gr1-Gr2	K-Gr2
1	Fluid intelligence	.26*	.37**	.28*	.51**	.48**	.44**	.17	.17	.12	.22†	.21†	-.07	.12	.44**	.37**
2	Vocabulary	--	--	--	.74**	.63**	.60**	.35**	.23*	.26*	.30**	.30**	.25*	.18	.20*	.27*
3	STM	.29**	.33**	.32**	.02	.13	.12	.08	.25*	.23*	.19	.14	.17	.20	.06	.04
4	WM	-.13	.14	-.08	.06	.11	.08	.32*	.09	.09	.18	.27*	.22	.10	.05	.15
3	WM	.09	.21	.15	.06	.13	.14	.30*	.13	.21†	.21	.30**	.25	.20	.06	.14
4	STM	.30**	.29**	.30**	-.02	.11	.04	-.14	.23*	.12	.16	-.06	.13	.10	.05	-.06
5	Phonological awareness	.12	.03	.13	.09	.17	.17	-.02	.42**	-.02	.39**	-.08	.45**	-.02	.48**	.03
	With autoregressive effect															
1	Fluid intelligence	.26*	.38**	.27*	.51**	.48**	.44**	.17	.17	.12	.22†	.21†				
2	Vocabulary	--	--	--	.74**	.63**	.60**	.35**	.23*	.26*	.30	.30**				
3	Autoregressor	.88**	.88**	.88**	-.05	.57**	.16	.29*	.79**	.28*	.64**	.39**				
4	STM	-.13	-.01	-.10	.04	-.11	.07	-.01	.09	.15	.06	.04				
5	WM	-.02	.09	-.02	.07	.11	.08	.28*	.02	.06	.12	.24*				
4	WM	-.10	.09	-.07	.08	.09	.11	.22†	.03	.14	.13	.22†				
5	STM	-.09	-.02	-.06	-.01	-.13	.00	-.18	.09	.09	.05	-.11				
6	Phonological awareness	-.01	-.01	.03	.10	-.17	.15	-.05	.06	-.05	.10	-.08				
	With fluid intelligence and autoregressor as covariates															
1	Fluid intelligence	.26*	.38**	.27*	.51**	.48**	.44**	.17	.17	.12	.22†	.21†				
2	Autoregressor	.88**	.88**	.88**	.38**	.86**	.50**	.29*	.83**	.28*	.70**	.39**				
3	Phonological awareness	-.03	.01	.01	.14	-.09	.18	.08	.08	.04	.16	.00				

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; $^{\dagger}p < .10$. $^{*}p < .05$. $^{**}p < .01$ (approximate values)

6.2.6. Summary

The preceding analyses explored predictive relations of STM and WM with subsequent learning after controlling for fluid intelligence, vocabulary, phonological awareness, and the autoregressive effects. The main findings are summarized in Figure 6.9. Arrows marked in boldface represent associations that remained significant after controlling for the autoregressive effect in addition to the other predictors.

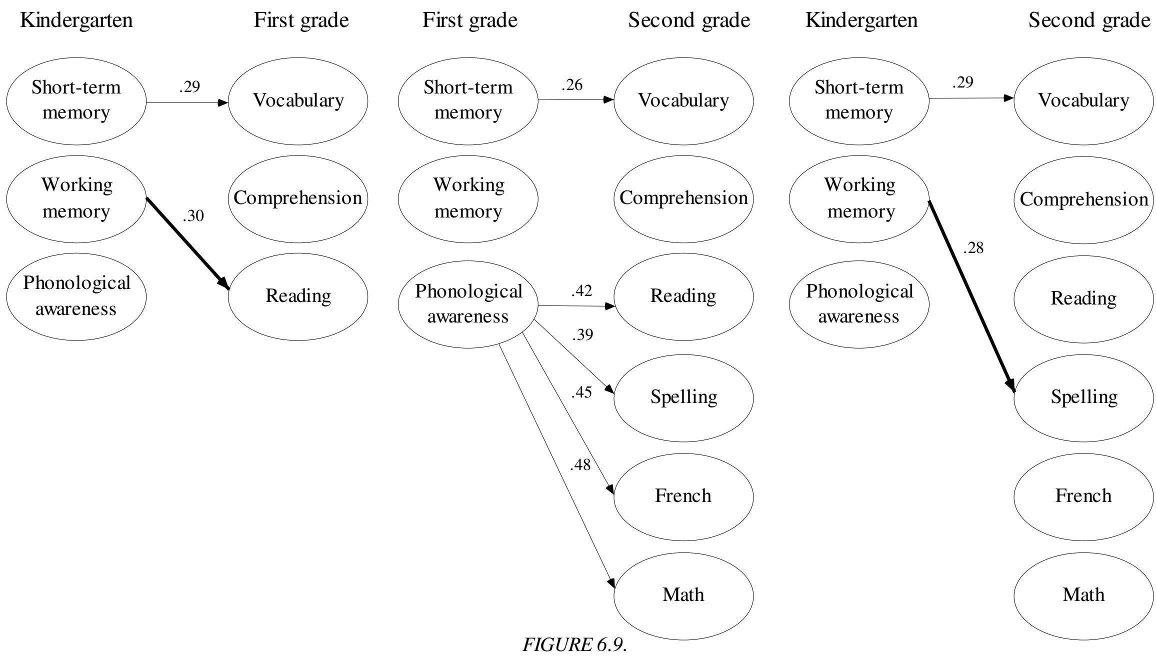

FIGURE 6.9.
Summary of the hierarchical regression models controlling for fluid intelligence, vocabulary, phonological awareness, verbal STM, and WM Lines in boldface indicate path coefficients that remained significant after taking the autoregressive effect into account

In summary, the data showed that verbal STM significantly predicted vocabulary knowledge in the native language and the foreign language German one and two years later. Highly specific links were further observed between kindergarten WM and reading in first grade and spelling in second grade; Importantly, these links were very robust and remained significant even after the autoregressive effect was taken into account. Both, verbal STM and WM in kindergarten predicted reading in second grade when considered independently; when controlling for their common variance these links dropped to a non-significant level, suggesting that the causal influences of kindergarten STM and WM on reading in second grade might be redundant with one another.

The analyses further showed that WM and verbal STM did not make significant contributions to language comprehension once related cognitive abilities were taken into account. Two results are, however, worth pointing out: First, the relationship between verbal STM and subsequent comprehension appeared to be mediated by vocabulary knowledge - raising the possibility that STM might impact on early vocabulary development which in turn might contribute to later comprehension skills. Second, the data showed that WM significantly predicted subsequent comprehension skills when vocabulary and verbal STM were considered as covariates. Only after fluid intelligence was entered as additional covariate into the analysis the significant link disappeared, suggesting that it is the variance that WM and fluid intelligence have in common that accounts for the WM-comprehension relationship. The same pattern was observed for mathematical abilities: WM in kindergarten was found to make a significant contribution to mathematics in second grade that was independent of vocabulary and verbal STM, however, once fluid intelligence was controlled the association dropped to non-significant level. No strong links were observed between any of the memory components and French language once related cognitive abilities were considered.

For phonological awareness the data showed that rhyme detection in kindergarten was not significantly associated with any of the learning outcomes one and two years later. Phonological awareness in first grade significantly predicted reading, spelling, French, and mathematical skills in second grade; associations with reading and spelling disappeared, however, once the autoregressive effect was taken into account.

6.3. Reversed causality: Causal influences of learning on basic cognitive abilities

The foregoing analyses have shown that WM, STM, and phonological awareness affected learning in subsequent years. A further question is whether specific learning abilities also impact on the development of basic cognitive abilities. Claims have been made that learning to read determines the development of phonological abilities (Morais et al., 1979) and of verbal WM (de Jong & van der Leij, 1999). In the same way it has been suggested that individual differences in vocabulary knowledge make important contributions to verbal STM (Snowling et al., 1991). The following section focuses more particularly on these issues by exploring reversed causality effects. It is important to bear in mind that reversed causality can be present in addition to causal effect; interpretations in both directions are therefore not mutually exclusive.

Reversed causality effects could only be explored for constructs that were assessed on more then one occasion. The preceding section has identified strong and highly specific links between verbal STM and vocabulary, and between WM and phonological awareness with reading. Less specific associations were observed between reading and verbal STM. The following analyses focus on these effects and explore them in the opposite direction. With one exception (described below) no multivariate outliers were detected for any of the models tested so all of the analyses were performed on the full sample of 119 cases. The distribution of scores in all of the analyses manifested multivariate normality. To get accurate estimates of relations among the latent variables, residual error variances of identical observed variables were allowed to correlate and retained in the final model if significant.

6.3.1. Influences of vocabulary knowledge on verbal STM

Links between vocabulary knowledge and subsequent verbal STM were explored by conducting latent variable hierarchical regression analysis, including the autoregressive effect of prior verbal STM and fluid intelligence as additional causal influences. Fit statistics in Table 6.22. indicate that the tested models provided a good account of the data with non-significant χ^2 values, CFI and IFI indices above .97, and RMSEAs below .05. The estimation of the second model (Gr1 to Gr2) led to a negative error variance of the STM factor that was, however, not significantly different from 0 and therefore constrained to .005 (Bentler, 1976).

TABLE 6.22.
Fit Indices of the Hierarchical Regression Models (One and Two Year Gaps) with Vocabulary, Fluid Intelligence, and Autoregressor (Kindergarten and First Grade) and Subsequent STM

Time period	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
K to Gr1[1]	31.02	34	.61	1.00	1.00	.00	53.02
Gr1 to Gr2[1]	34.34	35[2]	.50	1.00	1.00	.00	54.34
K to Gr2[1]	41.66	34	.17	.98	.98	.04	63.66

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; [1]correlated residuals of nonword repetition; [2]error variance of STM constrained to .005

Standardized parameter estimates in Table 6.23. showed that none of the links from vocabulary to subsequent verbal STM were highly significant. The most likely explanation of these findings is the year to year stability of individual differences in verbal STM. When the model was deliberately misspecified by omitting the autoregressive effect, apparent links between vocabulary and subsequent verbal STM skills emerged (bottom of Table 6.23.).

TABLE 6.23.
Standardized Regression Coefficients from Hierarchical Regression Analysis With Fluid Intelligence, Vocabulary, and Autoregressor in Kindergarten and First Grade Predicting Subsequent STM in First and Second Grade

		Verbal STM dependent factor		
Step	Latent predictor	K-Gr1	Gr1-Gr2	K-Gr2
1	Fluid intelligence	.11	.25*	.09
2	Autoregressor	.97**	.97**	.93**
3	Vocabulary	-.01	-.07	-.01
	Without autoregressor			
1	Fluid intelligence	.11	.25*	.09
2	Vocabulary	.45**	.24*	.44**

Note. K: kindergarten; Gr1: first grade; Gr2: second grade;
$^{*}p < .05$. $^{**}p < .01$ (approximate values)

Figure 6.10. represents the cross-lagged standardized coefficients between verbal STM and vocabulary controlling for fluid intelligence, across each adjacent pair of time interval sampled in the present study. Cross-lagged relationships refer to the effect of latent variables on a previous time on other variable at a later time (Bast & Reitsma, 1997).

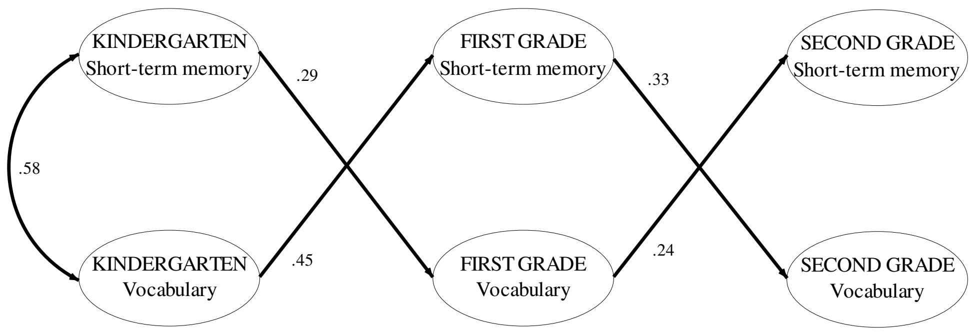

FIGURE 6.10.
Cross-lagged relationships with standardized path coefficients between STM and vocabulary controlling for fluid intelligence
Lines in boldface indicate path coefficients significant at the .05 level

Both latent constructs manifested significant relations with their respective counterparts over subsequent years. Most notably, kindergarten vocabulary manifested strong links with first grade verbal STM, whereas all other structural coefficients indicated medium effect sizes (Cohen, 1988).

A more accurate model of causal relations, including the autoregressive effect, is represented in Figure 6.11. This model could be explicitly tested. The fluid intelligence factor was not included in this model since it did not describe additional variance after the autoregressive effects had been controlled for. One multivariate outlier was detected. After exclusion of this case (N = 118), the distribution of scores in all of the measures manifested multivariate normality. All the parameters were freely estimated. The estimate of the variance of the second grade STM factor residual was negative, yet not significantly different from zero; this parameter was therefore fixed to .005. Although the χ^2 index of this model was slightly high, the remaining fit indices indicated acceptable model fit: $\chi^2(38) = 56.06$, $p = .03$; CFI = .99; IFI = .99; RMSEA = .06. As expected, when the autoregressive effects were included no causal influences of verbal STM on subsequent vocabulary skills and vice versa emerged.

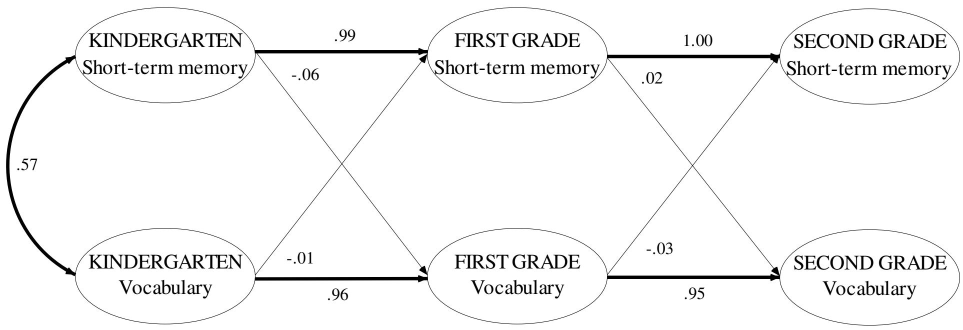

FIGURE 6.11.
Cross-lagged relationships with standardized path coefficients between STM and vocabulary including the autoregressive effect
Lines in boldface indicate path coefficients significant at the .05 level

6.3.2. Influences of reading on basic cognitive abilities

WM, verbal STM, and phonological awareness have been found to make significant contributions to subsequent reading skills that were independent of fluid intelligence and verbal abilities. Reversed causality effects were explored for each of these cognitive abilities by performing separate hierarchical regression analyses including the autoregressive effect, fluid intelligence, and vocabulary knowledge of the previous years as covariates. Fit statistics in Table 6.24. indicate that all of the tested models provided an acceptable fit to the data, with non-significant χ^2 values (with the exception of the phonological awareness model, Gr1-Gr2), CFI and IFI indices above .95, and RMSEA indices below .07. For the STM model, the estimation of the second model (Gr1-Gr2) led to a negative value of the STM factor residual; the negative estimate did not depart significantly from zero and was therefore fixed to .005.

TABLE 6.24.
Fit Indices of the Hierarchical Regression Models (With One and Two Year Gaps) With Reading, Vocabulary, Fluid Intelligence, and Autoregressor (Kindergarten and First Grade) and Subsequent WM, STM, or phonological awareness (First and Second Grade)

Time period	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
Working memory dependent factor							
K to Gr1[1]	31.02	34	.61	1.00	1.00	.00	53.02
Gr1 to Gr2[1]	34.34	35	.50	1.00	1.00	.00	54.34
K to Gr2[1]	41.66	34	.17	.98	.98	.04	63.66
Short-term memory dependent factor							
K to Gr1[2]	39.74	50	.85	1.00	1.02	.00	71.74
Gr1 to Gr2[2]	46.75	51[3]	.64	1.00	1.00	.00	76.75
K to Gr2[2]	55.04	50	.29	.99	.99	.03	87.04
Phonological awareness dependent factor							
K to Gr1	41.48	51	.83	1.00	1.04	.00	71.48
Gr1 to Gr2	75.58	51	.02	.96	.96	.06	105.58
K to Gr2	38.56	51	.90	1.00	1.04	.00	68.56

Note . K: kindergarten; Gr1: first grade; Gr2: second grade; [1]correlated residuals of counting recall; [2]correlated residuals of nonword repetition; [3]residual of STM constrained to .005

Standardized parameter estimates of all the models are shown in Table 6.25. As indicated in the upper part of Table 6.25., no causal influences of reading on subsequent WM and STM abilities were found. Importantly, influences of individual differences in reading emerged for subsequent individual differences in phonological awareness. When the model was intentionally misspecified, by omitting the autoregressive effect (bottom part of Table 6.25.), the overall pattern of results did not change considerably (with the exception of a significant link between first grade reading and second grade WM).

TABLE 6.25.
Standardized Regression Coefficients from Hierarchical Regression Analysis With Fluid Intelligence, Vocabulary, Autoregressor, and Reading in Kindergarten and First Grade Predicting Subsequent WM, STM, or Phonological Awareness in First and Second Grade

		Dependent variable								
		Working memory			Verbal short-term memory			Phonological awareness		
Step	Latent predictor	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2	K-Gr1	Gr1-Gr2	K-Gr2
1	Fluid intelligence	.24	.50**	.35**	.11	.25*	.09	.34**	.27**	.23*
2	Vocabulary	.42**	-.02	.13	.45**	.24*	.44**	.31**	.22*	.36**
3	Autoregressor	.26	.57**	.55**	.86**	.94**	.82**	.27*	.51*	.32**
4	Reading	.00	.16	-.11	-.11	-.07	-.20	.33**	.17*	.29**
	Without autoregressor									
1	Fluid intelligence	.24	.50**	.35**	.11	.25*	.09	.34**	.27**	.23*
2	Vocabulary	.42**	-.02	.13	.45**	.24*	.44**	.31**	.22*	.36**
3	Reading	.07	.23*	.05	.14	.10	.01	.38**	.42**	.34**

Note. K: kindergarten; Gr1: first grade; Gr2: second grade; $^{*}p < .05$. $^{**}p < .01$ (approximate values)

The cross-lagged standardized coefficients controlling for fluid intelligence and verbal abilities are summarized in Figures 6.12. for WM, Figure 6.13. for phonological awareness, and Figure 6.14. for STM.

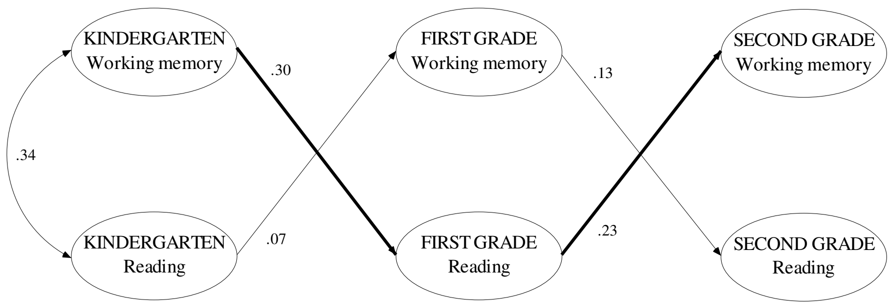

FIGURE 6.12.
Cross-lagged relationships with standardized path coefficients between WM and reading controlling for fluid intelligence and verbal abilities Lines in boldface indicate path coefficients significant at the .05 level

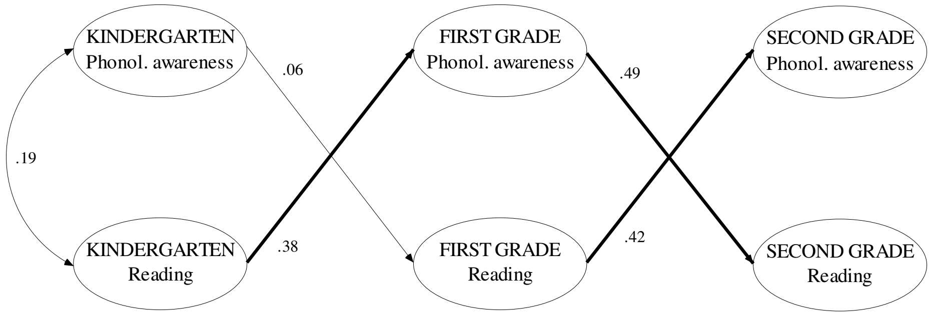

FIGURE 6.13.
Cross-lagged relationships with standardized path coefficients between phonological awareness and reading controlling for fluid intelligence and verbal abilities; Lines in boldface indicate path coefficients significant at the .05 level

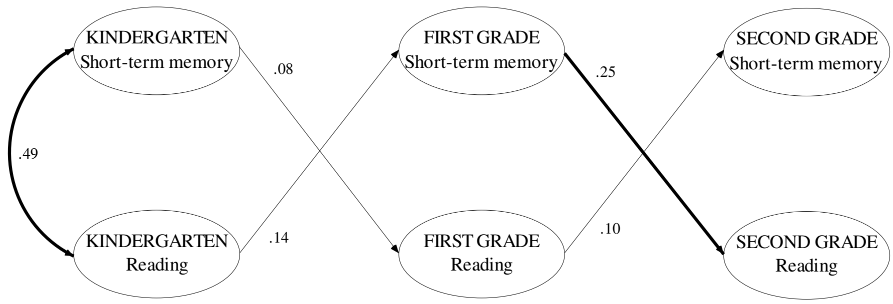

FIGURE 6.14.
Cross-lagged relationships with standardized path coefficients between STM and vocabulary controlling for fluid intelligence
Lines in boldface indicate path coefficients significant at the .05 level

The figures showed that WM in kindergarten manifested significant links with reading in first grade (Figure 6.12.). Importantly, the converse lead-lagged coefficient between reading related knowledge and subsequent WM skills was non-significant. The opposite pattern was observed for phonological awareness (Figure 6.13.). Reading-related knowledge in kindergarten significantly predicted phonological awareness skills in first grade; but rhyme detection in kindergarten was not significantly associated with reading skills one year later. After the children had been introduced into literacy in first grade both constructs appeared to influence each other mutually. For WM in contrast, only reading in first grade was significantly associated with WM skills one year later, whereas links between first grade WM and subsequent reading were no longer significant. Finally, for verbal STM (Figure 6.14.) the only significant link was found between verbal STM in first grade and reading in second grade.

Although informative in nature, it is important to treat the preceding analyses with caution because the autoregressive effects were intentionally omitted from the analyses. The following models incorporate the autoregressive effects and provide therefore a more accurate account of the data. To avoid model complexity the covariates fluid intelligence and verbal abilities were not entered into the analyses. No multivariate outliers were detected and the data manifested multivariate normality. All of the parameters were freely estimated for all the models tested. Estimates of the variances of some of the factor residuals were negative but not significantly different from zero and could therefore be fixed to .005.

Fit indices in Table 6.26. showed that the models incorporating the WM and STM factors fitted the data well, with highly significant χ^2 values, CFI and IFI indices of 1, and RMSEA values of 0. For the model involving the phonological awareness construct the initial solution did not reach a satisfactory fit (significant χ^2 index). Inspection of the modification indices suggested that the model could be improved by adding an additional correlation between the residual terms of the reading and phonological awareness factors in first grade. Adding this path significantly improved model fit as indicated by a χ^2 difference test [$\Delta\chi^2(1) = 36.83$, $p < .01$] and led to an acceptable overall model fit.

