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Generalizing solutions across functionally similar problems correlates with world knowledge and working memory in 2.5- to 4.5-year-olds

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ABSTRACT

Analogical transfer, denoting the ability to use an action that solved a given problem in order to successfully handle a seemingly different but functionally similar problem, requires well-developed self-regulation, as it draws on previous knowledge and demands selecting and shifting between relevant features while ignoring irrelevant ones. Thus, analogical transfer involves executive functions (EFs), yet the contribution of specific EFs is unclear, particularly during the development of the capacity before the age of 5. Here, for the first time, we investigated the contribution of world knowledge, working memory and set-shifting in 2.5- to 4.5-year-olds' ($N = 86$) capacity for single-event analogical transfer in a simple, non-verbal, tool-use task. Analogical transfer was independent of age but was predicted by a measure of world knowledge and a measure of working memory across the age-span tested. Our results suggest that world knowledge and working memory underscore analogical transfer early in development.

1. Introduction

We live in rapidly changing environments that demand swift and accurate responses to unfamiliar problems. This requires well-developed analogical transfer, a cognitive skill of applying previously acquired knowledge to a present situation that shares the same relational structure but involves dissimilar components (Brown et al., 1989; Crisafi & Brown, 1986; Gentner, 1988; Goswami, 1991; Goswami & Brown, 1989). Despite multiple studies examining the development of analogical transfer, how this skill is related, early in development, to other capacities such as cognitive and temperamental components of self-regulation, remains understudied. Investigating how individual differences in knowledge base and self-regulation are related to analogical transfer in toddlerhood may not only further the current understanding of the development of analogical reasoning but also facilitate the support of very young children in developing this core ability. Therefore, the present study focuses, for the first time, on clarifying the contribution of knowledge base and cognitive aspects of self-regulation to analogical transfer during toddlerhood and early preschool years.

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2. Analogical transfer in toddlerhood

Analogical transfer is critical to functioning in everyday environments (Bobrowicz, 2019; Speed, 2010) because it allows generalizing from one situation to other, perceptually dissimilar situations sharing a common relational structure (Gentner, 1988; Gentner & Smith, 2013; Holyoak, 2012), and, therefore, requiring a similar solution. Such generalization is typically preceded by exposure to two parallel situations, a source and a target. Although the source and the target situations are dissimilar, they comprise similar relations that need to be identified and mapped across the source and the target to facilitate transfer of the common solution (Chen, 1996; Gentner & Smith, 2013; Holyoak, 2012). The development of the ability to map matching relational structures across perceptually dissimilar situations is pivotal for human cognitive development (Halford & Wilson, 1980; Holyoak, 2012).

As analogical transfer builds upon attending to functional similarity across objects, it requires knowledge of object functions (Goswami, 1991; Goswami & Brown, 1990), rapidly acquired in the first year of life (Luo et al., 2009; Madole et al., 1993). Although even 12-month-olds can attend to functional rather than overall perceptual similarity across familiar and unfamiliar objects (Träuble & Pauen, 2007), the ability to prioritize the objects' function over their salient perceptual similarity develops later, after the 2nd year of life (Baker & Keen, 2007; Imai et al., 2005; Pauen & Bechtel-Kuehne, 2016); but see (Chen, 1996).

Synchronous to selectively attending to object function, analogical transfer develops substantially between the second and the fifth year of life, as the children's knowledge base develops (Brown et al., 1989; Chen, 1996; Crisafi & Brown, 1986; Goswami, 1991). While 2-year-olds fail to transfer spontaneously across problems (Crisafi & Brown, 1986), most 3-year-olds are capable of such transfer but may require repeated exposure to a given source problem before they can transfer its solution onto another, perceptually dissimilar problem (Brown et al., 1989). By age of 4- to 5-years, children appear proficient on analogical transfer tasks and solve them spontaneously after short exposures to the source problem (Brown et al., 1989; Crisafi & Brown, 1986).