TABLE 6.26.
Fit Indices of the Cross-Lagged Regression Models Involving Reading

Model	χ^2	*df*	*p*	*CFI*	*IFI*	*RMSEA*	*AIC*
WM	50.41	54[1]	.61	1.00	1.00	.00	124.41
STM	52.48	54[2]	.53	1.00	1.00	.00	126.48
Phonological awareness	102.66	58	.00	.95	.95	.08	168.66
Phonological awareness: with correlated residuals	65.83	57	.20	.99	.99	.04	133.83

Note . [1]residual variance of second grade WM factor fixed to .005; [2]residual variance of second grade STM factor fixed to .005

The path diagrams of the different models with their standardized path coefficients are represented in Figure 6.15. for WM, Figure 6.16. for phonological awareness, and Figure 6.17. for verbal STM. The analyses showed that the strong forward link between WM in kindergarten and reading in first grade was upheld even when pre-reading skills were taken into account (Figure 6.15.). The opposite pattern (i.e. influence of early reading skills on subsequent WM abilities) was, however, not observed, suggesting that the impact of WM on subsequent reading cannot simply reflect an earlier influence of reading on memory development.

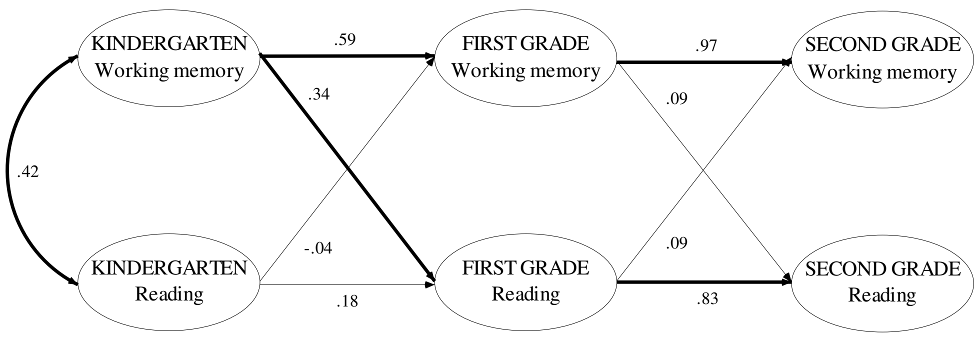

FIGURE 6.15.
Cross-lagged relationships with standardized path coefficients between WM and reading including the autoregressive effect
Lines in boldface indicate path coefficients significant at the .05 level

For phonological awareness the results showed that reading skills in kindergarten made a significant contribution to phonological awareness in first grade even after rhyme detection in kindergarten was controlled (Figure 6.16.). In contrast, phonological awareness in kindergarten did not appear to influence subsequent reading skills. The contribution of reading on subsequent phonological awareness did therefore not seem to reflect an earlier influence of phonological awareness on reading related knowledge.

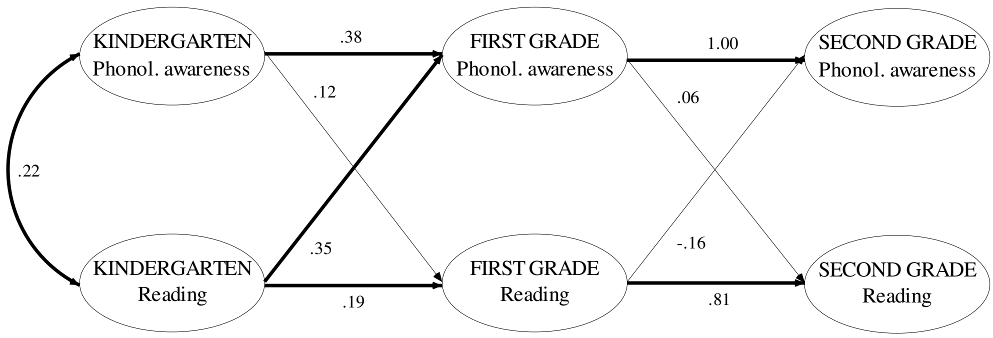

FIGURE 6.16.
Cross-lagged relationships with standardized path coefficients between phonological awareness and reading including the autoregressive effect; Lines in boldface indicate path coefficients significant at the .05 level

Finally, results on verbal STM showed that the previously identified link between first grade STM and second grade reading dropped to a non-significant level once the autoregressive effects were controlled (Figure 6.17.). Verbal STM in kindergarten appeared, however, to make significant contributions to reading in first grade. The converse lead-lagged coefficient between reading related knowledge and later STM skills was not significant, suggesting that verbal STM in kindergarten positively affected reading development one year later. It is, however, important to bear in mind that neither fluid intelligence nor verbal abilities were controlled in the present models. Previous analyses have shown that the link between STM in kindergarten and reading in first grade was mediated by vocabulary knowledge (p: 215)[24].

[24] This pattern was not observed for WM in kindergarten that remained highly associated with reading in first grade even after the common varixance with fluid intelligence, verbal abilities, and verbal STM was taken into account.

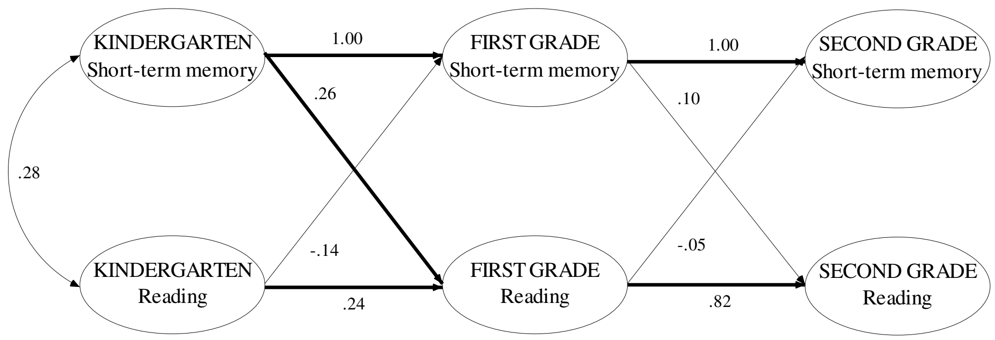

FIGURE 6.17.
Cross-lagged relationships with standardized path coefficients between short-term memory and reading including the autoregressive effect; Lines in boldface indicate path coefficients significant at the .05 level

6.4. Impact of WM and verbal STM on French vocabulary and reading comprehension

A final part of the analysis focused more particularly on two specific learning domains namely French vocabulary and reading comprehension. Each of these learning abilities will be considered in turn.

6.4.1. French vocabulary

The foregoing analyses have shown that verbal STM in kindergarten significantly predicted French language two years later independently of fluid intelligence and phonological awareness. The longitudinal analyses from first to second grade and also the cross-sectional analyses in second grade showed that in these later stages of development STM did not seem to make significant contributions to French language. It is, however, important to point out that in all cases verbal STM was significantly associated with French when considered in isolation; the links only dropped to a non-significant level once phonological awareness was taken into account, absorbing a considerable amount of variance in the French language variable. Interpretations of these findings are not straight forward as STM and phonological awareness were highly correlated which might have prevented the attempts to statistically partial out the unique effects of STM on subsequent French language knowledge.

To get a clearer picture of the contribution of verbal STM to foreign language learning the following analyses therefore focused on observed variables. Although these analyses do not benefit from the advantages of latent constructs (i.e. control for measurement error), they might provide important insights into the underlying nature of the relationship between verbal STM and foreign vocabulary learning in French, in young Luxembourgish children.

General overview of the analyses

In contrast to the structural equation modelling analyses in which the overall composite score of nonword repetition was considered, the present analyses involved the two nonword repetition subscores obtained from the repetition of high and of low wordlike nonwords. Analyses in chapter 4 have shown that both repetition scores were significantly associated with digit recall. In total three verbal STM measures were thus included in the analysis: digit span, repetition of high wordlike nonwords, and repetition of low wordlike nonwords. The main aim of the analysis was to investigate the predictive relationship of STM, WM, and phonological awareness measures obtained in kindergarten, first, and second grade with French expressive and receptive vocabulary in second grade. Furthermore, the analysis intends to specify whether the observed relations differed across languages by including vocabulary measures of the native language Luxembourgish and the highly familiar language German into the analyses.

Correlations

Bivariate correlations between the different STM, WM, and phonological awareness measures obtained in kindergarten, first, and second grade with the French, Luxembourgish, and German vocabulary measures in second grade (receptive and expressive) are provided in Table 6.27. The table further contains the correlations between native vocabulary and subsequent vocabulary knowledge in Luxembourgish, German, and French.

TABLE 6.27.
Correlations Between the Basic Cognitive Ability Measures and Native Vocabulary in Kindergarten, First, and Second Grade With the Vocabulary Measures in Second Grade Using Pearson's Correlation Coefficient

		Kindergarten						
		Short-term memory			Working memory		Phonological awareness	
Dependent factor	Native Voc.	Nonword repetition High WL	Low WL	Digit recall	Counting recall	Backwards digit recall	Rhyme detection Easy	Difficult
Gr2 French Rec. Voc.	**.22**	.15	**.28**	.16	.08	.13	.03	-.05
Gr2 French Exp. Voc.	**.28**	.14	**.23**	.08	.08	.08	.04	-.06
Gr2 German Exp. Voc.	**.74**	**.36**	**.30**	**.18**	.06	**.20**	.17	.02
Gr2 Native Exp. Voc.	**.76**	**.46**	**.41**	**.26**	.06	**.23**	**.26**	**.20**
		First grade						
		Short-term memory			Working memory		Phonological awareness	
Dependent factor	Native Voc.	Nonword repetition High WL	Low WL	Digit recall	Counting recall	Backwards digit recall	First Sound detection	Spoonerism
Gr2 French Rec. Voc.	.17	.05	**.20**	.13	.09	.07	**.31**	.16
Gr2 French Exp. Voc.	**.27**	.10	.14	.15	-.01	.14	**.30**	.16
Gr2 German Exp. Voc.	**.83**	**.34**	**.23**	**.25**	.11	**.18**	**.20**	**.20**
Gr2 Native Exp. Voc.	**.82**	**.42**	**.34**	**.29**	.09	**.23**	**.21**	**.34**
		Second grade						
		Short-term memory			Working memory		Phonological awareness	
Dependent factor	Native Voc.	Nonword repetition High WL	Low WL	Digit recall	Counting recall	Backwards digit recall	OOO	Spoonerism
Gr2 French Rec. Voc.	.12	.14	**.26**	.16	.08	.07	**.23**	**.19**
Gr2 French Exp. Voc.	**.26**	.16	**.28**	.08	.13	.07	**.31**	**.27**
Gr2 German Exp. Voc.	**.83**	**.29**	**.32**	**.21**	.17	.10	**.20**	**.24**
Gr2 Native Exp. Voc.	**--**	**.35**	**.41**	**.29**	.14	.15	**.28**	**.31**

Note . Gr2: second grade; Rec: receptive; Voc: vocabulary; WL: wordlike; OOO: Odd-one-out

There are several important findings: First, as noted before, Luxembourgish vocabulary correlated highly with German vocabulary across the years (*r*'s ranging from .74 to .83). Luxembourgish vocabulary manifested a medium association with French expressive vocabulary (*r*'s ranging from .26 to .28) that was, however, significantly weaker than the Luxembourgish - German vocabulary association (kindergarten: $t = 5.52$; first grade: $t = 7.74$; second grade: $t = 7.87$; $p > .05$ in all cases). For French receptive vocabulary significant links with Luxembourgish were only found for the kindergarten-second grade time period ($r = .22$).

The second, and most important, finding was the differential association between the verbal STM measures and vocabulary knowledge: Whereas all three measures of STM - digit recall, high, and low wordlike nonword repetition - were significantly associated with Luxembourgish and German vocabulary knowledge (r's ranging from .18 to .46), only the repetition of the low wordlike nonwords manifested significant links with French vocabulary (r's ranging from .14 to .28). This pattern was consistent across the different time intervals with the exception of the first to second grade time period in which the link between low wordlike nonword repetition and expressive French vocabulary failed to reach significance. Comparing the strengths of the associations between high and low wordlike nonword repetition with French vocabulary showed that the correlation between low wordlike nonword repetition in first grade and French receptive vocabulary ($r = .20$) was significantly higher than the corresponding association between French and the repetition of high wordlike nonwords ($r = .05$): $t = 2.15$; $p = .03$. The remaining correlation comparisons - i.e. low and high wordlike nonword repetition and French vocabulary in each case - did, however, not reveal significant differences in the strengths of associations: kindergarten; French receptive, $t = 1.92$, $p = .06$, French expressive, $t = 1.31$, $p = .19$; first grade: French expressive, $t = .06$, $p = .95$; second grade: French receptive, $t = 1.73$, $p = .09$; French expressive, $t = 1.74$, $p = .08$. Further studies are clearly needed in order to clarify the underlying nature of the relationship between low and high wordlike nonword repetition and French foreign language learning in Luxembourgish school children. The data further showed that none of the WM measures made significant contributions to French vocabulary knowledge.

Results on the phonological awareness measures were less consistent: Neither rhyme detection in kindergarten, nor Spoonerism in first grade significantly predicted French vocabulary. First sound detection in first grade in contrast, manifested significant links with French vocabulary one year later (r's of .30 and .31). These associations were not significantly stronger than the corresponding links between low wordlike nonword repetition and both expressive ($t = 1.08$, $p > .05$) and receptive French vocabulary ($t = 1.55$, $p > .05$). The cross-sectional data in second grade showed that both measures of phonological awareness, Spoonerism and odd-one-out, were significantly linked to French vocabulary (r's ranging from .19 to .31).

Principal component analysis

The observed pattern of differential association between high and low wordlike nonword repetition and digit recall with French vocabulary raised concerns about the appropriate interpretation of the underlying factor driving the repetition of low wordlike nonwords. Given that the phonological awareness measures (first sound detection, odd-one-out, and Spoonerism) and low wordlike nonword repetition correlated significantly with French vocabulary, it might be possible that both type of measures tapped a common underlying factor that was driving the relationship with French vocabulary. To explore this hypothesis the verbal STM, WM, and phonological awareness scores were submitted to a principal component analysis with Varimax rotation. Separate analyses were performed for kindergarten, first, and second grade. For each year three components, with eigenvalues of 1 or above, emerged and are represented in Table 6.28.

TABLE 6.28.
Factor Loadings for the Cognitive Ability Measures from Principal Component Analysis

Measure	Component 1	Component 2	Component 3
Kindergarten			
High wordlike nonword repetition	**.89**	.06	.03
Low wordlike nonword repetition	**.88**	.11	.09
Digit recall	**.73**	.09	.31
Counting recall	.02	-.11	**.88**
Backwards digit recall	.38	.18	**.69**
Rhyme detection easy	.16	**.83**	.22
Rhyme detection difficult	.04	**.85**	-.19
First grade			
High wordlike nonword repetition	**.89**	.06	-.02
Low wordlike nonword repetition	**.85**	.17	.03
Digit recall	**.76**	.12	.11
Counting recall	-.20	.39	**.63**
Backwards digit recall	.23	-.08	**.85**
Alliteration	.33	**.65**	.23
Spoonerism	.08	**.89**	-.03
Second grade			
High wordlike nonword repetition	**.85**	.19	.00
Low wordlike nonword repetition	**.87**	.19	.07
Digit recall	**.80**	.04	.24
Counting recall	.00	.15	**.83**
Backwards digit recall	.23	.11	**.77**
Spoonerism	.30	**.85**	.16
Odd one out	.07	**.92**	.14

Note. factor loadings above .50 marked in boldface

The results were very clear: An identical factor structure emerged in all three years. The two nonword repetition tasks and digit recall loaded highest on component 1. Component 2 mainly consisted of the phonological awareness measures (rhyme detection in kindergarten, Spoonerism and first sound detection in first grade, and Spoonerism and odd-one-out in second grade). Finally, the two WM measures loaded strongest on component 3. Most importantly, low wordlike nonword repetition was more strongly associated to digit recall and high wordlike nonword repetition than to the phonological awareness measures.

Nonword repetition

As mentioned above the most striking aspect of the findings was the differential relationship between high and low wordlike nonword repetition and French vocabulary. The final set of analysis therefore focused more particularly on the two nonword repetition measures by investigating the links between high and low nonword repetition at each of the five syllable lengths. Descriptive statistics of the means, standard deviations, and the range on each of the different syllable lengths nonwords are provided in Table 6.29.

TABLE 6.29.
Descriptive Statistics of Nonword Repetition for the Kindergarten, First, and Second Grade

	Kindergarten			First grade			Second grade		
Syllable length	Mean	*SD*	Range	Mean	*SD*	Range	Mean	*SD*	Range
				High wordlike nonword repetition					
1-syllable	4.58	.75	2-5	4.68	.60	2-5	4.76	.48	3-5
2-syllables	4.75	.49	3-5	4.87	.39	3-5	4.92	.31	3-5
3-syllables	4.52	.69	2-5	4.68	.58	2-5	4.62	.68	1-5
4-syllables	2.61	1.37	0-5	3.22	1.33	0-5	3.41	1.30	1-5
5-syllables	1.52	1.10	0-4	1.89	1.10	0-5	1.85	1.12	0-5
				Low wordlike nonword repetition					
1-syllable	4.55	.53	3-5	4.72	.49	3-5	4.69	.50	3-5
2-syllables	4.39	.77	2-5	4.71	.59	2-5	4.52	.70	2-5
3-syllables	4.37	.96	1-5	4.71	.59	2-5	4.81	.46	3-5
4-syllables	2.54	1.45	0-5	3.04	1.44	0-5	3.17	1.42	0-5
5-syllables	1.36	1.20	0-5	1.82	1.21	0-5	2.01	1.27	0-5

The distribution of the scores on the 1-, 2-, and 3-syllable lengths nonwords were highly skewed, most likely due to the ceiling effects on these measures. Logarithmic transformations of the measures reduced the extreme skewness considerably but did not change the overall pattern of results so only the analyses based on the raw data are presented here. Correlations between high and low wordlike nonwords at different syllable lengths in kindergarten, first, and second grade with the vocabulary measures in second grade are represented in Table 6.30. Given the violation of normality, bivariate correlation coefficients were computed using Spearman’s rank coefficient. In addition, partial correlations were conducted controlling for native vocabulary knowledge in kindergarten.

TABLE 6.30.
Correlations Between High Wordlike and Low Wordlike Nonwords at Different Syllable Lengths and Vocabulary in Second Grade Using Spearman's Correlations Coefficient

	Second grade vocabulary							
	French Rec.		French Exp.		German Exp.		Native Exp.	
	Bivariate	Partial	Bivariate	Partial	Bivariate	Partial	Bivariate	Partial
Kindergarten								
High wordlike								
1-syllable	.10	.06	.12	.12	**.25**	.14	**.28**	**.21**
2-syllables	.04	.01	.03	.07	.08	.11	**.19**	**.23**
3-syllables	**.18**	.07	.12	.02	**.23**	.04	**.33**	**.26**
4-syllables	.11	.02	.07	-.03	**.27**	.05	**.33**	.15
5-syllables	.14	.08	.07	.00	**.26**	.00	**.27**	.06
Low wordlike								
1-syllable	**.23**	**.18**	.10	.04	.13	-.11	.13	-.04
2-syllables	**.24**	.12	**.20**	.09	**.24**	-.09	**.31**	.11
3-syllables	**.21**	.12	**.21**	.13	**.29**	.05	**.31**	.08
4-syllables	.15	.04	.10	.01	**.31**	.08	**.36**	.16
5-syllables	**.36**	**.29**	**.26**	**.18**	.17	-.06	**.28**	.15
First grade								
High wordlike								
1-syllable	.03	-.03	.02	.05	-.09	-.14	-.06	-.05
2-syllables	.05	-.04	-.01	-.06	.03	-.07	**.21**	**.22**
3-syllables	.00	-.01	-.05	-.10	.13	.00	.12	-.01
4-syllables	.01	-.09	.07	-.04	**.34**	.09	**.34**	.10
5-syllables	.14	.07	.10	.05	**.32**	.12	**.39**	**.22**
Low wordlike								
1-syllable	.11	.10	.06	.07	.00	-.02	**.18**	**.21**
2-syllables	-.01	-.06	.06	.01	.13	.00	.14	-.03
3-syllables	.06	.04	.07	.01	.01	-.15	.12	-.01
4-syllables	.08	.03	.08	.02	**.26**	.13	**.27**	.15
5-syllables	**.30**	**.28**	.11	.07	**.21**	-.07	**.30**	.10
Second grade								
High wordlike								
1-syllable	-.04	-.07	-.10	-.09	-.07	-.06	-.10	-.05
2-syllables	.04	-.08	.07	.03	.07	-.07	.08	-.03
3-syllables	.14	.14	.15	**.19**	**.19**	-.03	.18	-.01
4-syllables	.02	-.09	.13	.04	**.32**	.03	**.36**	.11
5-syllables	**.25**	**.20**	.09	.02	**.29**	.08	**.33**	.14
Low wordlike								
1-syllable	.11	.09	.09	.08	.10	-.02	.14	.04
2-syllables	.06	.02	.12	.08	**.29**	.13	**.29**	.15
3-syllables	.09	.01	.07	.01	.14	-.09	**.19**	.04
4-syllables	**.23**	.16	**.21**	.11	**.29**	.02	**.36**	.13
5-syllables	**.24**	**.20**	**.27**	**.21**	**.25**	-.02	**.29**	.10

Note . Rec: receptive; Exp: expressive; partial correlations controlling for native vocabulary in kindergarten; significant values marked in boldface, $p < .05$

The overall pattern of results showed that French vocabulary knowledge in second grade correlated highest with performance on the 5-syllable lengths low wordlike nonword repetition measure. Most importantly, the link between this measure and French vocabulary was maintained even after controlling for native vocabulary knowledge. For kindergarten and first grade the correlation between the 5-syllable lengths low wordlike nonword repetition with French receptive vocabulary (r's of .29 and .28) was significantly higher than the corresponding link involving the repetition of 5-syllable long high wordlike nonwords (r's of .08 and .07): kindergarten, t = 2.08, p = .04; first grade, t = 2.27, p = .02. For the German language the data showed that once Luxembourgish vocabulary knowledge was taken into account, none of the nonword repetition measures remained significantly associated with German vocabulary in second grade. Similar findings were observed for Luxembourgish vocabulary knowledge.

Motivational/ environmental factors

In the final analysis the impact of environmental factors on the acquisition of French vocabulary was investigated. Three variables were considered: first, the length of time children had learned French in school; second, the amount of French spoken by the teacher in a standard French lesson; and third the degree to which the children liked French. Correlation coefficients between these three variables and French vocabulary, presented in Table 6.31, indicated that none of these environmental and motivational factors had a significant impact on the acquisition of French in young Luxembourgish school children.

TABLE 6.31.
Correlations Between the Environmental Factors and French Vocabulary Knowledge Using Pearson's Correlation Coefficient

	French Vocabulary	
Environmental variables	Expressive	Receptive
Days learned French	-.01	.08
Percentage of French spoken by the teacher	.13	-.03
Liking of French by the child	.03	.06

6.4.2. Reading comprehension

The preceding structural equation modelling analyses were conducted with a transformed reading comprehension measure (controlling for reading). The following analyses are going to focus on the untransformed reading comprehension measure and its relationship with verbal STM, WM, phonological awareness, and fluid intelligence. Word decoding and language comprehension have been put forward as the two major proximal determinants of reading comprehension (Hoover & Gough, 1990). Furthermore, vocabulary knowledge has been suggested to effect reading comprehension (Torgesen, Wagner, Rashotte, Burgess, & Hecht, 1997). Reading, listening comprehension, and vocabulary were therefore included in the analysis in addition to the basic cognitive ability measures. Reading comprehension was treated as an observed variable.

The main objective of the analyses was to investigate the relationship of the seven latent constructs - reading, listening comprehension, vocabulary, verbal STM, WM, phonological awareness, and fluid intelligence in kindergarten, first, and second grade - with the manifest variable reading comprehension in second grade. Three sets of CFA models were conducted including in each case second grade reading comprehension. In the CFA models 1, 2, and 3, the respective latent variables from kindergarten, first grade, and second grade were entered into the analyses[25]. All of the parameters were freely estimated. Because children in Luxembourg only start reading instruction in first grade and they immediately read in the foreign language German, reading comprehension had hardly evolved in first grade and was only assessed in second grade. No autoregressive effect could therefore be included in the analyses.

Figure 6.18. provides an illustration of the logic behind the CFA analyses (for simplicity only 3 out of the 7 latent factors are represented). The manifest variable, reading comprehension in second grade, is represented on the right side of the model and bidirectional arrows correspond to correlations. As the main interest of the present analyses was to explore the relationship of the latent constructs with reading comprehension in second grade, only these correlation coefficients (marked in boldface in Figure 6.18.) are reported in the subsequent analyses (for interfactor correlations see foregoing sections).

[25] The listening comprehension construct in second grade consisted of the two TROG measures: TROG-Lu and TROG-D

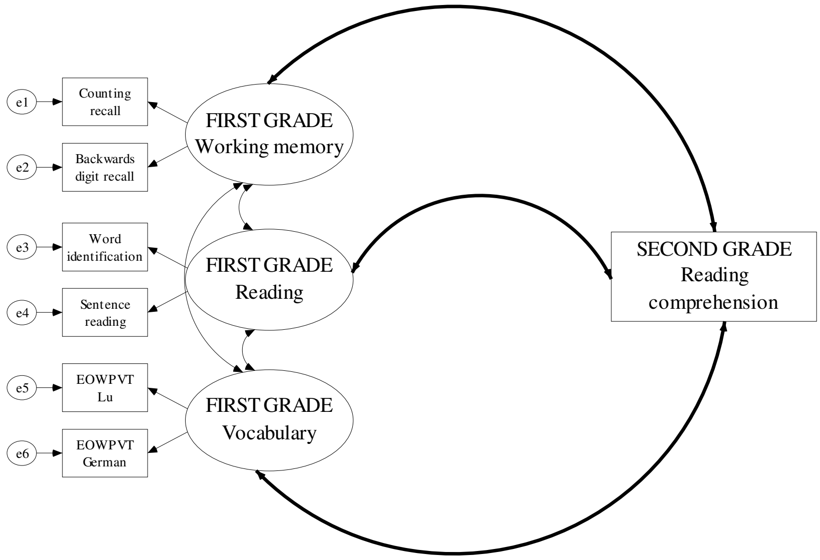

FIGURE 6.18.
Path model for confirmatory factor analysis

SR models were conducted to examine how the different latent factors related to reading comprehension considering their intercorrelations. Results of the CFA and SR analysis are reported in Table 6.32.; the total R^2 of the different models is provided in italics. Fit statistics in the lower part of Table 6.32. indicated that all three models tested provided an adequate account of the data.

TABLE 6.32.
Standardized Regression Coefficients and Model Fit from CFA and SR Analyses with Reading Comprehension as Dependent Factor

	Model 1: Kindergarten		Model 2: First grade		Model 3: Second grade	
Latent factor	CFA	SR	CFA	SR	CFA	SR
WM	.28*	.08	.38**	.23	.41**	-.01
STM	.36**	.19	.30**	.13	.31**	-.03
Phonological awareness	.13	.00	.54**	.09	.41**	-.18
Fluid intelligence	.15	.10	.19	.03	.15	-.02
Vocabulary	.39**	.44**	.42**	.52*	.38**	.10
Reading	.24*	.23	.67**	.55*	.82**	.83**
Listening comprehension	.15	.-38	.42**	-.52	.47**	.26
R^2	*.28*		*.56*		*.75*	
Model fit						
χ^2 (df)	67.42(65)		71.25 (77)		120.45 (92)	
p	.39		.66		.02	
CFI	.99		1.00		.97	
IFI	.99		1.00		.97	
RMSEA	.02		.00		.05	

Note . CFA: confirmatory factor analyses; SR: structural regression models

Consider first the CFA models: The data showed that WM and verbal STM were significantly associated with reading comprehension across all three time periods. Interestingly, fluid intelligence did not manifest significant links with reading comprehension. The data further showed that phonological awareness in kindergarten was not significantly associated with second grade reading comprehension; in first and second grade links with reading comprehension started, however, to emerge. For the language constructs the data showed that second grade reading comprehension manifested the highest correlations with vocabulary in kindergarten ($r = .39$), and with reading in first and second grade (r's of .67 and .82 respectively). Once the intercorrelations between the latent factors were considered (SR models), vocabulary knowledge in kindergarten remained as the single best predictor of reading comprehension two years later, accounting for 19% of its variance. In first grade both vocabulary and reading accounted for a large proportion of extra variance in second grade reading comprehension (27% and 30% respectively). Finally, in second grade 69% of the variance in reading comprehension was explained by reading. The data showed that listening comprehension did not appear to make significant specific contributions to reading comprehension.

6.5. Discussion

The present chapter examined the causal nature of the relations between WM, STM, and learning in a population of young multilingual children, followed from kindergarten through second grade. In contrast to the foregoing chapter that focused on the cross-sectional aspects of the dataset, the present analyses explored the data longitudinally by investigating time-lagged relationships of latent constructs at a previous time on themselves and other factors at a later point in time. To support a causal interpretation of the relations other plausible explanatory variables, including the autoregressive effect, were taken into account and reversed causality effects were considered. Overall the findings were consistent with the cross-sectional analyses: Progress in the key domains of language comprehension, literacy, and mathematics were found to be closely linked with children's WM abilities, whereas verbal STM appeared to make more specific contribution to vocabulary development in native and foreign languages. The following paragraphs will discuss these findings in more detail by considering developments in each learning domain - language, literacy and mathematics - in separate sections.

6.5.1. Language development

The study explored two distinct but highly related domains of language: vocabulary knowledge and language comprehension. The data showed that verbal short-term storage and the central executive components of WM made differential contributions to these two linguistic domains. Individual differences in verbal STM, but not in the central executive, substantially influenced subsequent individual differences in vocabulary at each time period examined. Importantly, these links were highly specific: They remained significant even after controlling for fluid intelligence, phonological awareness, and WM, and no specific associations were observed between either WM or phonological awareness and subsequent vocabulary. These results extend the findings of the previous cross-sectional analyses and are in line with other studies (Cheung, 1996; Gathercole et al., 1992; Jarrold et al., 2009; Masoura & Gathercole, 2005; Service, 1992) providing evidence that verbal STM constrains the long-term learning of new phonological forms.

Verbal STM was also found to make significant contributions to subsequent language comprehension. Importantly, these links appeared to be mediated by vocabulary knowledge, suggesting that STM might influence language comprehension indirectly via its impact on vocabulary development. The central executive was also significantly linked to language comprehension. In contrast to verbal STM, the relationship was maintained even after verbal abilities were taken into account; when controlling for fluid intelligence the association dropped, however, to a non-significant level. These findings raise the possibility that it might be the capacity for controlled processing - the postulated underlying common trait of fluid intelligence and WM (Engle et al., 1999b) - that was driving the relationship between WM and comprehension.

An important aspect of the data was that neither STM nor WM made specific contributions to subsequent vocabulary and language comprehension abilities when the autoregressive effects were considered. These findings challenge a causal interpretation of the observed relationships on the basis of the argument that causal predictors should have an extra effect on subsequent learning after the effect of prior learning has been taken into account (Gollob & Reichardt, 1987; Wagner et al., 1994). The absence of such additional effects as in this study does, however, not imply that STM or WM are not important for the development of vocabulary and comprehension. In the present context both vocabulary and language comprehension were extremely stable over the years. Accordingly, there was little unexpected growth to be explained which made it difficult to identify additional predictors of change after controlling for the autoregressive effect. The results showed that verbal STM manifested a strong indirect effect on vocabulary in first grade via vocabulary in kindergarten, providing further support for the hypothesis that the autoregressive effect of vocabulary controlled for most of the effects of verbal STM on subsequent vocabulary skills as well. Stoolmiller and Bank (1995) argue that it is unlikely that the autoregressor itself is the mechanism that is driving developmental change as the causal agents should be logically distinct from the factor that is to be explained. According to this position, negating the contributions of STM to vocabulary development or of WM to language comprehension because they failed to compete with initial levels of the dependent factors in an autoregressive model might be premature (Stoolmiller & Bank, 1995).

It is, however, important to point out that individual differences in comprehension were highly stable from first to second grade but not from kindergarten to first grade. Despite considerable unexpected growth in this particular time frame (kindergarten-first grade), WM was not found to have an extra effect on comprehension over and above the autoregressive effect; one might therefore argue that WM might not be causally linked to language comprehension. Interestingly, fluid intelligence in kindergarten explained a significant amount of extra variance in first grade comprehension even after the autoregressive effect was controlled, providing further evidence that it might be the component that WM shares with fluid intelligence – possibly controlled attention – that was responsible for its link with language comprehension. One speculative reason for the emergence of fluid intelligence as a stronger predictor of language comprehension may be that, in addition to controlled attention, the WM measures were tapping other processes that may not be directly relevant to language comprehension.

Not only vocabulary knowledge, but also verbal STM was characterized by remarkable stability, rendering the analyses of reversed causality effects difficult due to the powerful autoregressive effect of STM on itself at a later point in time. When the autoregressive effects were deliberately ignored, the findings supported the view of bidirectional relations between STM and vocabulary. Importantly, cross-lagged correlations between performance on vocabulary in kindergarten and STM in first grade were larger in magnitude than the converse association between STM and subsequent vocabulary knowledge. These findings are consistent with a study of Gathercole and colleagues (1992) demonstrating that in children above the age of 5, vocabulary was the major pacemaker in the developmental relationship. The same study showed that when children were younger, verbal STM exerted a direct influence on later vocabulary learning leading the authors to conclude that verbal STM might play an important causal role in the initial but possibly not in the later stages of vocabulary learning. In the present study, children had a mean chronological age of 6 in the first study wave; at this developmental stage it might therefore have been too late for individual differences in STM to have much of a causal impact on vocabulary acquisition in the native and the phonological similar second language German.

One possible reason for the absence of a causal contribution of STM to vocabulary is that at 6 years of age children might use their lexicons to mediate new word learning by access to lexical phonological representations of close neighbours rather than relying on the more basic mechanism of verbal short-term storage (Duyck et al., 2003; Gathercole et al., 1992; Jarrold et al., 2009; Papagno et al., 1991). Taken together, even though the findings indicate strong and highly specific links between verbal STM and subsequent vocabulary skills and less specific links between WM and language comprehension in 6- to-8-year-old Luxembourgish children, they do not permit one to draw strong conclusion regarding the direction of the causal relationship. In these stages of development the high level of stability of the dependent and the predictor factors - especially for STM and vocabulary - made it difficult to isolate specific contributions of either the basic cognitive ability factor to learning or of learning to basic cognitive skills.

A possible solution to the above described circular cause-and-effect problem might be provided by exploring the cognitive underpinnings of new word learning in the unfamiliar second language French. As children had not yet acquired any French in study wave one or two, and were tested at a very early stage of French instruction in study wave three, potential links between verbal STM and subsequent French could not be an artefact of the association of French with itself at a previous point in time. Results of the latent variable analyses showed that verbal STM in kindergarten and first grade were significantly linked with French in second grade, supporting the view that verbal STM is causally related to new word learning in a foreign language (Cheung, 1996; Masoura & Gathercole, 1999; Service, 1992). It is worth pointing out that the strengths of the associations were only moderate and disappeared once related cognitive abilities were taken into account. Importantly, analysing the data at the level of observed variables revealed that French vocabulary was significantly predicted by only one of the verbal STM measures - the repetition of low wordlike nonwords - but not by the two remaining STM tasks; this might explain the medium and not very specific effects of STM on French language learning observed in the latent variable analyses. The same pattern did not emerge for the Luxembourgish or the German language that manifested significant associations with all three STM measure. Notably, this pattern of results was consistent across the different time periods examined.

The differential association between high wordlike nonword repetition, low wordlike nonword repetition, and digit recall with French vocabulary was surprising given that all three measures were thought to rely on phonological storage. Two opposing interpretations of these findings are proposed here. One possibility is that the unique link between French vocabulary and low wordlike nonword repetition was not a product of the involvement of verbal STM in word learning as no corresponding association of French and any other measure of verbal short-term storage was observed. French language was significantly related to some measures of phonological awareness - first sound detection in particular - raising the possibility that the repetition of low wordlike nonwords might reflect phonological awareness rather than short-term storage, and that phonological awareness might be the driving force behind the relationship with French vocabulary (Bowey, 1997, 2001, 2006; Metsala, 1999). This hypothesis was rejected on the basis of principal component analysis showing that low wordlike nonword repetition loaded on the same factor as the two other measures of verbal short-term storage that was distinct from a latent phonological awareness construct.

A related suggestion is that low wordlike nonword repetition might tap some specific skill that is not directly involved in conventional STM or phonological awareness tasks but that might be shared by some specific measures of phonological awareness, such as first sound detection in this case. One potential candidate of this specific skill might be the ability to construct well defined phonological representations from incoming acoustic speech signals. This ability might involve phonological processes - such as perceptual analysis (Gathercole, 1999; Wimmer, 1993) - that are more basic than phonological awareness or verbal STM. For the correct repetition of unfamiliar nonwords, the syllabic and phonetic components of new words have to be correctly perceived and represented in order to yield a phonological memory trace but no explicit segmentation is required. This same ability might be particularly important in the early stages of acquiring a foreign language with an unfamiliar phonology as new words in such a language are essentially low wordlike nonwords.

A second possible explanation of the differential association between the STM measures and French vocabulary is that low wordlike nonword repetition might have tapped one specific component of verbal STM that is crucial to new word learning in French and that might be represented to a lesser extend by the other STM measures. In contrast to high wordlike nonword repetition and digit recall, long-term lexical or sub-lexical support via redintegrative processes or chunking mechanisms is supposed to be minimal in the repetition of low wordlike nonwords (Cowan, 1997; Gathercole, 1995b; Hulme et al., 1991). Furthermore, nonword repetition has been suggested to benefit less from subvocal rehearsal then digit recall for which subvocal rehearsal processes have been found to increase task performance in children as young as 5 years of age (Baddeley et al., 1998; Gathercole & Adams, 1994). Cognitive strategies that improve the encoding and maintenance of information in conventional STM tasks might not operate in the same way in the repetition of low wordlike nonwords as support from long-term memory and subvocal rehearsal processes are thought to be minimal for this measure. Low wordlike nonword repetition might therefore represent a purer assessment of the storage component of verbal STM, purportedly tapping the phonological store of the phonological loop in the Baddeley and Hitch model (1974) or the scope of attention in Cowan's conception of WM (Cowan, 1995; Cowan et al., 2006). This particular component of verbal STM might also play a key role in the initial stages of new word learning in a phonological unfamiliar second language. When learning new foreign words, individuals may not benefit from redintegrative support because long-term knowledge about the language with which to reconstruct degraded traces might be absent; consequently recall might be based on the contents of the phonological store (Thorn & Gathercole, 2001). According to this account either the rate of information loss or the capacity of phonological storage might determine the rate of new word learning in an unfamiliar second language.

In summary, the two proposed explanations make opposing claims regarding the contributions of verbal STM to foreign language learning. According to the first position verbal STM does not have a direct impact on French vocabulary learning, whereas the second account postulates that verbal STM constraints French language development. Although the available evidence does not provide a sufficiently strong basis for drawing robust conclusions about which of these two accounts might be more appropriate, some indications in the data are pointing towards the second position. When analysing the different subscores of the nonword repetition task it became apparent that French vocabulary in second grade was significantly predicted by the repetition of the five-syllable-long, low wordlike nonwords but not by the shorter low wordlike items. Importantly, these links remained even after native vocabulary knowledge was taken into account. As verbal STM is thought to be limited in capacity (Baddeley, 1986; Cowan, 2000), the repetition of longer nonwords should impose particular heavy demands on short-term storage. The stronger links between French and the repetition of the long but not the short nonword items might therefore reflect the crucial role played by phonological storage in French vocabulary development.

Taken together, the findings showed that the repetition of the five-syllable-long, low wordlike nonwords was a strong predictor of French language learning in Luxembourgish children up to two years later. Independently of the debate of whether or not verbal STM is critically involved in low wordlike nonword repetition, these findings have important practical implications as they highlight the potential utility of this particular measure as a screening tool for detection children at risk for future foreign language learning difficulties.

6.5.2. Literacy development

Reading and writing are complex skills involving a large number of basic cognitive abilities each of which could be an impediment to the acquisition of literacy. The present study has shown that a central role in children's early literacy development is played by the central executive component of WM. One of the most important findings was that children's WM abilities in kindergarten were causally linked to reading in first grade and spelling in second grade. Importantly, these links remained even after controlling for fluid intelligence, verbal abilities, verbal STM, and the autoregressive effect of prior literacy skills, providing a strong argument in favour of the causal nature of the association. Furthermore, the study showed that reading in kindergarten was not significantly related to WM skills in first grade supporting the correct specification of the direction of the causal relationship. Interestingly, in this study the WM tasks requiring numerical processing were good predictors of performance in reading and spelling, in line with the position that the predictive ability of complex span tasks is independent of the type of processing involved (Engle, Tuholski et al., 1999; Turner & Engle, 1989).

Two particular interesting findings deserve mention: First, the relationship between WM and reading appeared to be developmentally limited; individual differences in WM were a causal determinant of variation in reading achievement in first grade but had no further specific effects on reading efficiency in second grade. One potential reason for the reduced importance of WM in second grade reading might be that the phonological recoding processes, that are slow and effortful in early reading development, might be rapidly automatised in Luxembourgish children learning to read in the highly regular language German; consequently the WM demands of simple word decoding might be considerably lower in second then in first grade. In contrast to reading, WM was found to make significant contributions to spelling abilities in second grade. In this stage of development spelling might impose heavier WM loads than reading because in addition to decoding sounds to letters children have to manually produce the written symbols, an activity that is likely to require conscious control in inexperienced writers (Bourdin & Fayol, 1994). In the present study children had just acquired cursive handwriting which might have increased the WM demands of the task even further.

The second major finding was that the observed links of WM with reading and spelling remained significant even after fluid intelligence was taken into account. Interestingly, fluid intelligence did not make significant contributions to literacy development in any of the time periods assessed. What this finding shows is that the relationship between WM and subsequent literacy development is mediated by processes that are not shared with fluid intelligence. In the light of the proposal that the residual variance attributed to WM and fluid intelligence might be the demand for controlled attention (Conway et al., 2002; Engle, Tuholski et al., 1999), the present findings seem to suggest that the driving force behind the WM-reading relationship is something other than the ability to control attention. This suggestion is, however, to be treated with caution as controlled attention is a vague concept that most likely involves many different components, some of which are shared and some of which might be specific to measures of fluid intelligence and WM. This hypothesis is in line with a recent study by Swanson (2008), showing that in young children links between WM and fluid intelligence remained significant even after one specific aspect of controlled attention - the inhibition of well-learned sequences- was taken into account. Interestingly, the same study showed that controlling for inhibition eliminated the significant contribution of WM to reading. These findings fit well with the results of the present study and suggest that inhibition might be one potential candidate underlying the common variance between WM and reading. Another potential factor that might be driving the WM-reading relationship is speed of processing which has been suggested to make important contributions to early reading developments, especially in languages with fairly transparent grapheme to phoneme correspondences (de Jong & van der Leij, 1999; Wimmer, 1993). In a recent study Bayliss et al. (2005) have, however, shown that WM remained significantly related to reading in 6-, 8-, and 10-year-olds even after both storage capacity and processing efficiency were taken into account, suggesting that processing speed might not be the underlying ability that is responsible for the relationship between WM and reading.

In contrast to WM, neither STM nor phonological awareness were found to make significant contributions to reading or spelling after related cognitive abilities and the autoregressive effect were taken into account. The absence of strong evidence in favour of a causal relationship between STM and literacy is in line with the cross-sectional analyses in chapter 5 and other longitudinal studies suggesting that the contribution of verbal STM to literacy development is not very specific (de Jong & van der Leij, 1999; Dufva et al., 2001; Wagner et al., 1994). The finding that phonological awareness was not causally related to reading was more surprising in the light of previous longitudinal studies in which reading was found to be predicted by phonological awareness skills at a prior point in time (Dufva et al., 2001; Muter et al., 2004; Wagner et al., 1994; Wagner et al., 1997). Most importantly, the data showed that reading in kindergarten was causally related to individual differences in phonological awareness in first grade. These findings are in agreement with the notion that phonological awareness emerges as a product of reading instruction rather then as a natural consequence of speech production and perception (Morais et al., 1987; Ziegler & Goswami, 2005). Because phonological boundaries are not explicitly marked in the speech stream, children might need to be exposed to written word forms in an alphabetic language in order to become aware that spoken words have sounds in common.

It should be noted that in kindergarten only the awareness of rime could be reliably assessed as the other phonological awareness measures, pertaining to the phonemic level of analyses, proved to be to difficult for Luxembourgish kindergartners (see also de Jong & van der Leij, 1999 for a similar finding on Dutch children). The possibility that individual differences in higher level phonological awareness would have been detected with less difficult tasks can not be excluded; strong claims about the contributions of phonemic awareness to reading development can therefore not be made an the basis of the available evidence. The study, however, clearly showed that, in contrast to the position of Bryant and colleagues (Bryant et al., 1990), awareness of rhyme was not causally related to reading in young Luxembourgish children. These findings are consistent with studies on Dutch and German children (de Jong & van der Leij, 1999; Wimmer, Landerl, & Schneider, 1994), suggesting that rhyme awareness is of little importance when learning to read in the transparent language German (see also Muter, Hulme, Snowling, & Taylor, 1998 for similar findings on English speaking children). It has been suggested that in the early stages of learning to read in a regular language children rely heavily on alphabetic reading strategy via grapheme phoneme translation because the relationship between graphemes and phonemes is relatively consistent in a transparent orthography and the phoneme is therefore a reliable unit to focus on (Ziegler & Goswami, 2005).

Finally, the results showed that in second grade, reading comprehension was mainly determined by previous reading and vocabulary knowledge. These finding lend support to Hoover and Gough's (1990) "simple view of reading" according to which reading comprehension is a product of word decoding and language comprehension. In contrast to the prediction of de Jong and van der Leij (2002) neither short-term storage nor the central executive were found to make significant contributions to reading comprehension once reading and vocabulary were taken into account. Both memory components were, however, significantly linked to subsequent reading comprehension when considered in isolation. As the previous analyses have shown that verbal STM made significant contributions to vocabulary development and WM was causally related to reading, the contributions of the memory components to reading comprehension were most likely mediated by vocabulary and reading.

6.5.3. Mathematical development

The major finding in relation to mathematics was that WM in kindergarten significantly predicated mathematical abilities two years later, independently of STM, phonological awareness, and verbal abilities. Significant, but less specific, associations also emerged between WM in first grade and mathematical skills in second grade. For STM links with mathematics seemed to be largely mediated by the central executive. This pattern of results is in line with the previous cross-sectional analyses and many developmental studies suggesting that the central executive plays a key role in children's mathematical abilities (Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Bull & Scerif, 2001; Gathercole & Pickering, 2000a; St Clair-Thompson & Gathercole, 2006; Swanson, 2008). One possibility for the observed link might be that math classroom situations impose heavy demands on WM, the capacity of which therefore might have a direct effect on the frequency of task failure or success in these classroom activities (Gathercole, Lamont et al., 2006). An alternative suggestion is that WM might constrain mathematical abilities directly by providing the mental workspace in which the outcomes of certain operations are maintained whilst other calculations are performed.