In everyday life, analogical transfer usually requires knowledge acquired in temporally remote contexts and retrieved from long-term memory (Gentner & Smith, 2013; Gick & Holyoak, 1980; Gick & Holyoak, 1983; Holyoak, 2012). Between the ages of 3 and 5 years, such retrieval becomes more robust to prolonged retention intervals (Scarf et al., 2013) and allows richer, more detailed recollection of past events (Hayne et al., 2011). Thus, children may become more proficient at analogical transfer between delayed contexts at these ages.

3. Analogical transfer, world knowledge and executive functions

Since analogical transfer draws on knowledge about relevant relations between components of the source and the target, knowledge base underpins analogical performance, both in children (Gentner & Smith, 2013; Goswami, 1992; Goswami, 2001; Goswami & Brown, 1989) and adults (Gick & Holyoak, 1980; Gick & Holyoak, 1983; Richland & McDonough, 2010). While analogical reasoning can be said to be an essential tool for solving unfamiliar problems, solving unfamiliar problems cannot be reduced to analogical reasoning and world knowledge.

Accumulation of world knowledge may partially explain age-related increases in child's analogical performance, but these increases may also depend on improvement of child's executive functions (Richland et al., 2006; Thibaut & French, 2016), since several potentially applicable experiences must be sorted, selected and prioritized before issuing a response. Executive functions (EFs) are the top-down cognitive processes that exert cognitive control over information processing, from acquiring the information to issuing a behavioral response (Glady et al., 2017; Miller & Cohen, 2001; Thibaut & French, 2016). The process of selecting the most relevant piece of information to apply to a current problem can be construed as comprising three components: (1) suppressing irrelevant information; (2) holding and operating on the relevant information; and (3) switching between relevant bits of information to identify the most relevant for solving the problem. These three components refer to the core EFs of inhibition, working memory and shifting (Diamond, 2012; Miyake et al., 2000), and are thus in the focus in the present paper.

Executive inhibition supports overriding attention to salient perceptual similarities in favor of functional ones (Simms et al., 2018), disregarding salient but irrelevant associations (Thibaut & French, 2016; Thibaut et al., 2010) and acting on features of the problem that are relevant for its solution. Thus, executive inhibition facilitates efficient holding and operating on the relevant information, carried out by working memory (Diamond, 2012; Smith & Jonides, 1999). Shifting (or cognitive flexibility) allows sifting through information bits before acting upon the most relevant ones (Megalakaki, 2016).

EFs develop during the 2nd year of life and beyond, supporting more voluntary deploying of attention, switching between different sources of information and planning actions with increasing efficiency (Anderson, 1998; Chevalier et al., 2012; Rothbart et al., 2007). As all these skills are prerequisite for everyday problem solving, the development of EFs may play an important role in the development of analogical transfer (Bridgett et al., 2013; Zhou et al., 2012). For the age span investigated in the current study, inhibition, working memory and shifting frequently form a unitary cluster, and emerge as separate components only later in development (Carlson et al., 2013; Lensing & Elsner, 2018). Although all three core EFs are potentially implicated in analogical transfer, a recent study with 5- to 11-year-olds showed that individual differences in working memory predicted performance on an analogical reasoning task, while inhibition and shifting did not (scene analogy; (Simms et al., 2018).

4. Aims and hypotheses

The present study aimed at clarifying the contribution of world knowledge and cognitive aspects of self-regulation to single-event analogical transfer during toddlerhood and early preschool years. We investigated the development of analogical transfer and its relation to world knowledge, working memory and set-shifting in 2.5- to 4.5-year-old children. Our hypotheses were that:

(H1) Age will predict children's performance on analogical transfer task, in line with Simms and colleagues' (2018) study with 5-to-11-year-olds. Furthermore, younger children will be more likely to solve the analogical transfer task after a short (5-min) delay than after a long (24-hr) delay.

(H2) The increased likelihood of older children, compared to younger children, to succeed in the analogical transfer task will correlate with world knowledge and executive functions. Analogical reasoning is closely tied to knowledge base in children and adults, and working memory (Simms et al., 2018) and shifting (Megalakaki, 2016) in children.