An interesting aspect of the data was that fluid intelligence made substantial contributions to subsequent mathematical skills and accounted for almost all of the variance that WM and maths had in common. The same pattern was observed in the cross-sectional analyses suggesting that the link between WM and mathematics is driven by the variance that is shared with fluid intelligence. Finally, it is worth pointing out that mathematical skills were only assessed in second grade so the analyses did not included the autoregressive effect of prior mathematical abilities and consequently caution has to be taken in interpreting the observed relations in causal terms.

6.5.4. Conclusion

The present chapter explored the time-lagged relationships of WM and STM with developments in the key learning domains of language, literacy, and mathematics in multilingual children followed longitudinally from kindergarten to second grade. The presented evidence suggests that verbal STM is one of the main contributors to new word learning in both native and non-native languages by supporting the formation of stable phonological representations of new words in long-term memory. Whereas the contribution of verbal STM to vocabulary development was highly specific, links of STM with other domains of learning were largely mediated by related cognitive abilities and vocabulary knowledge in particular.

In contrast to verbal short-term storage, the central executive component of WM was not significantly related to vocabulary development but was found to make specific contributions to subsequent comprehension, reading, spelling, and mathematical abilities. Importantly, the observed links with comprehension and mathematics were largely shared with fluid intelligence, indicating that it might be the ability to control attention - the suggested common underlying trait of WM and fluid intelligence - that was driving the relationship. For early reading and spelling development the study showed that the contribution of the central executive was highly specific and robust even after controlling for the autoregressive effect, providing a strong argument in favour of a causal influence of WM on initial reading and spelling development. Furthermore, in contrast to comprehension and mathematics, links with reading and spelling remained significant after controlling for fluid intelligence. These findings suggest that an additional ability is involved in WM measures that is independent of short-term storage and fluid intelligence and that contributes to the prediction of early reading and spelling abilities.

CHAPTER SEVEN

General Discussion

The major aim of this thesis was to advance the understanding of the intrinsic factors that can affect learning in young children. Its main focus was on one particular domain of cognition - working memory - suggested to play a salient role in supporting the acquisition of new knowledge and skills over the school years (Gathercole, Lamont et al., 2006). More particularly, the presented work explored variations and the development of two specific components of the working memory system - verbal short-term storage and the central executive - in a large population of young multilingual Luxembourgish children, followed from kindergarten through second grade.

The main objectives were to explore the underlying factor structure and the development of these two memory components; their distinctiveness from related cognitive abilities; and most importantly, their relationship and possible causal contributions to children's learning in the key domains of language, literacy, and mathematics. These issues were explored by a latent variable longitudinal study in which 119 Luxembourgish children were assessed on three occasions, between the age of 6 and 8, with a one-year time lag between each study wave. Children completed multiple tasks of WM, STM, phonological awareness, fluid intelligence, and different learning domains (vocabulary, comprehension, foreign language knowledge, reading, spelling, and mathematics). The study is the first of its kind to integrate this variety of assessments on a large multilingual population of young children, in a single longitudinal study. A range of theoretical accounts relating to WM and learning could be tested, extending previous developmental research exploring the theoretical structure of WM in monolingual English children (e.g. Alloway et al., 2006; Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Kail & Hall, 2001; Swanson, 2008) and longitudinal studies examining the nature of the developmental association between phonological memory and native vocabulary knowledge (Gathercole et al., 1992), reading (de Jong & van der Leij, 2002; Dufva et al., 2001; Wagner et al., 1997), and reading and arithmetic (de Jong & van der Leij, 1999).

This final chapter will summarize the main findings of this research, discuss important assets as well as limitations of the study, address the theoretical implications of the results, and formulate recommendations for future research projects. Finally, the chapter will conclude with a discussion of the practical implications of the findings.

7.1. Summary of the main results

The study set out to answer a number of specific research questions revolving around the three central objectives that directed this study. A summary of the main findings with respect to each research objective is presented below. Table 7.1. provides an overview of the different research questions, outlined in chapter 2 (p. 65), and the corresponding results obtained from the analyses reported in chapter 4, 5, and 6.

7.1.1. Objective I: Explore the underlying factor structure of WM and STM and their relations with related cognitive skills in a population of young multilingual children

In this population of young multilingual Luxembourgish children, individual differences in verbal STM and WM were distinct, but associated, and clearly separable from phonological awareness and fluid intelligence. The finding that assessments of WM shared considerable variance with measures of STM, but that they also contained some unique variance is consistent with the view that performance on verbal complex span measures of WM reflect both storage in STM and attentional support from the central executive (Baddeley, 2000; Cowan, 1995; Engle et al., 1999b). It has been suggested that removing the variance common to WM and STM tasks should leave a WM residual that mainly reflects controlled attention, and that it is this component of WM that is driving the relation with higher order cognitive abilities (Conway et al., 2002; Engle et al., 1999b). In line with this hypothesis, fluid intelligence was found to be more strongly related to the WM residual then to STM in this population of young children. According to Engle and colleagues (1999b) both WM and fluid intelligence should mainly reflect the ability to maintain task goal relevant information activated, especially in the face of interference or distraction.

The distinction between the central executive and verbal STM fits well with previous findings from studies on English speaking children (Alloway et al., 2006; Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Kail & Hall, 2001; Swanson, 2008) and is consistent with the adult WM model proposed by Baddeley (2000) and Engle et al. (1999a, 1999b). Furthermore, the results challenge the hypothesis that WM and STM should be less distinct in younger then in older children or adults (Cowan et al., 2005; Engle, Tuholski et al., 1999). Importantly, the two-factor structure was highly stable across the three waves of the study, indicating no significant developmental change in the relationship between verbal STM and WM from the age of 6 to 8 (see also Alloway et al., 2006 for similar findings on children between ages 4 and 11 years).

Finally, the finding that phonological awareness was separate from verbal short-term storage reinforces previous evidence of a distinction between these two cognitive systems (Alloway et al., 2004; de Jong & van der Leij, 1999; Wagner et al., 1997), with the possibility that both might be constrained by the quality of phonological representations which might explain the observed associations between the two constructs (Boada & Pennington, 2006; Gathercole et al., 1992; Service et al., 2007).

7.1.2. Objective II: Investigate the links between verbal STM, WM, and learning

The major result with respect to the second research objective was that the short-term storage and the central executive components of WM manifested markedly distinct patterns of associations with different learning domains over the years. Whereas progress in language comprehension, literacy, and mathematics was closely associated with the central executive, verbal short-term storage was found to be more specifically linked with vocabulary development in native and foreign languages. The study further showed that some of the contributions of the memory components to learning were shared with phonological awareness and fluid intelligence, whereas others were highly specific. These findings are important as the supplemental explanatory power of WM, STM, and related cognitive ability measures to one another for scholastic performance are revealing theoretically in that they shed light on the cognitive underpinning of learning.

The finding that the central executive made general rather then specific contributions to learning and manifested particularly strong links with learning domains that are explicitly taught as part of the curriculum, fits well with the position of Gathercole and colleagues (Gathercole & Alloway, 2008; Gathercole, Lamont et al., 2006; Pickering & Gathercole, 2004) suggesting that WM and academic learning are related because many classroom situations involve a significant WM load. Most day-to-day classroom activities require to process new information and integrating it with information from long-term memory. Furthermore, lengthy and complex classroom instructions or difficult task structures might lead to WM overload in children with low WM abilities and consequently result in task failure or abandonment which might constrain the acquisition of new knowledge or skills across the curriculum. A related suggestion is that WM resources might be required whenever complex cognitive activities occur. As completion of complex tasks, such as reading or mathematics, often involve to remember some task elements and to inhibit others, the key role of the central executive in these learning activities might be to actively maintain crucial information and to regulate controlling processes (Engle, Kane et al., 1999; Engle, Tuholski et al., 1999).

Two particular interesting aspects of the findings deserve mention: First, the study showed that the unique predictive relationship of verbal STM to learning was limited to vocabulary development. This finding adds to existing evidence suggesting that one of the key functions of verbal STM lies in supporting the long-term learning of the phonological structure of new words (Baddeley et al., 1998; Cheung, 1996; Gathercole et al., 1992; Jarrold et al., 2009; Masoura & Gathercole, 2005; Service, 1992). Interestingly, the study further showed that when considered in isolation verbal STM was also significantly related to literacy and comprehension skills in later stages of development. These associations were, however, largely mediated by vocabulary knowledge that appeared to be critical for many learning domains. Whereas links between verbal STM and vocabulary development have consistently been reported in the literature, research evidence regarding the contributions of STM to other domains of learning, and reading in particular, has been less conclusive (Alloway et al., 2005; de Jong & Olson, 2004; Dufva et al., 2001; Wagner et al., 1997). What the present study suggests is that verbal STM makes an indirect contribution to many learning activities via its impact on vocabulary. A deficit in verbal STM could therefore have repercussions not only for the development of vocabulary but also impact on a range of other learning domains that are dependent on lexical abilities. As vocabulary knowledge represents one of the main building blocks for learning, verbal STM can thus be seen as an important indirect factor for successful academic progress.

The second interesting result was that the relationship of the central executive with comprehension and mathematics could be fully accounted for by the component that it had in common with fluid intelligence. This finding is in line with the position of Engle et al. (1999b; see also Conway et al., 2002) suggesting that the common underlying trait of WM and fluid intelligence is the demand for controlled attention and that it is this latter ability that is driving the relationship with learning. Importantly, the same pattern of results was not observed for the development of reading and spelling abilities: In both cases links with the central executive remained significant even after controlling for fluid intelligence. Taken together, the relationship of the central executive with mathematics and comprehension primarily seems to reflect processes that are shared with fluid intelligence, with the latter being the more important ability, while its association with literacy seems to depend on non-shared processes.

What exactly the resulting WM residual - after controlling for STM and fluid intelligence - represents is at present unclear. The results, however, show that it is this particular component of WM that contributes to the prediction of early reading and spelling abilities but not to the prediction of mathematics and comprehension. This differential pattern of association indicates that WM tasks are multifaceted and that different aspects of the central executive might be relevant for different domains of learning.

7.1.3. Objective III: Explore the causal nature of the relations of WM and STM with learning

The study provides strong evidence that the central executive is causally related to initial reading and spelling skills: Time-lagged links between WM and subsequent literacy remained significant even after controlling for the autoregressive effect, and the data manifested no evidence of reversed causality. These effects are robust in the light of the highly conservative nature of the statistical procedures employed. The data showed that the impact of WM on subsequent reading was particularly marked in the first year of reading instruction. These influences faded, however, with development as more of the variance of subsequent reading was accounted by previous reading. It is worth pointing out that the cross-sectional analyses revealed that WM and reading manifested a medium association in second grade, suggesting that even though individual different in WM might not influence the further acquisition of reading after first grade, these abilities remain an important component of reading throughout the initial school years.

When the autoregressive effect was included, no evidence of a causal influence of STM on vocabulary or WM on comprehension was found. The absence of a causal relationship can be traced to the stability of individual differences in vocabulary and comprehension which resulted in a powerful autoregressive effect. There is, however, some evidence in the data suggesting that verbal STM is causally related to new word learning in the highly unfamiliar second language French. Whether these links are specific to verbal short-term storage or related to a more general phonological processing construct is as yet unclear.

Finally, it is worth pointing out that the measures of STM and WM used in the present study manifested good criterion validity for scholastic performance up to two years later. Importantly, assessments of WM in kindergarten were found to be a better predictor of subsequent reading and spelling skills then a conventional measure of fluid intelligence. Furthermore, the repetition of low wordlike nonwords in kindergarten was identified as the single best predictor of French vocabulary. Together with the finding that the measures presented good psychometric properties and were highly stable over the years, the study suggests that assessments of WM and STM in kindergarten might provide reliable and valid screening instruments for the early identification of children at risk of poor scholastic progress.

TABLE 7.1.
Summary of the Research Questions and the Main Findings of the Present Thesis

OBJECTIVE I

Explore the underlying factor structure of WM and STM and their relations with related cognitive skills in a population of young multilingual children

Research questions	Chapter	Main findings
Are WM and STM operating as distinct processes in young Luxembourgish children?	4	- Measures of STM were distinguishable from, but related, to measures of WM in Luxembourgish children as young as 6 years of age. - WM tasks shared substantial variance with measures of STM but also reflected some unique variance. - Consistent with the adult WM model of Baddeley (2000) and Engle et al. (1999b) with separate but related elements corresponding to verbal short-term storage and a central executive. - Challenge the hypothesis of Engle et al. (1999b) and Cowan et al. (2005) that WM and STM should be less distinct in children then in adults.
Do phonological awareness task and verbal STM measures reflect the same underlying construct?	4	- Phonological awareness and verbal STM were separate but related constructs. - Phonological awareness also manifested substantial associations with measures of WM.
What is the nature of the relationship between WM, STM, and fluid intelligence in young children?	4 & 5	- Individual differences in fluid intelligence were separable from variations in verbal STM and the central executive. - Fluid intelligence was more strongly related to the central executive then to STM.
Does the identified factor structure change through the years, and how stable are these abilities over time?	4	- Remarkable consistency of the factor structure across the developmental period from kindergarten to second grade.

OBJECTIVE II

Investigate the links between verbal STM, WM, and learning

Research questions	Chapter	Main findings
Relationship of WM and STM with children's learning	4, 5, & 6	- WM and STM manifested disparate relations with learning over the years. - Progress in language comprehension, literacy, and mathematics were closely linked with children's WM abilities. - Verbal STM appeared to make more specific contribution to vocabulary development in native and foreign languages.
Which aspects of WM - short-term storage or the central executive - relate to which domains of learning? Are these links mediated by related cognitive skills?	5	- STM–vocabulary: strong and specific links across the years. - STM–French language: links mediated by phonological awareness. - STM–comprehension: specific link in kindergarten; in first and second grade associations largely mediated by vocabulary knowledge. - STM–literacy: links mediated by phonological awareness and/or verbal abilities. - Central executive–comprehension: specific link in second grade; associations in earlier years largely mediated by fluid intelligence. - Central executive–literacy: specific link in second grade. - Central executive–mathematics: links mediated by fluid intelligence.

TABLE 7.1. Continued

OBJECTIVE III **Explore the causal nature of the relations of WM and STM with learning**		
Research questions	Chapter	Main findings
Does the pattern of associations observed in the cross-sectional analyses remain when exploring time lagged relationships with one- and two-year time lags?	6	- STM: • specific links with subsequent vocabulary knowledge in Luxembourgish and German at each time period. • links with subsequent French: mediated by phonological awareness. • links with subsequent comprehension: mediated by vocabulary. • links with subsequent literacy: mediated by phonological awareness and/or verbal abilities. • links with subsequent mathematics: mediated by the central executive. - Central executive: • specific links with subsequent comprehension; shared with fluid intelligence. • highly specific links with subsequent reading in first grade and spelling in second grade; independent of fluid intelligence. • specific links with mathematics; shared with fluid intelligence.
Can the associations be interpreted in causal terms?	6	- With the autoregressive effects included: no evidence of a causal influence of STM on vocabulary or WM on comprehension. - Potential causal role of verbal STM in the acquisition of new words in the foreign language French. - Strong support for a causal influence of the central executive in early literacy development.
Are WM and/or STM making specific contributions to reading comprehension?	6	- No additional contributions of WM or STM to reading comprehension after controlling for lexical knowledge and word decoding.
Are measures of WM and STM in kindergarten valid predictors of learning progress during the first years of school?	4 & 6	- WM and STM could be reliably assessed in pre-reading kindergarten children. - Stable and coherent individual difference variables. - Measures manifested good criterion validity for scholastic performance. - Assessments of WM: better predictor of reading and spelling than a conventional measure of fluid intelligence. - Repetition of low wordlike nonwords: single best predictor of French foreign language learning in Luxembourgish children.

7.2. Strengths and limitations of the study

The following sections will address the methodological assets as well as the limitations of the study in relation to the observed results. First the main strengths of the presented work will be outlined followed by a discussion on the major limitation.

7.2.1. Strengths of the study

The major strong points of the study lie in a) its methodology; b) the rigorous structural equation modelling approach adopted; and c) the scientific novelty of the work. Each of these issues will be briefly described in the following paragraphs.

Methodology

Study design

The study was based on a 3-wave longitudinal design in which each measurement interval marked a key developmental learning stage. The main advantage of this approach was that it provided crucial information about the stability and change of the variables and the lead and cross-lagged relations between the different constructs of interest. The dynamic nature of the processes under study could be captured by exploring the developmental changes in the relationships between the factors during a developmental period in which intense learning occurs.

Measures

All of the measures were rigorously designed and manifested good psychometric properties with satisfactory internal reliability and construct validity.

Method of analysis

The vast majority of the analyses were performed on latent variables, capturing the common variance among the manifest indicators and minimizing variance attributable to task specific strategies. The observed effects of WM and STM on learning are therefore likely to reflect the underlying cognitive mechanisms responsible for the relationship rather then communalities between the surface manifestations of the tasks. According to Engle and Kane (2004) this macroanalytic approach to the study of individual differences: “gives a much cleaner and clearer picture of WM at the construct level and the degree of relationship of other constructs with WM” (Engle & Kane, 2004, p.157). The relationship among the latent constructs was explored via structural equation modelling, which represents an adequate method for analysing different types of causal relationships and across-time differences among groups (Kline, 2005). Finally, the study carefully controlled for known plausible causes (autoregressive effect, fluid intelligence, verbal abilities, phonological awareness) and thereby minimized the chances of model misspecifications (Wagner et al., 1994).

Taken together the 3-wave design and latent variable approach of studying individual differences was a valuable tool in examining the nature and direction of the cross-lagged relations between the different basic cognitive ability factors and learning domains. The methodological quality of this research can therefore be regarded as a strong asset.

Structural equation modelling approach

The structural equation models did not only assess the specific contributions of WM to learning but also explored the unique predictive relationship of verbal STM to learning after controlling for the shared variance with WM. Although WM and STM were found to be distinguishable in the present population of young children, the possibility can not be excluded that the STM assessments might have involved some contribution from the central executive (Conway et al., 2002; Cowan, 1995; Engle, Kane et al., 1999). Indeed, there are indications in the data that this might have been the case: significant links emerged between STM and fluid intelligence, when controlling for WM these links, however, disappeared. This finding raises the possibility that in some previous studies, the contributions of STM to higher order cognitive abilities might have been over-interpreted as a result of the failure to control for the shared variances with the central executive (Bayliss, Jarrold, Baddeley, & Gunn, 2005; Colom, Rebollo et al., 2006). The structural equation modelling approach adopted in the present study therefore provided the opportunity to theorize about the specific aspect of WM that might have been responsible for the relationship with learning, by identifying the unique contribution not only of the central executive but also of short-term storage to variations in different learning domains.

Novelty of the study

The presented work is unique in examining the theoretical issue of the structure and interrelationships of different WM components and a wide range of learning domains using multiple assessments and including tasks of phonological awareness and fluid intelligence, in a single population of multilingual children that were followed over three years. Furthermore, it is among the few studies exploring new word learning in a natural setting, and it is the first of its kind to examine second and third language learning in a large population of trilingual children.

7.2.2. Limitations of the study

Although the study can presumably be considered as high-quality longitudinal research, there were also some limitations referring to a) the number of indicators per latent constructs; b) the presence of a potential confounder; and c) causality.

Number of indicators per latent constructs

For the majority of the latent constructs only two observed variables were obtained. Although structural equation modelling with two indicators is of common practice, three or four indicators are generally preferred as it is widely accepted that relations between constructs can be misrepresented when few measures are used to identify the factors (Kline, 2005). In order to counterbalance for the small number of indicators per latent constructs, measures were carefully selected on the basis of sound theoretical knowledge and past research evidence in which the measures in question were found to reliably tap the hypothesized factors of interest (Alloway et al., 2006; Gathercole & Pickering, 2000a). Furthermore, scores on the tasks were submitted to a reliability analyses and appeared to manifest good psychometric properties in the present population of young Luxembourgish children.

Although the overall pattern of results suggests that the selected measures manifested good construct validity and nonconvergence of iterative model estimations was not a major concern, one particular model - the WM and STM two-factor model in first grade - proved to be problematic. In contrast to the data in kindergarten and second grade, the counting recall and backwards digit recall measures in first grade presented a considerably lower correlation with each other and weaker factor loadings onto the common WM construct. Furthermore, there are some indications in the data that WM and STM in first grade manifested a slightly different pattern of association with learning than in the other two study waves: Overall the relations between the central executive and learning were weaker, especially in the case of reading.

As only two tasks of WM were administered it was difficult to identify the problematic measure, and it is at present unclear why this specific pattern of result in first grade emerged. One potential reason might be that in first grade children had just been introduced into arithmetic which might have impacted on the performance on the WM measures that were largely number based. Most importantly for the present context is that caution needs to be taken when interpreting the reduced predictive power of first grade WM to learning, as in this study wave the central executive factor could not be strongly identified. It is thus not possible to determine if the particular pattern of results observed in first grade reflects a state of reality or is an artefact of the limited set of manifest variables.

Unmeasured variable

As complex span tasks of WM involve storage and processing, including a measure of processing in the analysis would have provided the opportunity to draw more definite conclusions regarding the specific aspect of WM that was driving its relationship with learning. In this study only the storage component of the complex span task was controlled; it is therefore unclear whether the residual WM reflected a central executive component responsible for the control of information within WM or simply individual differences in processing efficiency.

Earlier research has shown that in adults, controlling for speed and difficulty of processing did not change the relationship between complex span scores and higher level cognition (Conway & Engle, 1996; Engle, Cantor, & Carullo, 1992). Similar results were observed for children: In a series of studies, Bayliss and colleagues have shown that a WM residual, obtained after controlling for independent measures of storage capacity and processing efficiency, significantly correlated with measures of reading and mathematics in young children between 7 and 10 (Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Bayliss et al., 2003). These findings seem to suggest that the links between the WM residual and learning observed in the present study might have been independent of processing efficiency. It is, however, important to point out that in contrast to the children in the Bayliss studies (Baddeley et al., 1988; Bayliss, Jarrold, Baddeley, Gunn et al., 2005; Bayliss et al., 2003) who learned to read and write in English (opaque orthography), the children in the present study were introduced into literacy in a language with a consistent orthography (German). As speed of processing has been shown to be more important for the development of early reading in regular than opaque languages (de Jong & van der Leij, 1999; Wimmer, 1993), the possibility can not be excluded that the observed link between the WM residual and reading was mediated by speed of processing, especially in the light of the finding that the associations remained even after controlling for fluid intelligence.

Causality

Although the present study provides valuable insights into the cognitive underpinning of learning by showing that WM and STM administered at an earlier date effectively predicted learning outcomes at a later point in time, causality can not be unambiguously established on the basis of the presented correlational data. The primary limitation to valid causal inference in the present context refers to the issue of unobserved variable bias, i.e. the possibility that a particular observed relationship might have been mediated by a third factor that was not measured in the study (Dowd & Town, 2002). Ultimately, the causal account that explains how and why WM predicts learning can only be established through experimental manipulation and random allocation to “treatment” and control groups.

7.3. Theoretical implications and recommendations for future research

In spite of the aforementioned limitations, the results presented in this thesis have important theoretical implications and raise a number of questions that could be the impetus for further research. Two of the main questions that emerged are addressed below.

7.3.1. What does the working memory residual represent?

The presented results extend the findings of Engle and colleagues (1999b) to children that when controlling for the common variance between WM and STM, the residual WM factor is significantly linked to fluid intelligence and reliably predicts learning in subsequent years. Complex span tasks thus appear to tap something essentially more than simple storage measures which seems to be a key component of reading, spelling, language comprehension, and mathematics.

One contentious issue that remains unresolved is what this remaining variance represents. According to one popular account, it might correspond to a controlled attention or central executive component (Conway et al., 2002; Engle et al., 1999b). More particularly, it has been speculated that this factor reflects the executive costs of coordinating the processing and the storage operations of complex span tasks (Bayliss et al., 2003; Engle, Tuholski et al., 1999; Jarrold & Bayliss, 2008). A related suggestion is that it might represent the ability to switch attention between different cognitive operations (Cowan, 1997; Emerson, Miyake, & Rettinger, 1999). Further research is clearly needed to specify this source of variation in greater detail. A key issue for future studies is to identify direct assessments of controlled attention and explore their contributions to children's WM performance and their implications for learning.

The present study further showed that when controlling for fluid intelligence, the link between the WM residual with comprehension and mathematics disappeared but remained significant for reading and spelling. These results have been interpreted to suggest that different aspects of controlled attention might be relevant for different domains of learning. This position would have been strengthened considerably if measures of processing efficiency would have been included in the analyses. As described in greater detail before, without such measures the possibility can not be excluded that the observed links between the WM residual and learning might have been mediated by speed of processing.

It is important to note that although performance in the Ravens matrices task has been suggested to tap controlled attention in adults (Carpenter et al., 1990), it is at present less clear what this measure represents in young children. In contrast to the adult version (Raven, 1962) which requires the discovery and maintenance of rules that govern the variation among entries in a problem (Carpenter et al.,1990), the Raven Coloured Progressive Matrices test for children (Raven et al., 1986) includes a number of items that require visual matching only, leading to the suggestion that the Raven's for children might reflect predominantly visuo-spatial abilities rather than general fluid intelligence (Gunn & Jarrold, 2004). Further research into the nature of the underlying cognitive processes involved in the completion of the Raven in young children is clearly needed in order to clarify what might be driving its relationship with WM. Furthermore, such research efforts would provide valuable information about what the different WM residuals observed in the present study (after controlling for STM alone and after controlling for both STM and fluid intelligence) might index and most importantly help to determine more clearly which aspects of the central executive relate to which domains of learning in young children.

7.3.2. Does verbal short-term memory support new word learning?

One influential claim has been that verbal short-term storage plays a significant and highly specific role in supporting the long-term learning of new words within a language, based on extensive research evidence showing that verbal STM skills are closely related to native and foreign vocabulary knowledge (Baddeley et al., 1998; Gathercole et al., 1992; Jarrold et al., 2008; Service, 1992). Whether these links can be interpreted as causal connections or simple associations has been the focus of considerable debate in recent years (Bowey, 1996; Gathercole et al., 1992). The present study makes an important theoretical contribution to this area of research by showing that one particular measure of verbal STM - the repetition of low wordlike nonwords - significantly predicted subsequent vocabulary knowledge in a foreign language for which no lexical knowledge at a prior point in time existed and that was phonologically dissimilar from the native language.

Two interpretations have been proposed to explain the degree of uniqueness of the link between French vocabulary knowledge and the repetition of low wordlike nonwords: According to one account the repetition of low wordlike nonwords provides a more sensitive measure of verbal STM than the repetition of high wordlike nonwords or digit recall because of the reduced opportunity for long-term lexical or sub-lexical support and subvocal rehearsal processes. A second possibility is that cognitive mechanisms other than verbal STM, such as the perception of phonological categories (e.g. Serniclaes, van Heghe, Mousty, Carré, & Sprenger-Charolles, 2004), lie at the root of the observed association between the repetition of low wordlike nonword and French vocabulary knowledge. Clearly, further work is needed in order to tease these two alternatives apart and to determine whether it is verbal short-term storage or a third factor, potentially related to basic phonological processing procedures, that is important in early aspects of French vocabulary development in Luxembourgish school children. Future research projects that consider direct measure of phonological representations (e.g. Boada & Pennington, 2006) may provide an important step towards resolving this issue.

Another possibility is that both, verbal STM skills and the ability to construct well defined phonological representation make significant contributions to new word learning in French; their degree of importance might, however, depend on the stage of French language development. In the initial phases of learning French, after only a few month of formal instruction as in the present study, children might still be in the process of discovering the phonemic elements of spoken French words which might blur the contribution of verbal STM to new word learning in French. After being familiar with the French phonology, significant links between French and verbal STM might emerge. To explore this hypothesis further, it would be essential to assess the French vocabulary knowledge of the same children at a later stage in development, possibly after one year of formal instruction, and examine whether significant links with verbal STM would appear.

7.4. Practical implications

The work presented in this thesis may have important practical implications especially for teachers, educators, and child psychologists. The findings that different components of the WM system can be reliably assessed in children as young as 5, and most importantly that these assessments are highly predictive of future learning in key academic domains, suggest that measures of WM may offer valuable methods for early screening to identify children who are at present and future educational risk. The observed stability of individual differences in most of the learning domains assessed indicates that the scholastic progress made by children in the early school years is decisive for long-term academic success. It is therefore at the utmost importance to detect potential learning difficulties as early as possible in order to be able to provide appropriate educational support. There have been important recent advances in developing effective WM intervention programs either by classroom-based support (see Gathercole & Alloway, 2008 for further details) or by directly training WM skills (Klingberg et al., 2005). Early identification of WM problems can increase the effectiveness of these interventions as the implementation of remediational support at early stages of development prevents that children miss out on important learning opportunities.

Three specific characteristics of the WM measures that were used in the present study are particularly relevant for practitioners: First the measures are relatively easy and fast to administer and are appropriate for use by teachers as well as psychologists (Alloway, 2007). Second, the assessments are highly stable over time, supporting the feasibility of early screening of WM abilities to identify children who are at risk for learning difficulties. Finally, the measures are relatively independent of environmental factors. In a recent study (Engel et al., 2008) we compared children from impoverished and wealthy families in Brazil on the same WM and STM tasks as the ones used in the present research. The results showed that, in contrast to norm-referenced tests of language ability, the WM measures were impervious to substantial differences in socioeconomic background (see also Campbell et al., 1997). Together with the present results showing that WM manifest good criterion validity for academic learning, these findings suggest that assessments of WM might provide culture fair and sensitive indicators of a child' s learning potential. These measures might therefore represent a promising means of separating cognitive from environmentally based risk factors for learning difficulties.

Finally, as the acquisition of knowledge and skills is the ultimate goal of formal education, the results of this thesis might also have important implications for policy makers. When children face difficulties in scholastic progress, instructional resources are often devoted to higher-order mental processing. As shown by the present study and many others in the field (see Pickering 2006 for a review) learning difficulties may, however, often stem from more basic cognitive processing mechanisms, leading to the suggestion that instructional resources might potentially be better spent if directed more specifically at the cognitive mechanisms that underlie the learning difficulties instead of targeting the problems at the learning outcome level.

7.5. Conclusion

The present thesis has shown that the WM system in young children appears to be composed of separate, but interacting components, corresponding to short-term storage and a central executive support system. The different components can be further distinguished by the roles they play in supporting the acquisition of knowledge and skills in young children. Whereas verbal short-term storage appears to make important contributions to vocabulary development, the central executive component of WM seems to support learning in a wide range of domains, including language comprehension, literacy, and mathematics.

Taken together, the evidence suggests that tests of working memory appear to measure cognitive processes that are not explicitly taught but that underlie the acquisition of key scholastic abilities. These findings have important implications: An improved understanding of the cognitive underpinnings of learning in childhood is essential for optimizing teaching and learning support in order to provide the opportunity to all children to make normal academic progress and become independent and active members of society.

Appendix 1

Linguistic background of the sample

TABLE A.1.1.
Linguistic Background of the Sample: Information on the Children (N = 119)

		Frequency	Missing	%
Place of birth	Luxembourg	118	--	99.2
Nationality	Luxembourgish	119	--	100.0
Sex	Boy	61	--	51.3
	Girl	58	--	48.7
Number of languages the child learned to speak in	One	111	--	93.3
	Two	8	--	6.7
Learned to speak in	Luxembourgish	119	--	100.0
	German	3	--	2.5
	French	3	--	2.5
	Other	2	--	1.7
Mainly speaks at home	Luxembourgish	119	--	100.0
	German	3	--	2.5
	French	1	--	.8
Mainly speaks with friends	Luxembourgish	119	--	100.0
	Other	3	--	2.5
Watches TV in	Luxembourgish	43	--	36.1
	German	116	--	97.5
	French	13	--	10.9
	Other	11	--	9.2
Reads in/ is read to in	Luxembourgish	109	--	91.6
	German	73	--	61.3
	French	3	--	2.5
	Other	3	--	2.5
Amount of books at home	0-10	2	4	1.7
	11-25	4	4	3.5
	26-50	10	4	8.7
	51-100	30	4	26.1
	101-250	31	4	27.0
	251-500	19	4	16.5
	over 500	19	4	16.5
Mostly at home with child	Mother	113	--	95.0
	Father	32	--	26.9
	Other	10	--	8.4
Number of siblings	0	13	--	10.9
	1	65	--	54.6
	2	29	--	24.4
	3	8	--	6.7
	more then 3	3	--	2.5

TABLE A.1.2.
Linguistic Background of the Sample: Information on the Parents (N = 119)

		Mother			Father		
		Freq.	Miss.	%	Freq.	Miss.	%
Place of birth	Luxembourg	106	--	89.1	107	4	93.0
	Other	13	--	10.9	8	4	7.0
Nationality	Luxembourgish	114	--	95.8	109	4	94.8
	Other	5	--	4.2	6	4	5.2
Native language	Luxembourgish	106	--	89.1	104	--	87.4
	German	7	--	5.9	2	--	1.7
	French	3	--	2.5	1	--	.8
	Other	5	--	4.2	9	--	7.6
Fluency in Luxembourgish	Fluent	119	--	100.0	119	--	100.0
	Medium	0	--	.0	0	--	.0
	None	0	--	.0	0	--	.0
Understanding of Luxembourgish	Good	119	--	100.0	119	--	100.0
	Medium	0	--	.0	0	--	.0
	None	0	--	.0	0	--	.0
Languages mainly spoken to the child	Luxembourgish	119	--	100.0	114	5	100.0
	German	4	--	3.4	0	5	.0
	French	2	--	1.7	0	5	.0
	Other	0	--	.0	0	5	.0
Luxembourgish is spoken to the child	Always	115	--	96.6	114	4	99.1
	Often	4	--	3.4	1	4	.9
	Sometimes	0	--	.0	0	4	.0
	Never	0	--	.0	0	4	.0
Watches TV in	Luxembourgish	74	--	62.2	73	4	63.5
	German	113	--	95.0	107	4	93.0
	French	48	--	40.3	53	4	46.1
	Other	3	--	2.5	7	4	6.1
Reads in	Luxembourgish	40	--	33.6	34	4	29.6
	German	116	--	97.5	103	4	86.6
	French	41	--	34.5	42	4	35.3
	Other	5	--	4.2	23	4	19.3
Understands	German	119	--	100.0	115	4	100.0
	French	117	--	98.3	113	4	98.3
	English	100	--	84.0	95	4	82.6
	Other	27	--	22.7	29	4	25.2
Activity	In a profession	58	2	49.6	104	5	91.2
	At home	51	2	43.6	5	5	4.4
	Part-time job	4	2	3.4	2	5	1.8
	Other	4	2	3.4	3	5	2.6
Attained school level	Primary school	8	2	6.8	7	6	6.2
	Secondary first cycle[1]	17	2	14.5	8	6	7.1
	Secondary second cycle[2]	28	2	23.9	17	6	15.0
	Professional training	30	2	25.6	42	6	37.2
	Higher education	21	2	17.9	25	6	22.1
	Other	13	2	11.1	14	6	12.4

Note. Freq: frequency; Miss: missing data; [1]5^{ième} or 11^{ième}; [2]1^{ière} or 13^{ième}

Appendix 2

Design of the Luxembourgish Nonword Repetition Task (LuNRep)

Since phonotactic frequency rules are not available in Luxembourgish and research on the phonological structure of Luxembougish itself is poor, the Luxembourgish language had to be analyzed prior to the design of the nonwords in order to identify the most frequent word structures and sound patterns at each syllable lengths. In this respect eight Luxembourgish children's stories were analyzed[26]: All the nouns (excluding plurals) were extracted and grouped into categories of one, two, three, four, and five syllable lengths words: 42 one-syllable words; 42 two-syllable words; 22 three-syllable words; 20 four syllable words; and 8 five-syllable words were identified. The last category of five-syllable words was completed with 12 translated words from a list of frequent words in German[27] leading up to a total of 20 five-syllable words.

Each word was analyzed on its consonant-vowel structure. The four most frequent structure types for each syllable length were selected:

- One-syllable CVC/ CVCC/ CCVC/ CCVCC;
- Two-syllables CVCVC/ CVVC/ CVCCVC/ CCVCVC;
- Three-syllables CVCVCCVC/ CVCVCV/ CVCCCVCV/ CVCVCVC;
- Four-syllables CVCVCCVCVC/ CVCVCVCVC/ CVCVCVCCCVC/ CVCCVCCVCCVC;
- Five-syllables VCCVCVCVCVVC/ VCVCCVCVCCVC/ CVCVCCVCVVC/ CVCVCVCVCCVCC.

[26] Schoul? Nee Merci; Käschten och oder eng deier Wichs; D'Geschicht vun der Krëppchen; D'Geschicht on der Kuelscheier; D'Geschicht vum Boxmatch; D'Geschicht vun der laanger Houmass; D'Geschicht vum Wiederméchel; D'Geschicht vum hëlzene Brot (SNE, 2002)

[27] Wortschatz Universität Leipzig: *http://wortschatz.uni-leipzig.de/*

The sound patterns of the words were analyzed in order to identify consonant-vowel combinations corresponding to clusters that occur naturally in spoken Luxembourgish.

On the basis of the identified consonant-vowel structures and sound patterns, nonwords were designed using Luxembourgish vowels and consonants (see Table A.2.1.). None of the nonwords contained illegal Luxembourgish sound combinations and could therefore be co-articulated by Luxembourgish speakers. For each structure type five nonwords were created (20 words of each syllable lengths). The stress pattern of these nonwords followed the natural syllabic stress contour of the Luxembourgish language, based on readings of the list of nonwords by four native speakers. Generally words followed the rule of "initial stress" typical for Germanic languages (*Erstbetonung*). The stress pattern of the syllables was mainly strong-weak with a few exceptions (14 out of the 100 nonwords) where the words received the stress on the last or the middle syllable.

The corpus of 100 nonwords received ratings of "wordlikeness" from 20 adult Luxembourgish speaking participants. For this purpose the nonwords were recorded by a female native speaker in a random order onto an audio CD. Participants were listening individually to the CD recording and were asked to judge the degree to which the spoken form of each nonword would pass for a real word in Luxembourgish using a 5 point rating scale that ranged from 1 (very unlikely to pass for a real word in Luxembourgish) to 5 (very likely to pass for a real word in Luxembourgish). The instructions emphasised that the rating should not be based on how similar the nonword is to a particular existing word in Luxembourgish but on the extend to which its sound structure would pass for a real word in Luxembourgish[28]. After each nonword an interval of 8 seconds occurred giving the participants' time to rate the word. For all the participants Luxembourgish was the first language.

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[28] Instructions: *'you are going to hear a series of made up, funny sounding words which are not real words and do not have any meaning. Just by the sound of the word I would like you to give them a score on how much they sound like a possible Luxembourgish word. The rating should not be based on how similar the nonword is to a specific, existing Luxembourgish word but on the extend to which its sound structure would pass for a real word in Luxembourgish.'*

TABLE A.2.1.
Corpus of 100 Luxembourgish Nonwords According to Syllable Structure

	One-syllable		
CVC	CVCC	CCVC	CCVCC
Péik	Dimp	Schlat	Grascht
Boos	Kiels	Pluek	Schwuerf
Tum	Guent	Dräil	Brinsch
Jheef	Sungt	Sties	Speent
Méisch	Roscht	Bramm	Pliengt
	Two-syllables		
CVCVC	CVVC	CVCCVC	CCVCVC
Sunger	Réiel	Kausbiff	Stadil
Scheekes	Fauen	Bierwel	Schliemen
Baséisch	Moier	Maardel	Truloire
Mitéck	Nouesch	Fouchnen	Frinetz
Kawul	Toer	Nospaan	Schrëtzen
	Three-syllables		
CVCVCCVC	CVCVCV	CVCCCVCV	CVCVCVC
Weemelchen	Rolimei	Kuschtmucki	Zéilinesch
Kuleklin	Kanudi	Woltwanei	Besutick
Maschenzun	Faturo	Baschtrilo	Poneemen
Tomistéik	Wikela	Karschtali	Jasikeg
Nuwelter	Musani	Nerklissa	Komussil
	Four-syllables		
CVCVCCVCVC	CVCVCVCVC	CVCVCVCCCVC	CVCCVCCVCCVC
Wotendingel	Betzebilung	Rowerounsbick	Kolperbischnel
Bauleschnéiker	Kanousickesch	Gaulenerschnied	Nuespentéister
Foukesdipes	Sackimokeet	Misegespreik	Lapzerbeisdun
Sienermeeletz	Luerekaechel	Woserickspeen	Schéiwleksuestel
Gemuelzesiet	Noukenieser	Verangelsbaul	Moultestéister
	Five-syllables		
VCCVCVCVCVVC	VCVCCVCVCCVC	CVCVCCVCVVC	CVCVCVCVCCVCC
Ongeriemelioun	Unoofhingaster	Papperschërioul	Kassegounelsift
Orgalousinioun	Inistéilegkeet	Zemustanioun	Natileckeschwenk
Ieschpelitzanioun	Eraunzeschuergem	Seefespëlious	Weimeleverkest
Arbenoufelioun	Opichtenielten	Léimispacioun	Lakeschéinäeftegt
Eeschtepuelanioun	Aarespuelienter	Moonausfuetioun	Komaanenieltent

Average wordlikeness ratings were computed for each nonword in the corpus. At each syllable lengths the five nonwords that received the lowest and the five nonwords that received the highest wordlikeness rating were selected for the final corpus (see Table A.2.2.). The mean wordlikeness rating for the 25 “low wordlike” nonwords was 2.07 with a range of values from 1.45 to 2.7. The mean wordlikeness rating for the 25 “high wordlike” nonwords was 3.61 with a range of values from 3.3 to 4.15.

TABLE A.2.2.
Means and Standard Deviations of the Wordlikeness Ratings of the 20 Highest and the 20 Lowest Wordlike Nonwords (from 20 Luxembourgish Adults)

One-syllable					
Nonword	Mean	*SD*	Nonword	Mean	*SD*
Dimp	2.15	.99	Dräil	4.15	1.22
Bramm	2.20	.89	Grascht	4.05	1.14
Brinsch	2.60	1.31	Kiels	4.00	.86
Pliengt	2.60	1.27	Guent	3.85	1.35
Boos	2.70	.92	Méisch	3.80	1.10
Mean	2.45	.25	Mean	3.97	.14
Two-syllables					
Nonword	Mean	*SD*	Nonword	Mean	*SD*
Kausbiff	2.05	1.14	Toer	3.70	1.45
Truloire	2.05	1.00	Scheekes	3.65	1.14
Baséisch	2.15	1.04	Schrëtzen	3.65	1.22
Mitéck	2.20	1.06	Maardel	3.50	1.28
Fauen	2.30	1.03	Nouesch	3.40	1.19
Mean	2.15	.11	Mean	3.58	.12
Three-syllables					
Nonword	Mean	*SD*	Nonword	Mean	*SD*
Nerklissa	1.45	.69	Weemelchen	4.15	.93
Komussil	1.50	.76	Kuschtmucki	3.40	.99
Mussani	1.50	.69	Nuwëlter	3.30	1.08
Faturo	1.50	.83	Zéilinesch	3.25	1.12
Besutick	1.55	.89	Maschenzun	2.75	1.37
Mean	1.50	.03	Mean	3.37	.50
Four-syllables					
Nonword	Mean	*SD*	Nonword	Mean	*SD*
Sackimokeet	1.55	.82	Bauleschnéiker	3.70	1.08
Lapzerbéisdun	1.65	.81	Kanousickesch	3.80	1.00
Woserickspeen	2.20	1.20	Schéiwléksuestel	3.80	.95
Wotendingel	2.30	.73	Gemuelzesiet	3.60	.94
Rowerounsbick	2.55	1.28	Nuespentéister	3.55	1.36
Mean	2.05	.43	Mean	3.69	.11
Five-syllables					
Nonword	Mean	*SD*	Nonword	Mean	*SD*
Komaanenieltent	2.00	1.26	Eraunzeschuergem	3.60	1.23
Unoofhingaster	2.10	1.12	Ongeriemelioun	3.45	1.32
Papperschërioul	2.20	1.10	Seefespëlious	3.40	1.09
Zemustanioun	2.30	1.03	Lakeschéinäeftegt	3.45	1.05
Moonausfuetioun	2.35	1.18	Inistéilegkeet	3.30	.86
Mean	2.19	.14	Mean	3.44	.11

As can be seen from Table A.2.3. the selected low and high wordlike nonwords manifested approximately the same degree of syllabic complexity.

TABLE A.2.3.
Selected Nonwords According to Syllable Structure With Low Wordlike Nonwords in Boldface

	One-syllable		
CVC	CVCC	CCVC	CCVCC
Boos	***Dimp***	***Bramm***	***Brinsch***
Tum	Kiels	Dräil	***Pliengt***
	Guent		Grascht
	Two-syllables		
CVCVC	CVVC	CVCCVC	CCVCVC
Baséisch	***Fauen***	***Kausbiff***	***Truloire***
Mitéck	Nouesch	Maardel	Schrëtzen
Scheekes	Toer		
	Three-syllables		
CVCVCCVC	CVCVCV	CVCCCVCV	CVCVCVC
Weemelchen	***Faturo***	***Nerklissa***	***Besutick***
Maschenzun	***Musani***	Kuschtmucki	***Komussil***
Nuwelter			Zéilinesch
	Four-syllables		
CVCVCCVCVC	CVCVCVCVC	CVCVCVCCCVC	CVCCVCCVCCVC
Wotendingel	***Sackimokeet***	***Rowerounsbick***	***Lapzerbeisdun***
Bauleschnéiker	Kanousickesch	***Woserickspeen***	Nuespentéister
Gemuelzesiet			Schéiwleksuestel
	Five-syllables		
VCCVCVCVCVVC	VCVCCVCVCCVC	CVCVCCVCVVC	CVCVCVCVCCVCC
Ongeriemelioun	***Unoofhingaster***	***Papperschërioul***	***Komaanenieltent***
	Inistéilegkeet	***Zemustanioun***	Lakeschéinäeftegt
	Eraunzeschuergem	***Moonausfuetioun***	
		Seefespëlious	

Furthermore, both types of nonwords did not differ significantly in terms of the number of phonemes that each nonword contained (Table A.2.4.).

TABLE A.2.4.
Mean Number of Phonemes According to Nonword Type

	High wordlike	Low wordlike	*t*	*p*
1 syllable	4.00	4.20	-.41	.69
2 syllables	4.80	5.40	-.77	.46
3 syllables	7.60	6.80	1.79	.11
4 syllables	10.20	10.60	-.52	.62
5 syllables	11.60	11.40	.35	.73

The final 50 nonwords (Table A.2.5.) were recorded by a female native Luxembourgish speaker in a neural accent, using the software program Goldwave (2004). Wordlike and nonwordlike nonwords were alternated and the number of syllables was randomised across the test.

TABLE A.2.5.

Nonwords of the Luxembourgish Nonword Repetition Task (LuNRep)

One-syllable		Two-syllables		Three-syllables		Four-syllables		Five-syllables	
Item	IPA	Item	IPA	Item	IPA	Item	IPA	Item	IPA
Dimp	[’dimp]	Kausbiff	[’kɛʊsbɪf]	Nerklissa	[’nɛʁklɪsa]	Sackimokeet	[’zakimokeːt]	Komaanenieltent	[ko’mɑnənɪəltənt]
Bramm	[’bʁam]	Truloire	[’tʁuːlwɑʁ]	Komussil	[’komusɪl]	Lapzerbéisdun	[’laptsabeɪsdun]	Unoofhingaster	[unoːfhiŋ’astɐ]
Brinsch	[’bʁinʃ]	Baséisch	[ba’seɪʃ]	Mussani	[’musani]	Woserickspeen	[voza’ʁikʃpeːn]	Papperschërioul	[papaχʃə’ʁioʊl]
Pliengt	[’plɪəŋt]	Mitéck	[’mɪtek]	Faturo	[’fatuʁo]	Wotendingel	[’votəndiŋəl]	Zemustanioun	[tsəmusta’nioʊn]
Boos	[’boːs]	Fauen	[’faʊən]	Besutick	[’bəzutɪk]	Rowerounsbick	[ʁova’ʁoʊnsbɪk]	Moonausfuetioun	[moːnɛʊsfʊə’sioʊn]
Dräil	[’dʁɛɪl]	Toer	[’toɐ]	Weemelchen	[’veːməlʃən]	Bauleschnéiker	[’bɛʊləʃneɪkaχ]	Eraunzeschuergem	[ə’ʁɛʊntsəʃʊəʒəm]
Grascht	[’gʁaʃt]	Scheekes	[’ʃeːkəs]	Kuschtmucki	[’kuʃtmuki]	Kanousickesch	[ka’noʊzikəʃ]	Ongeriemelioun	[ɔŋgəʁɪəmə’ʎoʊn]
Kiels	[’kɪəls]	Schrëtzen	[’ʃʁətsən]	Nuwëlter	[’nuvəltʌχ]	Schéiwléksuestel	[’ʃeɪvlɛksʊəstəl]	Seefespëlious	[zeːfəʃpə’lioʊs]
Guent	[’gʊənt]	Maardel	[’mɑʁdəl]	Zéilinesch	[’tseɪlinəʃ]	Gemuelzesiet	[gə’mʊəltsəzɪət]	Lackeschéinäeftegt	[lakəʃeɪn’ɛftəʃt]
Méisch	[’meɪʃ]	Nouesch	[’noʊəʃ]	Maschenzun	[’maʃəntsun]	Nuespentéister	[’nʊəspənteɪstɐ]	Inistéilegkeet	[ini’ʃteɪləʃkeːt]

Appendix 3

Development of the TECOSY[29]

In the course of the research it became apparent that standardized tests used to assess grammatical understanding of French in French speaking children in France and Canada (e.g. L'É.CO.S.SE; Lecocq, 1996) were too difficult for monolingual Luxembourgish speaking children. There is a lack of language tests suitable for Luxembourgish children that are introduced from an early age to several foreign languages in school (German and French). The main motivation for developing the TECOSY was the need for test material appropriate for children growing up in this multilingual situation. The TECOSY was designed to assess early language comprehension skills of young Luxembourgish speaking children.

Test design was based on the *Test for Reception of Grammar* (TROG-2; Bishop, 2003) an English receptive language tests designed for speech and language therapist, psychologist, researchers and teachers. The TROG consists of 20 blocks, assessing understanding of grammatical contrasts marked by inflections, function words and word order. The TECOSY in contrast is much shorter, consisting of only 8 blocks. Furthermore, the selected test items differed considerably from the English original. All of the test pictures were hand drawn and coloured. Pictures that were hard to discriminate on a visual basis were excluded.

Constructions included in the TECOSY

A restricted simple vocabulary based on the vocabulary introduced in the second grade was used in test sentences. Table A.3.1. summarizes the constructions included in the TECOSY.

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[29] This work was completed in collaboration with Prof. Romain Martin from the University of Luxembourg.

TABLE A.3.1.
Constructions Included in the TECOSY

Block	Construction	Example
A	Two elements	Le garçon saute
B	Grand/ petit	Le nounours est grand
C	Dans/derrière	Le crayon est derrière la balle
D	Three elements	La souris mange le pain
E	Sur/sous	La pomme est sur l'assiette
F	Plural	Les souris sont grises
G	Four elements with 'and'	Le garçon montre un chat et une balle
H	Complex sentences	La fille dessine un garçon au tableau

Only constructions that are introduced in the second grade of Luxembourgish primary schools and that could be depicted unambiguously were selected for inclusion in the test. The school books "Allô Martine" (FGIL, 1996; MEN, 1986) were used as reference books. Advice on the grammatical contrasts was sought from teachers of the second grade in Luxembourg.

Selection of the distracters

Item difficulty depends not only on the grammatical construction but also on the foils that are used. Lexical or/and grammatical distracters served as foils. A lexical distracter differed from the target sentence in terms of a noun, verb or adjective. A grammatical distracter is a picture which differed from the test sentence by a grammatical contrast only, i.e. by an inflection, function word or by word order.

Blocks A, B, D and G included lexical distracters. Block C and E contained grammatical distracters and block F and H included both grammatical and lexical distracters. E.g. in item H1 ("*La fille lit un livre au garcon*"), picture 2 ("*Le garçon lit un livre à la fille*") is a grammatical distracter, whereas picture 3 ("*La fille lit un livre au chat*") and 4 ("*La fille donne un livre au garcon*") are lexical distracters. Table A.3.2. provides the target and distracter sentences as well as the nature of the distracters.

TABLE A.3.2.
Target Items and Distracters

	A. Two elements	
A1	1. Le garçon est debout	lexical
	2. Le chat est debout	lexical
	3. La fille saute	lexical
	4. **Le garçon saute**	**target**
A2	1. Le crayon est blanc	lexical
	2. Le canard est jaune	lexical
	3. **Le crayon est jaune**	**target**
	4. Le livre est blanc	lexical
A3	1. **La fille montre**	**target**
	2. L'éléphant mange	lexical
	3. La fille pousse	lexical
	4. Le garçon montre	lexical
A4	1. La fleur est blanche	lexical
	2. La pomme est blanche	lexical
	3. Le peigne est rouge	lexical
	4. **La pomme est rouge**	**target**

	B. Grand/Petit	
B1	1. Le nounours est petit	lexical
	2. La balle est grande	lexical
	3. La balle est petite	lexical
	4. **Le nounours est grand**	**target**
B2	1. Le ballon est grand	lexical
	2. **Le ballon est petit**	**target**
	3. Le chat est petit	lexical
	4. Le chat est grand	lexical
B3	1. **La souris est grande**	**target**
	2. La souris est petite	lexical
	3. La pomme est grande	lexical
	4. La pomme est petite	lexical
B4	1. La vache est grande	lexical
	2. **La fille est petite**	**target**
	3. La vache est petite	lexical
	4. La fille est grande	lexical

TABLE A.3.2. continued

	C. dans/ derrière	
C1	1. La tasse est à droite du bol	grammatical
	2. **La tasse est dans le bol**	**target**
	3. Le bol est dans la tasse	grammatical
	4. La tasse est derrière le bol	grammatical
C2	1. La fille est à droite de la table	grammatical
	2. La fille est devant la table	grammatical
	3. **La fille est derrière la table**	**target**
	4. La fille est à gauche de la table	grammatical
C3	1. Le chat est en dessous de l'armoire	grammatical
	2. La chat est sur l'armoire	grammatical
	3. **Le chat est dans l'armoire**	**target**
	4. Le chat est à droite de l'armoire	grammatical
C4	1. Le crayon est à gauche de la balle	grammatical
	2. **Le crayon est derrière la balle**	**target**
	3. Le crayon est sur la balle	grammatical
	4. La balle est derrière le crayon	grammatical

	D. Three elements	
D1	1. La souris regarde le pain	lexical
	2. **La souris mange le pain**	**target**
	3. Le chien mange le pain	lexical
	4. La souris mange le chocolat	lexical
D2	1. La fille tient la balle	lexical
	2. Le garçon lance la balle	lexical
	3. **Le garçon tient la balle**	**target**
	4. La garçon tient la tasse	lexical
D3	1. **La fille ouvre la fenêtre**	**target**
	2. Le garçon ouvre la fenêtre	lexical
	3. La fille regarde la fenêtre	lexical
	4. La fille ouvre la porte	lexical
D4	1. Le garçon touche le chat	lexical
	2. La fille dessine un chat	lexical
	3. Le garçon dessine un triangle	lexical
	4. **Le garçon dessine un chat**	**target**

TABLE A.3.2. continued

	E. sur/sous	
E1	1. **La tasse est sur la table**	**target**
	2. La tasse est à droite de la table	grammatical
	3. La tasse est sous la table	grammatical
	4. La tasse est à gauche de la table	grammatical
E2	1. Le chat est à gauche de l'armoire	grammatical
	2. **La chat est sous l'armoire**	**target**
	3. Le chat est sur l'armoire	grammatical
	4. Le chat est à droite de l'armoire	grammatical
E3	1. La pomme est sous l'assiette	grammatical
	2. La pomme est à gauche de l'assiette	grammatical
	3. **La pomme est sur l'assiette**	**target**
	4. La pomme est à droite de l'assiette	grammatical
E4	1. **Le crayon est sous le livre**	**target**
	2. Le crayon est à gauche du livre	grammatical
	3. Le crayon est sur le livre	grammatical
	4. Le crayon est à droite du livre	grammatical

	F. Plural	
F1	1. **Les chats mangent**	**target**
	2. Le chat mange	grammatical
	3. Le cochon mange	lexical
	4. Les cochons mangent	lexical
F2	1. La souris est grise	grammatical
	2. Le chat est brun	lexical
	3. **Les souris sont grises**	**target**
	4. Les chats sont bruns	lexical
F3	1. Le chien saute	grammatical
	2. La vache saute	lexical
	3. **Les chiens sautent**	**target**
	4. Les vaches sautent	lexical
F4	1. Le crayon est bleu	lexical
	2. **Les pommes sont rouges**	**target**
	3. La pomme est rouge	grammatical
	4. Les crayons sont bleus et verts	lexical

TABLE A.3.2. continued

	G. Four elements with 'and'	
G1	1. Le garçon montre un chat et une tasse	lexical
	2. **Le garçon montre un chat et une balle**	**target**
	3. Le garçon montre une fleur et une balle	lexical
	4. Le garçon ne montre pas un chat et une balle	lexical
G2	1. Voilà une balle rouge et une fleur	lexical
	2. Voilà un crayon vert et un soulier	lexical
	3. **Voilà un crayon vert et une balle rouge**	**target**
	4. Voilà un crayon blanc et une balle rouge	lexical
G3	1. La fille regarde la table et la tasse	lexical
	2. La fille regarde la chaise et le chat	lexical
	3. La fille ne regarde pas la chaise et la tasse	lexical
	4. **La fille regarde la chaise et la tasse**	**target**
G4	1. Voilà une pomme blanche et une tasse grande	lexical
	2. Voilà une tasse grande et une fleur	lexical
	3. Voilà une pomme rouge et un crayon blanc	lexical
	4. **Voilà une pomme rouge et une tasse grande**	**target**

	H. Complex sentences (Quelque chose à quelqu'un)	
H1	1. **La fille lit un livre au garçon**	**target**
	2. Le garçon lit un livre à la fille	grammatical
	3. La fille lit un livre au chat	lexical
	4. La fille donne un livre au garçon	lexical
H2	1. La fille montre un chat au garçon	grammatical
	2. **Le garçon montre un chat à la fille**	**target**
	3. Le garçon montre une tasse à la fille	lexical
	4. Le garçon montre une chaise à la fille	lexical
H3	1. **La fille dessine un garçon au tableau**	**target**
	2. Le garçon dessine une fille au tableau	grammatical
	3. La fille dessine un chat au tableau	lexical
	4. La fille dessine un garçon dans le cahier	lexical
H4	1. **Le garçon donne une pomme à la fille**	**target**
	2. Le garçon donne un crayon à la fille	lexical
	3. Le garçon donne une balle au chien	lexical
	4. La fille donne une pomme au garçon	grammatical

Acronyms

AIC	Akaike Information Criterion Index
AMOS	Analysis of Moment Structures
AWMA	Automated Working Memory Assessment
CFA	Confirmatory Factor Analysis
CFI	Comparative Fit Index
D	German (Deutsch)
e	Error
ELFE 1-6	Ein Leseverständnistest Für Elementarschüler
EOWPVT	Expressive One Word Picture Vocabulary Test
Gf	General Fluid intelligence
Gr1	1st Grade
Gr2	2nd Grade
HSP	Hamburger Schreibprobe
IFI	Incremental Fit Index
IPA	International Phonetic Alphabet
K	Kindergarten
Lu	Luxembourgish
LuNRep	Luxembourgish Nonword Repetition Task
MEN	Ministère de l'Éducation National
OOO	Odd-One-Out
PhAB	Phonological Assessment Battery
RMSEA	Root Mean Square Error of Approximation
SR	Structural Regression Model
STM	Short-Term Memory
TECOSY	Test de Compréhension Syntaxique
TROG	Test for Reception Of Grammar
WL	Wordlike
WM	Working memory

Glossary

CENTRAL EXECUTIVE

An attentional subcomponent of *working memory* with no storage capacity whose main function is to *control attention* and to coordinate activities within the entire memory system.

CHUNKING

A cognitive mechanism by which items are bound together on the basis of established knowledge.

CONFIRMATORY FACTOR ANAYLSIS (CFA)

Statistical procedure that is used to determine if the number of factors and the loadings of measured variables on them conform to what is expected on the basis of pre-established theory.

CONTROLLED ATTENTION

The capacity to maintain relevant information active in the face of interference or distraction.

CROSS-SECTIONAL DESIGN

Observational studies that are based on a single time period; stands in contrast to *longitudinal research*.

CRYSTALLIZED INTELLIGENCE

Refers to academic achievement or cultural knowledge acquired through implicit or explicit instruction; stands in contrast to *fluid intelligence.*

FLUID INTELLIGENCE (GF)

The ability to reason under novel conditions, independently of previously acquired knowledge; stands in contrast to *crystallized intelligence*.

GRAND-DUCHY OF LUXEMBOURG

Country in Western Europe - bordered by France, Germany, and Belgium - with an estimated population of 484.000. The *official languages* of the country are: Luxembourgish, German, and French; and the *national language* is *Luxembourgish*.

GRAPHEME

Graphic representation of a *phoneme* in a particular language.

INTERNATIONAL PHONETIC ALPHABET (IPA)

An internationally recognized set of symbols for phonetic transcription.

LANGUAGE

In the context of the present thesis, a means of oral communication between people including words, their pronunciation and meaning, and methods of combining them.

LATENT VARIABLE

A variable that is not directly observed but that can be inferred by extracting the common variance of several manifest variables that are directly measured.

LEARNING CYCLES

A teaching approach which is less strict in segmenting the curriculum into years but instead focuses more on the competences of each individual child.

LEXICAL RESTRUCTURING

A cognitive mechanism by which lexical entries are represented in terms of smaller segments of sounds, such as syllables or phonemes, as a consequence of vocabulary or literacy development.

LEXICALITY EFFECT

The greater difficulty of remembering nonwords as compared to real words in a serial recall task.

LEXICON

Repertory of words - i.e. vocabulary knowledge - of an individual person.

LITERACY

Written form of a language.

LONGITUDINAL RESEARCH

Observational studies that provide data about the same individuals at different points in time.

LONG-TERM MEMORY

Memory system that can hold vast amounts of information over hours, days, and even years; including episodic memory, autobiographical memory, semantic memory, and procedural memory.

LUXEMBOURGISH (LU)

A Moselle Franconian language that belongs to the family of Germanic languages and that serves as the national and official language of the *Grand-Duchy of Luxembourg*.

MULTILINGUALISM

The habitual use by a person or a community of two or more languages.

NATIONAL CURRICULUM

The specification of the set of courses and their content that must be taught in state school in the *Grand-Duchy of Luxembourg;* established by the Luxembourgish Ministry of Education (MEN).

NATIONAL LANGUAGE

Language in current use throughout the entire, or parts, of a country; it often represents the national identity of its speakers and may also bear the status of *official language*.

NATIVE LANGUAGE

The first language acquired by a person; also referred to as mothertongue

NONWORD

An artificially designed nonsense word that does not exist in the given language but that respects the phonotactic rules of that language.

OFFICIAL LANGUAGE

Language that has a legal status in a political entity (e.g. country, state) and that serves as a language of administration. It may also bear the status of *national language*.

PHONEME

The smallest unit of sound in the phonological structure of a language that is capable to convey a distinction in meaning.

PHONOLOGICAL AWARENESS

The ability to recognize and manipulate the sounds of spoken words.

PHONOLOGICAL REPRESENTATIONS

Cognitive–linguistic representations of speech that vary in grain sizes; including phrases, words, syllables, demi-syllables, and phonemes.

PHONOLOGY

The study of speech sounds and their functions in a specific language.

PHONOTACTIC FREQUENCIES

The frequency of specific sound combinations within a language.

PHONOTACTIC RULES

Rules that determine the permissible combinations of phonemes within a language.

REDINTEGRATION

The use of stored long-term knowledge of the lexical and sublexical properties of a language to reconstruct incomplete phonological memory traces.

REHEARSAL

Subvocal repetition of information with the aim of refreshing memory traces in the short-term store.

SHORT-TERM MEMORY (STM)

Memory system that is responsible for holding information temporarily accessible in mind.

STRUCTURAL EQUATION MODELLING

A set of regression equations in which various patterns of hypothesis regarding the causal relations among variables can be defined.

TEAM-TEACHING

Teaching approach in which two or more teachers are instructing in the same class.

WORDLIKENESS EFFECT

The superior performance of repeating nonsense words that sound similar to real words as compared to nonwords that bear no relationship with known words in a nonword repetition task.

WORKING MEMORY (WM)

A cognitive system in which information can be temporary storage and manipulation while complex cognitive activities are carried out.

References

Ackerman, P. L., Beier, M. E., & Boyle, M. O. (2005). Working memory and intelligence: The same or different constructs? *Psychological Bulletin, 131*(1), 30-60.

Akaike, H. (1987). Factor analysis and AIC. *Psychometrica, 52*, 317-332.

Alloway, T. P. (2007). *Automated working memory assessment*. London: Harcourt Assessment.

Alloway, T. P., & Gathercole, S. E. (2006). How does working memory work in the classroom? *Educational Research and Reviews, 1*(4), 134-139.

Alloway, T. P., Gathercole, S. E., Adams, A. M., Willis, C., Eaglen, R., & Lamont, E. (2005). Working memory and phonological awareness as predictors of progress towards early learning goals at school entry. *British Journal of Developmental Psychology, 23*, 417-426.

Alloway, T. P., Gathercole, S. E., & Pickering, S. J. (2006). Verbal and visuo-spatial short-term and working memory in children: Are they separable? *Child Development, 77*(6), 1698-1716.

Alloway, T. P., Gathercole, S. E., Willis, C., & Adams, A. M. (2004). A structural analysis of working memory and related cognitive skills in young children. *Journal of Experimental Child Psychology, 87*, 85-106.

Anastasi, A., & Urbina, S. (1997). *Psychological Testing*. New Jersey: Prentice-Hall.

Anderson, J. C., & Gerbing, D. W. (1988). Structural equation modeling in practice - a review and recommended two step approach. *Psychological Bulletin, 103*(3), 411-423.

Arbuckle, J. L. (2006). *AMOS 7 [Computer software]*. Chicago: SmallWaters.

Atkinson, R. C., & Shiffrin, R. M. (1968). Human memory: A proposed system and its control processes. In K. W. Spence & J. T. Spence (Eds.), *The psychology of learning and motivation: Advances in research and theory* (Vol. 2, pp. 742-775). New York: Academic Press.

Avons, S. E., Wragg, C. A., Cupples, L., & Lovegrove, W. J. (1998). Measures of phonological short-term memory and their relationship to vocabulary development. *Applied Psycholinguistics, 19*(4), 583–601.

Baddeley, A. D. (1986). *Working memory*. Oxford: Oxford University Press.

Baddeley, A. D. (1990). The development of the concept of working memory: Implications and contributions of neuropsychology. In G. Vallar & T. Shallice (Eds.), *Neuropsychological impairments of short-term memory*. Cambridge, UK: Cambridge University Press.

Baddeley, A. D. (1996). Exploring the central executive. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology, 49*(1), 5-28.

Baddeley, A. D. (1997). *Human memory: Theory and practice* (revised ed.). Hove: Psychology Press.

Baddeley, A. D. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences, 4*(11), 417-423.

Baddeley, A. D. (2003). Working memory: Looking back and looking forward. *Nature Reviews Neuroscience, 4*(10), 829-839.

Baddeley, A. D. (2006). Working memory: an overview. In S. J. Pickering (Ed.), *Working memory and education* (pp. 1-31). London: Elsevier.

Baddeley, A. D., Gathercole, S. E., & Papagno, C. (1998). The phonological loop as a language learning device. *Psychological Review, 105*(1), 158-173.

Baddeley, A. D., Gathercole, S. E., & Spooner, A. L. R. (2003). *The reading decision test*. Brighton: Psychology Press.

Baddeley, A. D., & Hitch, G. J. (1974). Working memory. In B. G. (Ed.), *The psychology of learning and motivation* (Vol. 8, pp. 47–90). New York Academic Press.

Baddeley, A. D., & Logie, R. H. (1999). The multiple-component model. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 28–61). New York: University Press.

Baddeley, A. D., Papagno, C., & Vallar, G. (1988). When long term learning depends on short-term storage. *Journal of Memory and Language, 27*(5), 586-595.

Baddeley, A. D., & Warrington, E. K. (1970). Amnesia and distinction between long-and short-term memory. *Journal of Verbal Learning and Verbal Behavior, 9*(2), 176-189.

Baddeley, A. D., & Wilson, B. A. (1993). A developmental deficit in short-term phonological memory: implications for language and reading. *Memory, 1*(1), 65-78.

Barrouillet, P., & Camos, V. (2001). Developmental increase in working memory span: Resource sharing or temporal decay? *Journal of Memory and Language, 45*(1), 1-20.

Basso, A., Spinnler, H., Vallar, G., & Zanobio, M. E. (1982). Left-hemisphere damage and selective impairment of auditory verbal short-term memory: A case study. *Neuropsychologia, 20*(3), 263-274.

Bast, J., & Reitsma, P. (1997). Mathew effects in reading: A comparison of latent growth curve models and simplex models with structured means. *Multivariate Behavioral Research, 32*(2), 135-167.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., & Gunn, D. M. (2005). The relationship between short-term memory and working memory: Complex span made simple? *Memory, 13*(3-4), 414-421.

Bayliss, D. M., Jarrold, C., Baddeley, A. D., Gunn, D. M., & Leigh, E. (2005). Mapping the developmental constraints on working memory span performance. *Developmental Psychology, 41*(4), 579-597.

Bayliss, D. M., Jarrold, C., Gunn, D. M., & Baddeley, A. D. (2003). The complexities of complex span: Explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General, 132*(1), 71–92.

Bekerian, D. A., & Baddeley, A. D. (1980). Saturation advertising and the repetition effect. *Journal of Verbal Learning and Verbal Behavior, 19*(1), 17-25.

Bentler, P. M. (1976). Multistructure statistical model applied to factor analysis. *Multivariate Behavioral Research, 11*(1), 3-25.

Bentler, P. M. (1990). Comparative fit indexes in structural models. *Psychological Bulletin, 107*(2), 238–246.

Bishop, D. V. M. (1983). *Test for reception of grammar*. Manchester: Chapel Press.

Bishop, D. V. M. (1989). *Test for reception of grammar*. Manchester: University of Manchester.

Bishop, D. V. M. (2003). *Test for reception of grammar-Version 2*. London: Psychological Corporation.

Bishop, D. V. M., North, T., & Donlan, C. (1996). Nonword repetition as a behavioural marker for inherited language impairment: Evidence from a twin study. *Journal of Child Psychology and Psychiatry and Allied Disciplines, 37*(4), 391-403.

Bjorklund, D. F., & Douglas, R. N. (1997). The development of memory strategies. In N. Cowan (Ed.), *The development of memory in childhood*. Hove: Psychology Press.

Boada, R., & Pennington, B. F. (2006). Deficient implicit phonological representations in children with dyslexia. *Journal of Experimental Child Psychology, 95*(3), 153-193.

Bollen, K. A. (1989). *Structural equations with latent variables*. New York: Wiley.

Bourdin, B., & Fayol, M. (1994). Is written language production more difficult than oral language production? A working memory approach. *International Journal of Psychology, 29*(5), 591–620.

Bowey, J. A. (1996). On the association between phonological memory and receptive vocabulary in five-year-olds. *Journal of Experimental Child Psychology, 63*(1), 44-78.

Bowey, J. A. (1997). What does nonword repetition measure? A reply to Gathercole and Baddeley. *Journal of Experimental Child Psychology, 67*(2), 295-301.

Bowey, J. A. (2001). Nonword repetition and young children's receptive vocabulary: A longitudinal study. *Applied Psycholinguistics, 22*(3), 441-469.

Bowey, J. A. (2006). Clarifying the phonological processing account of nonword repetition. *Applied Psycholinguistics, 27*(4), 548-552.

Bradley, L., & Bryant, P. E. (1983). Categorizing sounds and learning to read - A causal connection. *Nature, 301*(5899), 419-421.

Brown, G. D. A., Vousden, J. I., McCormack, T., & Hulme, C. (1999). The development of memory for serial order: A temporal-contextual distinctiveness model. *International Journal of Psychology, 34*(5-6), 389-402.

Browne, M. W., & Cudeck, R. (1993). Alternative ways of assessing model fit. In K. A. Bollen & J. S. Long (Eds.), *Testing structural models*. Newbury Park, CA: Sage.

Brownell, R. (2000). *Expressive one word picture vocabulary test*. London: Psychological Corporation.

Bryant, P. E., Maclean, M., Bradley, L. L., & Crossland, J. (1990). Rhyme and alliteration, phoneme detection, and learning to read. *Developmental Psychology, 26*(3), 429-438.

Buehner, M., Krumm, S., & Pick, M. (2005). Reasoning is working memory and not attention. *Intelligence, 33*(3), 251-272.

Bull, R., & Espy, K. A. (2006). Working memory, executive functioning, and children's mathematics. In S. J. Pickering (Ed.), *Working memory and education* (pp. 93-123). London: Elsevier.

Bull, R., Espy, K. A., & Wiebe, S. A. (2008). Short-term memory, working memory, and executive functioning in preschoolers: Longitudinal predictors of mathematical achievement at age 7 years. *Developmental Neuropsychology, 33*(3), 205-228.

Bull, R., & Scerif, G. (2001). Executive functioning as a predictor of children's mathematics ability: Inhibition, task switching, and working memory. *Developmental Neuropsychology, 19*(3), 273–293.

Butterworth, B., Campbell, R., & Howard, D. (1986). The uses of short-term memory - A case study. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology, 38*(4), 705-737.

Byrne, B. M. (2001). *Structural equation modeling with AMOS: Basic concepts, applications, and programming*. London: LEA.

Campbell, T., Dollaghan, C., Needleman, H., & Janosky, J. (1997). Reducing bias in language assessment: Processing dependent measures. *Journal of Speech Language and Hearing Research, 40*(3), 519-525.

Cantor, J., Engle, R. W., & Hamilton, G. (1991). Short-term memory, working memory and verbal abilities: How do they relate? *Intelligence, 15*(2), 229–246.

Carpenter, P. A., Just, M. A., & Shell, P. (1990). What one intelligence test measures - A theoretical account of the processing in the Raven Progressive Matrices Test. *Psychological Review, 97*(3), 404-431.

Carroll, J. B. (1993). *Human cognitive abilities: A survey of factor analytic studies*. New York: Cambridge University Press.

Case, R., Kurland, D. M., & Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology, 33*(3), 386–404.

Cattell, R. B. (1971). *Abilities: Their structure, growth, and action*. New York: Houghton Mifflin.

Chen, F., Bollen, K. A., Paxton, P., Curran, P. J., & Kirby, J. B. (2001). Improper solutions in structural equation models. *Sociological Methods and Research, 29*(4), 468-508.

Chen, H. C., & Leung, Y. S. (1989). Patterns of lexical processing in a nonnative language. *Journal of Experimental Psychology-Learning Memory and Cognition, 15*(2), 316-325.

Cheung, H. (1996). Nonword span as a unique predictor of second-language vocabulary learning. *Developmental Psychology, 32*(5), 867-873.

Chiappe, P., Glaeser, B., & Ferko, D. (2007). Speech perception, vocabulary, and the development of reading skills in English among Korean- and English-speaking children. *Journal of Educational Psychology, 99*(1), 154-166.

Cocchini, G., Logie, R. H., Della Sala, S., MacPherson, S. E., & Baddeley, A. D. (2002). Concurrent performance of two memory tasks: Evidence for domain-specific working memory systems. *Memory and Cognition, 30*(7), 1086–1095.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (second ed.). New York: Academic Press.

Colom, R., Abad, F. J., Quiroga, M. A., Shih, P. C., & Flores-Mendoza, C. (2008). Working memory and intelligence are highly related constructs, but why? *Intelligence, 36*(6), 584-606.

Colom, R., Abad, F. J., Rebollo, I., & Shih, P. C. (2005). Memory span and general intelligence: A latent-variable approach. *Intelligence, 33*(6), 623-642.

Colom, R., Escorial, S., Shih, P. C., & Privado, J. (2007). Fluid intelligence, memory span, and temperament difficulties predict academic performance of young adolescents. *Personality and Individual Differences, 42*(8), 1503-1514.

Colom, R., Flores-Mendoza, C., Quiroga, M. A., & Privado, J. (2005). Working memory and general intelligence: The role of short-term storage. *Personality and Individual Differences, 39*(5), 1005-1014.

Colom, R., Flores-Mendoza, C., & Rebollo, I. (2003). Working memory and intelligence. *Personality and Individual Differences, 34*(1), 33-39.

Colom, R., Rebollo, I., Abad, F. J., & Shih, P. C. (2006). Complex span tasks, simple span tasks, and cognitive abilities: A reanalysis of key studies. *Memory and Cognition, 34*(1), 158-171.

Colom, R., Shih, P. C., Flores-Mendoza, C., & Quiroga, M. A. (2006). The real relationship between short-term memory and working memory. *Memory, 14*(7), 804-813.

Conway, A. R. A., Cowan, N., Bunting, M. F., Therriault, D. J., & Minkoff, S. R. B. (2002). A latent variable analysis of working memory capacity, short-term memory capacity, processing speed, and general fluid intelligence. *Intelligence, 30*(2), 163-183.

Conway, A. R. A., & Engle, R. W. (1996). Individual differences in working memory capacity: More evidence for a general capacity theory. *Memory, 4*(6), 577-590.

Conway, A. R. A., Jarrold, C., Kane, M. J., Miyake, A., & Towse, J. N. (2008). Variation in working memory: an introduction. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake & J. N. Towse (Eds.), *Variation in working memory*. New York: Oxford University Press.

Couture, M., & Tremblay, S. (2006). Exploring the characteristics of the visuospatial Hebb repetition effect. *Memory and Cognition, 34*(8), 1720-1729.

Cowan, N. (1995). *Attention and memory: An integrated framework.* Oxford: Oxford University Press.

Cowan, N. (1997). *The development of memory in childhood*. Hove: Psychology Press.

Cowan, N. (2000). On working memory capacity: Is there a numerical limit? *International Journal of Psychology, 35*(3-4), 385-385.

Cowan, N. (2001). The magical number 4 in short-term memory: A reconsideration of mental storage capacity. *Behavioral and Brain Sciences, 24*(1), 87-114.

Cowan, N. (2005). *Working memory capacity*. Hove: Psychology Press.

Cowan, N. (2008). Working memory In N. J. Salkind (Ed.), *Encyclopedia of Educational Psychology* (Vol. 2, pp. 1015-1016). London: Sage Publications.

Cowan, N., Elliott, E. M., Saults, J. S., Morey, C. C., Mattox, S., Hismjatullina, A., et al. (2005). On the capacity of attention: Its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology, 51*(1), 42-100.

Cowan, N., Fristoe, N. M., Elliott, E. M., Brunner, R. P., & Saults, J. S. (2006). Scope of attention, control of attention, and intelligence in children and adults. *Memory and Cognition, 34*(8), 1754-1768.

Cowan, N., Wood, N. L., Wood, P. K., Keller, T. A., Nugent, L. D., & Keller, C. V. (1998). Two separate verbal processing rates contributing to short-term memory span. *Journal of Experimental Psychology-General, 127*(2), 141-160.

CRP-CU. (1998). *Le sondage "baleine": Une étude sociologique sur les trajectoires migratoires, les langues et la vie associative au Luxembourg*. Luxembourg: Collection RED.

D'Odorico, L., Assanelli, A., Franco, F., & Jacob, V. (2007). A follow-up study on Italian late talkers: Development of language, short-term memory, phonological awareness, impulsiveness, and attention. *Applied Psycholinguistics, 28*(1), 157-169.

Daneman, M., & Blennerhassett, A. (1984). How to assess the listening comprehension skills of prereaders. *Journal of Educational Psychology, 76*(6), 1372-1381.

Daneman, M., & Carpenter, P. A. (1980). Individual-differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior, 19*(4), 450-466.

Daneman, M., & Green, I. (1986). Individual differences in comprehending and producing words in context. *Journal of Memory and Language, 25*(1), 1-18.

De Cara, B., & Goswami, U. (2003). Phonological neighbourhood density: effects in a rhyme awareness task in five-year-old children. *Journal of Child Language, 30*(3), 695-710.

de Jong, P. F. (1998). Working memory deficits of reading disabled children. *Journal of Experimental Child Psychology, 70*(2), 75-96.

de Jong, P. F. (1999). Hierarchical regression analysis in structural equation modeling. *Structural Equation Modeling, 6*(2), 198-211.

de Jong, P. F., & Olson, R. K. (2004). Early predictors of letter knowledge. *Journal of Experimental Child Psychology, 88*(3), 254-273.

de Jong, P. F., Seveke, M. J., & van Veen, M. (2000). Phonological sensitivity and the acquisition of new words in children. *Journal of Experimental Child Psychology, 76*(4), 275-301.

de Jong, P. F., & van der Leij, A. (1999). Specific contributions of phonological abilities to early reading acquisition: Results from a Dutch latent variable longitudinal study. *Journal of Educational Psychology and Aging, 91*(3), 450–476.

de Jong, P. F., & van der Leij, A. (2002). Effects of phonological abilities and linguistic comprehension on the development of reading. *Scientific Studies of Reading, 6*(1), 51-77.

Dehn, M. J. (2008). *Working memory and academic learning: Assessment and intervention*. New Jersey: Wiley.

Della Sala, S., Gray, C., Baddeley, A. D., Allemano, N., & Wilson, L. (1999). Pattern span: A tool for unwielding visuo-spatial memory. *Neuropsychologia, 37*(10), 1189–1199.

Dempster, F. N. (1978). Memory span and short-term memory capacity - A developmental study. *Journal of Experimental Child Psychology, 26*(3), 419-431.

Deno, S. L. (1985). Curriculum-based measurement: The emerging alternative. *Exceptional Children, 52*(3), 219-232.

Dowd, B., & Town, R. (2002). *Does X really cause Y?* Washington, DC: Academy Health.

Dufva, M., Niemi, P., & Voeten, M. J. M. (2001). The role of phonological memory, word recognition, and comprehension skills in reading development: From preschool to grade 2. *Reading and Writing, 14*(1-2), 91-117.

Dunn, L. M., & Dunn, L. M. (1981). *Peabody picture vocabulary test - revised* (second ed.). Circle Pines, MN: American Guidance Service.

Dunn, L. M., Thériault-Whalen, C. M., & Dunn, L. M. (1993). *EVIP: Échelle de vocabulaire en images Peabody*. Toronto: Psycan.

Duyck, W., Szmalec, A., Kemps, E., & Vandierendonck, A. (2003). Verbal working memory is involved in associative word learning unless visual codes are available. *Journal of Memory and Language, 48*(3), 527-541.

Ehri, L. C. (1975). Word consciousness in readers and prereaders. *Journal of Educational Psychology, 67*(2), 204-212.

Emerson, M. J., Miyake, A., & Rettinger, D. A. (1999). Individual differences in integrating and coordinating multiple sources of information. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 25*(5), 1300–1312.

Engel, P. M. J., Santos, F. H., & Gathercole, S. E. (2008). Are working memory measures free of socioeconomic influence? *Journal of Speech Language and Hearing Research, 51*(6), 1580-1587.

Engle, R. W., Cantor, J., & Carullo, J. J. (1992). Individual differences in working memory and comprehension: A test of four hypotheses. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 18*(5), 972–992.

Engle, R. W., & Kane, M. J. (2004). Executive attention, working memory capacity, and a two-factor theory of cognitive control. In B. H. Ross & D. Irwin (Eds.), *Psychology of learning and motivation: Advances in research and theory* (Vol. 44, pp. 145-199). San Diego: Academic Press Inc.

Engle, R. W., Kane, M. J., & Tuholski, S. W. (1999). Individual differences in working memory capacity and what they tell us about controlled attention, general fluid intelligence, and functions of the prefrontal cortex. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 102–134). New York: Cambridge University Press.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., & Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: A latent-variable approach. *Journal of Experimental Psychology-General, 128*(3), 309-331.

Fan, X., Wang, L., & Thompson, B. (1999). Effects of sample size, estimation methods, and model specification on structural equation modeling fit indexes. *Structural Equation Modelling: A Multidisciplinary Journal, 6*(1), 56-83.

Fehlen, F. (2002). Luxembourg, a multilingual society at the Romance/Germanic language border. *Journal of Multilingual and Multicultural Development, 23*(1&2), 80-97.

Feldman Barrett, L., Tugade, M. M., & Engle, R. W. (2004). Individual differences in working memory capacity and dual-process theories of the mind. *Psychological Bulletin, 130*(4), 553-573.

Felser, C., Marinis, T., & Clahsen , H. (2003). Children's processing of ambiguous sentences: A study of relative clause attachment. *Language Acquisition, 11*(3), 127-163.

FGIL. (1996). *Allô Martine : jeux et exercices pour la deuxième année d'études*. Luxembourg: Éditions de la FGIL.

Flavell, J. H., Beach, D. R., & Chinsky, J. M. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development, 37*(2), 283-299.

Fox, A. V. (2006). *TROG-D: Test zur Überprüfung des Grammatikverständnisses* (first ed.). Idstein: Schulz-Kirchner.

Frederickson, N., Frith, U., & Reason, R. (1997). *Phonological assessment battery*. London: NFER-Nelson.

Fry, A. F., & Hale, S. (2000). Relationships among processing speed, working memory, and fluid intelligence in children. *Biological Psychology, 54*(1-3), 1-34.

Garlock, V. M., Walley, A. C., & Metsala, J. L. (2001). Age-of-acquisition, word frequency, and neighborhood density effects on spoken word recognition by children and adults. *Journal of Memory and Language, 45*(3), 468-492.

Gathercole, S. E. (1995a). The assessment of phonological memory skills in preschool children. *British Journal of Educational Psychology, 65*(2), 155-164.

Gathercole, S. E. (1995b). Is nonword repetition a test of phonological memory or long-term knowledge? It all depends on the nonwords. *Memory and Cognition, 23*(1), 83-94.

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences, 3*(11), 410-419.

Gathercole, S. E. (2006). Nonword repetition and word learning: The nature of the relationship. *Applied Psycholinguistics, 27*(4), 513-543.

Gathercole, S. E., & Adams, A. M. (1994). Children's phonological working memory: Contributions of long-term knowledge and rehearsal. *Journal of Memory and Language, 33*, 672-688.

Gathercole, S. E., Adams, A. M., & Hitch, G. J. (1994). Do young children rehearse - An individual differences analysis. *Memory and Cognition, 22*(2), 201-207.

Gathercole, S. E., & Alloway, T. P. (2008). *Working memory and learning*. London: Sage.

Gathercole, S. E., Alloway, T. P., Willis, C., & Adams, A. M. (2006). Working memory in children with reading disabilities. *Journal of Experimental Child Psychology, 93*(3), 265-281.

Gathercole, S. E., & Baddeley, A. D. (1989). Evaluation of the role of phonological STM in the development of vocabulary in children: A longitudinal study. *Journal of Memory and Language, 28*(2), 200-213.

Gathercole, S. E., & Baddeley, A. D. (1990). Phonological memory deficits in language disordered children: Is there a causal connection? *Journal of Memory and Language, 29*(3), 336-360.

Gathercole, S. E., & Baddeley, A. D. (1993). Phonological working memory - A critical building block for reading development and vocabulary acquisition. *European Journal of Psychology of Education, 8*(3), 259-272.

Gathercole, S. E., & Baddeley, A. D. (1996). *The children's test of nonword repetition*. London: Psychological Corporation.

Gathercole, S. E., Frankish, C. R., Pickering, S. J., & Peaker, S. (1999). Phonotactic influences on short term memory. *Journal of Experimental Psychology: Learning, Memory and Cognition, 25*(1), 84-95.

Gathercole, S. E., & Hitch, G. J. (1993). Developmental changes in short-term memory: a revised working memory perspective In A. Collins, S. E. Gathercole, M. A. Conway & P. E. Morris (Eds.), *Theories of memory* (pp. 189–210). London: Erlbaum.

Gathercole, S. E., Hitch, G. J., Service, E., & Martin, A. J. (1997). Phonological short-term memory and new word learning in children. *Developmental Psychology, 33*(6), 966-979.

Gathercole, S. E., Lamont, E., & Alloway, T. P. (2006). Working memory in the classroom. In S. J. Pickering (Ed.), *Working memory and education* (pp. 219-240). London: Elsevier.

Gathercole, S. E., & Pickering, S. J. (2000a). Assessment of working memory in six- and seven-year-old children. *Journal of Educational Psychology, 92*(2), 377-390.

Gathercole, S. E., & Pickering, S. J. (2000b). Working memory deficits in children with low achievements in the national curriculum at 7 years of age. *British Journal of Educational Psychology, 70*(2), 177-194.

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology, 40*(2), 177-190.

Gathercole, S. E., & Thorn, A. S. C. (1998). Phonological short-term memory and foreign language learning. In A. F. Healy & L. E. Bourne (Eds.), *Foreign language learning: Psycholinguistic studies on training and retention*. London: Laurence Erlbaum.

Gathercole, S. E., Tiffany, C., Briscoe, J., Thorn, A. S. C., & the ALSPAC team. (2005). Developmental consequences of poor phonological short-term memory function in childhood: A longitudinal study. *Journal of Child Psychology and Psychiatry, 46*(6), 598-611.

Gathercole, S. E., Willis, C. S., Baddeley, A. D., & Emslie, H. (1994). The children's test of nonword repetition: A test of phonological working memory. *Memory, 2*(2), 103-127.

Gathercole, S. E., Willis, C. S., Emslie, H., & Baddeley, A. D. (1992). Phonological memory and vocabulary development during the early school years: A longitudinal study. *Developmental Psychology, 28*(5), 887-898.

Glanzer, M., & Cunitz, A. R. (1966). Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behaviour, 5*(4), 351-360.

GoldWave Inc. (2004). *GoldWave digital audio editor software* (fifth ed.). St. John's, NL: GoldWave Inc.

Gollob, H. F., & Reichardt, C. S. (1987). Taking account of time lags in causal models. *Child Development, 58*(1), 80-92.

Gonzalez, R., & Griffin, D. (2001). Testing parameters in structural equation modeling: Every "one" matters. *Psychological Methods, 6*(3), 258-269.

Goswami, U., & Bryant, P. (1990). *Phonological skills and learning to read*. Hillsdale: Erlbaum.

Goswami, U., Porpodas, C., & Wheelwright, S. (1997). Children's orthographic representations in English and Greek. *European Journal of Psychology of Education, 12*(3), 273-292.

Gunn, D. M., & Jarrold, C. (2004). Raven's matrices performance in Down syndrome: Evidence of unusual errors. *Research in Developmental Disabilities, 25*(5), 443-457.

Gupta, P. (2003). Examining the relationship between word learning, nonword repetition, and immediate serial recall in adults. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology, 56*(7), 1213-1236.

Gupta, P. (2005). Primacy and recency in nonword repetition. *Memory, 13*(3-4), 318-324.

Gupta, P., Lipinski, J., Abbs, B., & Lin, P. H. (2005). Serial position effects in nonword repetition. *Journal of Memory and Language, 53*(1), 141-162.

Gupta, P., MacWhinney, B., Feldman, H. A., & Sacco, K. (2003). Phonological memory and vocabulary learning in children with focal lesions. *Brain and Language, 87*(2), 241-252.

Gustafsson, J. E., & Balke, G. (1993). General and specific abilities as predictors of school achievement. *Multivariate Behavioral Research, 28*(4), 407-434.

Haavisto, M. L., & Lehto, J. E. (2005). Fluid/spatial and crystallized intelligence in relation to domain-specific working memory: A latent-variable approach. *Learning and Individual Differences, 15*(1), 1-21.

Hanten, G., & Martin, R. C. (2000). Contributions of phonological and semantic short-term memory to sentence processing: Evidence from two cases of closed head injury in children. *Journal of Memory and Language, 43*(2), 335-361.

Hebb, D. O. (1961). Distinctive features of learning in the higher animal. In J. F. Delafresnaye (Ed.), *Brain mechanisms and learning* (pp. 37-46). Oxford: Blackwell.

Hitch, G. J., & Halliday, M. S. (1983). Working memory in children. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences, 302*(1110), 325-340.

Holden, M. H., & MacGinitie, W. H. (1972). Children's conceptions of word boundaries in speech and print. *Journal of Educational Psychology, 63*(6), 551-557.

Holmes, J., & Adams, J. W. (2006). Working memory and children’s mathematical skills: Implications for mathematical development and mathematics curricula. *Educational Psychology, 26*(3), 339-366.

Hoover, W. A., & Gough, P. B. (1990). The simple view of reading. *Reading and Writing, 2*(2), 127-160.

Horn, J. L., & Cattell, R. B. (1967). Age differences in fluid and crystallized intelligence. *Acta Psychologica, 26*(2), 107-129.

Hoyle, R. H. (1995). *Structural equation modeling*. Thousand Oaks: Sage.

Hu, C. F., & Schuele, C. M. (2005). Learning nonnative names: The effect of poor native phonological awareness. *Applied Psycholinguistics, 26*(3), 343-362.

Hu, L., & Bentler, P. M. (1995). Evaluating model fit. In R. H. Hoyle (Ed.), *Structural equation modeling: Concepts, issues, and applications* (pp. 76 – 99). Thousand Oaks: Sage.

Hulme, C., & Mackenzie, S. (1992). *Working memory and severe learning difficulties*. Hove: Erlbaum.

Hulme, C., Maughan, S., & Brown, G. D. A. (1991). Memory for familiar and unfamiliar words - Evidence for a long-term memory contribution to short-term memory span. *Journal of Memory and Language, 30*(6), 685-701.

Hulme, C., Thomson, N., Muir, C., & Lawrence, A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology, 38*(2), 241-253.

Hutton, U. M. Z., & Towse, J. N. (2001). Short-term memory and working memory as indices of children's cognitive skills. *Memory, 9*(4-6), 383-394.

Jaccard, J., & Wan, C. K. (1996). *LISREL approaches to interaction effects in multiple regression*. Thousand Oaks: Sage.

James, W. (1890). *The principles of psychology*. Cambridge, MA: Harvard University Press.

Jarrold, C., Baddeley, A. D., Hewes, A. K., Leeke, T. C., & Phillips, C. E. (2004). What links verbal short-term memory performance and vocabulary level? Evidence of changing relationships among individuals with learning disability. *Journal of Memory and Language, 50*(2), 134-148.

Jarrold, C., & Bayliss, D. M. (2008). Variation in working memory due to typical and atypical development. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake & J. N. Towse (Eds.), *Variation in working memory*. New York: Oxford University Press.

Jarrold, C., Thorn, A. S. C., & Stephens, E. (2009). The relationships among verbal short-term memory, phonological awareness, and new word learning: Evidence from typical development and Down syndrome. *Journal of Experimental Child Psychology, 102*(2), 196-218.

Jarrold, C., & Towse, J. N. (2006). Individual differences in working memory. *Neuroscience, 139*(1), 39-50.

Jarvis, H. L., & Gathercole, S. E. (2003). Verbal and non-verbal working memory and achievements on national curriculum tests at 11 and 14 years of age. *Educational and Child Psychology, 20*(3), 123–140.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension - Individual-differences in working memory. *Psychological Review, 99*(1), 122-149.

Kail, R., & Hall, L. K. (2001). Distinguishing short-term memory from working memory. *Memory and Cognition, 29*(1), 1-9.

Kane, M. J., Conway, A. R. A., Hambrick, D. Z., & Engle, R. W. (2008). Variation in working memory capacity as variation in executive attention and control. In A. R. A. Conway, C. Jarrold, M. J. Kane, A. Miyake & J. N. Towse (Eds.), *Variation in working memory*. New York: Oxford University Press.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., & Engle, R. W. (2004). The generality of working memory capacity: A latent variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*(2), 189–217.

Kartheiser, J. (2000). 'Ech léiere Lëtzebuergesch, well ech...' In G. Newton (Ed.), *Essays on politics, language and society in Luxembourg* (pp. 63-75). Lewiston: Edwin Mellen Press.

Kaufman, A. S., & Kaufman, N. L. (1983). *Kaufman assessment battery for children*. Bloomington, MN: Pearson Assessments.

Kenny, D. A. (1975). Cross-lagged panel correlation: A test for spuriousness. *Psychological Bulletin, 82*(6), 887-903.

Kirps, J., & Reitz, J. (2001). *National report: Grand-Duchy of Luxembourg*. Strasbourg: Council of Europe.

Kirtley, C., Bryant, P., Maclean, M., & Bradley, L. (1989). Rhyme, rime, and the onset of reading. *Journal of Experimental Child Psychology, 48*(2), 224-245.

Kishton, J. M., & Widaman, K. F. (1994). Unidimensional versus domain representative parceling of questionnaire items - an empirical example. *Educational and Psychological Measurement, 54*(3), 757-765.

Kline, P. (1990). *Intelligence: The psychometric view*. London: Routledge.

Kline, R. B. (2005). *Principles and practice of structural equational modeling* (second ed.). New York: The Guilford Press.

Klingberg, T., Fernell, E., Olesen, P., Johnson, M., Gustafsson, P., Dahlström, K., et al. (2005). Computerized training of working memory in children with Attention-Deficit/Hyperactivity Disorder – A randomized, controlled trial. *Journal of the American Academy of Child and Adolescent Psychiatry, 44*(2), 177-186.

Kyllonen, P. C. (1996). Is working memory capacity Spearman's g? In I. Dennis & P. Tapsfield (Eds.), *Human abilities: Their nature and measurement* (pp. 49-75). Mahwah, NJ: Erlbaum.

Kyllonen, P. C., & Christal, R. E. (1990). Reasoning ability is (little more than) working-memory capacity. *Intelligence, 14*(4), 389-433.

La Pointe, L. B., & Engle, R. W. (1990). Simple and complex word spans as measures of working memory capacity. *Journal of Experimental Psychology-Learning Memory and Cognition, 16*(6), 1118-1133.

Landerl, K., & Wimmer, H. (2008). Development of word reading fluency and spelling in a consistent orthography: An 8-year follow-up. *Journal of Educational Psychology, 100*(1), 150-161.

Landis, J. R., & Kock, G. G. (1977). The measurement of observer agreement for categorical data. *Biometrics, 33*(1), 159-174.

Leather, C. V., & Henry, L. A. (1994). Working-memory span and phonological awareness tasks as predictors of early reading-ability. *Journal of Experimental Child Psychology, 58*(1), 88-111.

LeCocq, P. (1996). *L'É.CO.S.SE: Une épreuve de compréhension syntaxico-sémantique*. Villeneuve d'Ascq: Septentrion.

Lenhard, W., & Schneider, A. (2006). *ELFE 1-6: Ein Leseverständnistest für Erst- bis Sechstklässler*. Göttingen: Hogrefe.

Little, T. D., Cunningham, W. A., Shahar, G., & Widaman, K. F. (2002). To parcel or not to parcel: exploring the question, weighing the merits. *Structural Equation Modeling, 9*(2), 151-173.

Loehlin, J. C. (1996). The Cholesky approach: A cautionary note. *Behavior Genetics, 26*(1), 65-69.

Luo, D., & Petrill, S. A. (1999). Elementary cognitive tasks and their roles in g estimates. *Intelligence, 27*(2), 157-174.

Luo, D., Thompson, L. A., & Detterman, D. K. (2006). The criterion validity of tasks of basic cognitive processes. *Intelligence, 34*(1), 79-120.

Majerus, S., Poncelet, M., Greffe, C., & Van der Linden, M. (2006). Relations between vocabulary development and verbal short-term memory: The relative importance of short-term memory for serial order and item information. *Journal of Experimental Child Psychology, 93*(2), 95-119.

Mann, V. A., & Liberman, I. Y. (1984). Phonological awareness and verbal short-term-memory. *Journal of Learning Disabilities, 17*(10), 592-599.

Martin, R., & Burton, R. (2003). *Untergrad Lesetest*. Luxembourg: University of Luxembourg.

Martin, R. C., & Lesch, M. F. (1996). Associations and dissociations between language impairment and list recall: Implications for models of short-term memory. In S. E. Gathercole (Ed.), *Models of short-term memory*. Hove: Psychology Press.

Martin, R. C., Lesch, M. F., & Bartha, M. C. (1999). Independence of input and output phonology in word processing and short-term memory. *Journal of Memory and Language, 41*(1), 3–29.

Masoura, E. V., & Gathercole, S. E. (1999). Phonological short-term memory and foreign language learning. *International Journal of Psychology, 34*(5-6), 383-388.

Masoura, E. V., & Gathercole, S. E. (2005). Contrasting contributions of phonological short-term memory and long-term knowledge to vocabulary learning in a foreign language. *Memory, 13*(3-4), 422-429.

May, P. (2007). *HSP 2: Hamburger Schreibprobe für zweite Klasse*. Hamburg: VPM.

McDonald, R. P., & Ho, M. H. R. (2002). Principles and practice in reporting structural equation analyses. *Psychological Methods, 7*(1), 64-82.

Mémorial A N° 112. (1999). *Règlement grand-ducal du 30 juillet 1999 portant réforme du système officiel d'orthographe luxembourgeoise*. Luxembourg: Les Extraits du Mémorial.

MEN. (1986). *Allô Martine*. Luxembourg: Ministère de l'Éducation Nationale.

MEN. (1989). *Enseignement Primaire: Plan d'Etudes*. Luxembourg: Ministère de l'Éducation Nationale.

MEN. (2006). *Livret scolaire*. Luxembourg: Ministère de l'Éducation Nationale.

MENFP, SCRIPT, FUNDP, & Collège des inspecteurs. (2004). *Cycles d'apprentissage et Team-Teaching: expériences, réflexions et recommandations*. Luxembourg: SCRIPT.

Metsala, J. L. (1999). Young children's phonological awareness and nonword repetition as a function of vocabulary development. *Journal of Educational Psychology, 91*(1), 3-19.

Metsala, J. L., & Walley, A. C. (1998). Spoken vocabulary growth and the segmental restructuring of lexical representations: Precursors to phonemic awareness and early reading ability. In J. L. Metsala & L. C. Ehri (Eds.), *Word recognition in beginning literacy* (pp. 89-120). Hillsdale, NJ: Erlbaum.

Miller, G. A. (1956). The magical number seven, plus or minus two. *The Psychological Review, 63*(2), 81-97.

Miyake, A., Friedman, N. P., Emerson, M. J., Witzki, A. H., Howerter, A., & Wager, T. D. (2000). The unity and diversity of executive functions and their contributions to complex "frontal lobe" tasks: A latent variable analysis. *Cognitive Psychology, 41*(1), 49-100.

Miyake, A., Friedman, N. P., Rettinger, D. A., Shah, P., & Hegarty, P. (2001). How are visuospatial working memory, executive functioning, and spatial abilities related? A latent-variable analysis. *Journal of Experimental Psychology-General, 130*(4), 621-640.

Montgomery, J. W. (1995). Sentence comprehension in children with specific language impairment - The role of phonological working-memory. *Journal of Speech and Hearing Research, 38*(1), 187-199.

Morais, J., Alegria, J., & Content, A. (1987). The relationship between segmental analysis and alphabetic literacy. *Cahiers de Psychologie Cognitive, 7*(5), 415-438.

Morais, J., Cary, L., Alegria, J., & Bertelson, P. (1979). Does awareness of speech as a sequence of phones arise spontaneously. *Cognition, 7*(4), 323-331.

Mosse, E. K., & Jarrold, C. (2008). Hebb learning, verbal short-term memory, and the acquisition of phonological forms in children. *Quarterly Journal of Experimental Psychology, 61*(4), 505-514.

Muter, V., Hulme, C., Snowling, M., & Taylor, S. (1998). Segmentation, not rhyming, predicts early progress in learning to read. *Journal of Experimental Child Psychology, 71*(1), 3-27.

Muter, V., Hulme, C., Snowling, M. J., & Stevenson, J. (2004). Phonemes, rimes, vocabulary, and grammatical skills as foundations of early reading development: Evidence from a longitudinal study. *Developmental Psychology, 40*(5), 665-681.

Muter, V., & Snowling, M. (1998). Concurrent and longitudinal predictors of reading: The role of metalinguistic and short-term memory skills. *Reading Research Quarterly, 33*(3), 320-337.

Neath, I., Brown, G. D. A., Poirier, M., & Fortin, C. (2005). Short-term and working memory: Past, progress, and prospects. *Memory, 13*(3-4), 225-235.

Nelson, C. A. (1995). The ontogeny of human memory - A cognitive neuroscience perspective. *Developmental Psychology, 31*(5), 723-738.

Newton, G. (1996). *Luxembourg and Lëtzebuergesch: Language and communication at the crossroad of Europe*. Oxford: Clarendon Press.

Nickerson, R. S., & Adams, M. J. (1979). Long-term memory for a common object. *Cognitive Psychology, 11*(3), 287-307.

Nittrouer, S. (1996). Discriminability and perceptual weighting of some acoustic cues to speech perception by 3-year-olds. *Journal of Speech and Hearing Research, 39*(2), 278-297.

Nunnally, J. C. (1978). *Psychometric theory* (second ed.). New York: McGraw-Hill.

Ormrod, J. E., & Cochran, K. F. (1988). Relationship of verbal ability and working memory to spelling achievement and learning to spell. *Reading Research and Instruction, 28*(1), 33-43.

Papagno, C., Cecchetto, C., Reati, F., & Bello, L. (2007). Processing of syntactically complex sentences relies on verbal short-term memory. Evidence from a short-term memory patient. *Cognitive Neuropsychology, 24*(3), 292-311.

Papagno, C., Valentine, T., & Baddeley, A. D. (1991). Phonological short-term-memory and foreign-language vocabulary learning. *Journal of Memory and Language, 30*(3), 331-347.

Passolunghi, M. C., & Siegel, L. S. (2001). Short-term memory, working memory, and inhibitory control in children with difficulties in arithmetic problem solving. *Journal of Experimental Child Psychology, 80*(1), 44–57.

Pedhazur, E. J., & Schmelkin, L. P. (1991). *Measurement, design, and analysis: An integrated approach*. Hillsdale, NJ: Lawrence Erlbaum Publishers.

Pickering, S. J. (2006). *Working memory and education*. London: Elsevier.

Pickering, S. J., & Gathercole, S. E. (2001). *Working memory test battery for children*. London: Psychological Corporation Europe.

Pickering, S. J., & Gathercole, S. E. (2004). Distinctive working memory profiles in children with special educational needs. *Educational Psychology, 24*(3), 393-408.

Plaut, D. C., McClelland, J. L., Seidenberg, M. S., & Patterson, K. (1996). Understanding normal and impaired word reading: Computational principles in quasi-regular domains. *Psychological Review, 103*(1), 56-115.

Portney, L. G., & Watkins, M. P. (2000). *Foundations of clinical research: Applications to practice* (second ed.). New Jersey: Prentice Hall Health.

Postman, L., & Phillips, L. W. (1965). Short-term temporal changes in free-recall. *Quarterly Journal of Experimental Psychology, 17*(2), 132-138.

Raven, J. C. (1962). *Advanced Progressive Matrices*. London: H. K. Lewis.

Raven, J. C., Court, J. H., & Raven, J. (1986). *Coloured progressive matrices*. London: H. K. Lewis.

Read, C., Zhang, Y., Nie, H., & Ding, B. (1986). The ability of manipulate speech sounds depends on knowing alphabetic writing. *Cognition, 24*(1-2), 31-44.

Roodenrys, S., Hulme, C., & Brown, G. (1993). The development of short-term memory span - separable effects of speech rate and long-term memory. *Journal of Experimental Child Psychology, 56*(3), 431-442.

Rossion, B., & Pourtois, G. (2004). Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception, 33*(2), 217-236.

SCRIPT. (2005). *Les chiffres clés de l'éducation nationale: Statistiques et indicateurs 2003-2004*. Luxembourg: MENFP.

Serniclaes, W., van Heghe, S., Mousty, P., Carré, R., & Sprenger-Charolles, L. (2004). Allophonic mode of speech perception in dyslexia. *Journal of Experimental Child Psychology, 87*(4), 336-361.

Service, E. (1992). Phonology, working memory, and foreign-language learning. *Quarterly Journal of Experimental Psychology Section A-Human Experimental Psychology, 45*(1), 21-50.

Service, E. (2006). Phonological networks and new word learning. *Applied Psycholinguistics, 27*(4), 581-584.

Service, E., Maury, S., & Luotoniemi, E. (2007). Individual differences in phonological learning and verbal short-term memory span. *Memory and Cognition, 35*(5), 1122-1135.

Shallice, T., & Warrington, E. K. (1970). Independent functioning of verbal memory stores - A neuropsychological study. *Quarterly Journal of Experimental Psychology, 22*(2), 261-273.

Shankweiler, D., Smith, S. T., & Mann, V. A. (1984). Repetition and comprehension of spoken sentences by reading disabled children. *Brain and Language, 23*(2), 241-257.

SNE. (2002). *Schreif deng Sprooch*. Luxembourg: SNE-Éditions.

Snodgrass, J. G., & Vanderwart, M. (1980). Standardized set of 260 pictures - Norms for name agreement, image agreement, familiarity, and visual complexity. *Journal of Experimental Psychology Human Learning and Memory, 6*(2), 174-215.

Snowling, M., Chiat, S., & Hulme, C. (1991). Words, nonwords, and phonological processes - Some comments on Gathercole, Willis, Emslie, and Baddeley. *Applied Psycholinguistics, 12*(3), 369-373.

St Clair-Thompson, H. L., & Gathercole, S. E. (2006). Executive functions and achievements in school: Shifting, updating, inhibition, and working memory. *Quarterly Journal of Experimental Psychology, 59*(4), 745-759.

Steiger, J. H. (1980). Test for comparing elements of a correlation matrix. *Psychological Bulletin, 87*(2), 245-251.

Stephens, M. (1976). *Linguistic minorities in western Europe*. Llandysul: Gomer Press.

Stoolmiller, M., & Bank, L. (1995). Autoregressive effects in structural equation models: We see some problems. In J. M. Gottman & G. Sackett (Eds.), *The analysis of change* (pp. 263–276). Hillsdale, NJ: Erlbaum.

Süß, H. M., Oberauer, K., Wittmann, W. W., Wilhelm, O., & Schulze, R. (2002). Working-memory capacity explains reasoning ability and a little bit more. *Intelligence, 30*(3), 261-288.

Swanson, H. L. (1993). Working-memory in learning-disability subgroups. *Journal of Experimental Child Psychology, 56*(1), 87-114.

Swanson, H. L. (1999). Reading comprehension and working memory in learning disabled readers: Is the phonological loop more important than the executive system? *Journal of Experimental Child Psychology, 72*(1), 1-31.

Swanson, H. L. (2008). Working memory and intelligence in children: What develops? *Journal of Educational Psychology, 100*(3), 581-602.

Swanson, H. L., & Beebe-Frankenberger, M. (2004). The relationship between working memory and mathematical problem solving in children at risk and not at risk for math disabilities. *Journal of Education Psychology, 96*(3), 471–491.

Swanson, H. L., & Sachse-Lee, C. (2001). Mathematical problem solving and working memory in children with learning disabilities: Both executive and phonological processes are important. *Journal of Experimental Child Psychology and Aging, 79*(3), 294–321.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (fifth ed.). Boston: Pearson Education.

Taris, T. W. (2000). *A primer in longitudinal data analysis*. Londen: Sage.

Taris, T. W., & Kompier, M. (2003). Challenges in longitudinal designs in occupational health psychology. *Scandinavian Journal of Work Environment and Health, 29*(1), 1-4.

Thomson, J., Richardson, U., & Goswami, U. (2005). Phonological similarity neighborhoods and children's short-term memory: Typical development and dyslexia. *Memory and Cognition, 33*(7), 1210-1219.

Thorn, A. S. C., & Gathercole, S. E. (2001). Language differences in verbal short-term memory do not exclusively originate in the process of subvocal rehearsal. *Psychological Bulletin and Review, 8*(2), 357-364.

Torgesen, J. K. (1996). A model of memory from an information processing perspective: The special case of phonological memory. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 157–184). Baltimore: Paul H. Brookes.

Torgesen, J. K., Wagner, R. K., Rashotte, C. A., Burgess, S., & Hecht, S. (1997). Contributions of phonological awareness and rapid automatic naming ability to the growth of word reading skills in second to fifth grade children. *Scientific Studies of Reading, 1*(2), 161-185.

Towse, J. N., Hitch, G. J., & Hutton, U. (1998). A reevaluation of working memory capacity in children. *Journal of Memory and Language, 39*(2), 195-217.

Towse, J. N., & Houston-Price, C. M. T. (2001). Combining representations in working memory: A brief report. *British Journal of Developmental Psychology, 19*(3), 319-324.

Trausch, G. (2002). *Histoire du Luxembourg. Le destin européen d'un « petit pays »*. Toulouse: Privat.

Turner, M. L., & Engle, R. W. (1989). Is working memory capacity task dependent. *Journal of Memory and Language, 28*(2), 127-154.

United Nations. (1948). *UDHR: The Universal Declaration of Human Rights*: United Nations General Assembly.

Unsworth, N., & Engle, R. W. (2006). Simple and complex memory spans and their relation to fluid abilities: Evidence from list-length effects. *Journal of Memory and Language, 54*(1), 68-80.

Vallar, G., & Baddeley, A. D. (1989). Developmental disorders of verbal short-term memory and their relation to sentence comprehension - A reply to Howard and Butterworth. *Cognitive Neuropsychology, 6*(5), 465-473.

Vallar, G., & Shallice, T. (1990). *Neuropsychological impairments of short-term memory*. New York: Cambridge University Press.

van Daal, J., Verhoeven, L., van Leeuwe, J., & van Balkom, H. (2008). Working memory limitations in children with severe language impairment. *Journal of Communication Disorders, 41*(2), 85–107.

Wagner, R. K., Balthazor, M., Hurley, S., Morgan, S., Rashotte, C., Shaner, R., et al. (1987). The nature of prereaders' phonological processing abilities. *Cognitive Development, 2*(4), 355–373.

Wagner, R. K., & Torgesen, J. K. (1987). The nature of phonological processing and its causal role in the acquisition of reading-skills. *Psychological Bulletin, 101*(2), 192-212.

Wagner, R. K., Torgesen, J. K., Laughon, P., Simmons, K., & Rashotte, C. A. (1993). Development of young readers phonological processing abilities. *Journal of Educational Psychology, 85*(1), 83-103.

Wagner, R. K., Torgesen, J. K., & Rashotte, C. A. (1994). Development of reading related phonological processing abilities - New evidence of bidirectional causality from a latent variable longitudinal study. *Developmental Psychology, 30*(1), 73-87.

Wagner, R. K., Torgesen, J. K., Rashotte, C. A., Hecht, S. A., Barker, T. A., Burgess, S. R., et al. (1997). Changing relations between phonological processing abilities and word level reading as children develop from beginning to skilled readers: A 5-year longitudinal study. *Developmental Psychology, 33*(3), 468-479.

Walton, D., & Brooks, P. (1995). The Spoonerism test. *Educational and Child Psychology, 12*(1), 50-52.

Wechsler, D. (1991). *Wechsler intelligence scale for children* (third ed.). San Antonio: The Psychological Corporation.

Willis, C. S., & Gathercole, S. E. (2001). Phonological short-term memory contributions to sentence processing in young children. *Memory, 9*(4-6), 349–363.

Wimmer, H. (1993). Characteristics of developmental dyslexia in a regular writing system. *Applied Psycholinguistics, 14*(1), 1-33.

Wimmer, H., Landerl, K., & Schneider, W. (1994). The role of rhyme awareness in learning to read a regular orthography. *British Journal of Developmental Psychology, 12*(4), 469-484.

Windfuhr, K. L., & Snowling, M. J. (2001). The relationship between paired associate learning and phonological skills in normally developing readers. *Experimental Child Psychology, 80*(2), 160–173.

Woodcock, R. W., McGrew, K. S., & Mather, N. (2001). *Woodcock-Johnson III tests of cognitive abilities*. Itasca, IL7: Riverside Publishing.

Ziegler, J. C., & Goswami, U. (2005). Reading acquisition, developmental dyslexia, and skilled reading across languages: A psycholinguistic grain size theory. *Psychological Bulletin, 131*(1), 3-29.

Ziegler, J. C., Jacobs, A. M., & Stone, G. O. (1996). Statistical analysis of the bidirectional inconsistency of spelling and sound in French. *Behavior Research Methods Instruments and Computers, 28*(4), 504-515.