5. Materials and methods

5.1. Participants

In total, 110 children were recruited from eleven public preschools in urban and semi-urban areas of southern Sweden. All children completed the analogical transfer task and several behavioral tests of executive functions. EFs were also estimated by parental report on Attentional Focusing and Inhibitory Control subscales of the Early Child Behavior Questionnaire (ECBQ; Putnam et al., 2006) and the Children's Behavior Questionnaire (CBQ; Putnam et al., 2006). Given the disparity in measurement type between behavioural tests included in this paper and the parental self-report questionnaires, the latter were excluded from the analysis. This data will be addressed in a separate publication and may also be made available upon reasonable request directed to the corresponding author.

Children 30–55 months of age were included ($M = 41.51$ months; $SD = 6.46$). Parental education was high, with 88.6% having a college or university degree. Data from 86 children (49 boys/37 girls; 30–55, $M = 41.37$, $SD = 6.31$ months) were included, while data from 24 children were excluded because of missing or distorted video recordings ($n = 9$), missing the second day of testing ($n = 3$), or not receiving any training in an analogical transfer task ($n = 12$). The sample size that would secure sufficient statistical power ($\beta = 0.8$) and strong effect size ($f^2 \geq 0.35$) was calculated in R (custom-built code; lme4 package; Bates et al., 2015). Based on this calculation, a sample of 86 children was deemed sufficient to avoid type II error in the statistical analysis.

5.2. Materials

Knowledge: Two subtests from the Swedish version of Wechsler Preschool and Primary Scale of Intelligence Test (WPPSI-IV, (Wechsler, 2014) were administered, as a proxy of the child's world knowledge: Information and Word Recognition.

Information measures the child's ability to acquire, remember and retrieve information. Children younger than three years had four pictures to select from when answering questions, such as "Which can be eaten?", before proceeding to twenty questions about themselves and the world. The child received a point for each correct answer and could accumulate a total of 29 points.

Word Recognition measures language comprehension, vocabulary, and the ability to follow verbal instructions and to identify items relevant for such instructions. Children were asked to point at the picture corresponding to a word among four pictures. Self-correction was possible. The child received a point for each correct answer and could accumulate a total of 31 points.

Core Executive Functions: We used non-verbal tests of working memory and shifting. Four behavioural tasks were administered, three to measure visuospatial working memory relevant for the transfer task and one to measure shifting.

Corsi Block Tapping Task: This task was developed to measure working memory capacity in a visuospatial setting (Farrell Pagulayan et al., 2006; Gade et al., 2017). In the task, the child is asked to reproduce the order in which the experimenter had tapped a number of identical items right beforehand (Farrell Pagulayan et al., 2006). The task consisted of a 9-item tray, allowing the manipulation of the difficulty level across trials. The child first received a practice trial, and thereafter testing began with taps on two items and increased gradually to nine taps. Each numerosity was repeated twice, and testing was interrupted after two incorrect responses on the same number. The highest number of items tapped in the correct order was recorded as the child's score (max. 9).

Find the Toy: This task was developed to measure working memory in a visuospatial setting (Bernier et al., 2010; Pauen & Bechtel-Kuehne, 2016), but only requires information about the location of a hidden item, not manipulation of this information, so it may be targeting short term and not working memory (Diamond, 2012). In the task, the child is asked to retrieve an item hidden by the experimenter in one of three, six, or nine locations (Pauen & Bechtel-Kuehne, 2016). The retrieval is allowed after 3, 5, or 8 s (compared to 5 or 8 s in (Pauen & Bechtel-Kuehne, 2016). After a practice trial with three (children younger than or 36 months) or six items (children older than 36 months), twelve test trials followed, with increasing numbers of locations and delay duration. Children 36 months or younger were tested on 3–6 locations, as in Pauen and Bechtel-Kuehne (Pauen & Bechtel-Kuehne, 2016), and children older than 36 months were tested on 6–9 locations. Testing was interrupted after three incorrect responses. The sum of all items found over the trials was recorded as the child's score (max. 12).

Find Them All: This task was developed to measure working memory in a similar visuospatial setting as the previous tasks, but requires keeping track of one's own, not the experimenter's, actions (Jayakody et al., 2018). The child is asked to check three to nine locations and retrieve the items hidden there, one at each location. The child is asked to perform searches across a row of locations. The child is allowed to plan and perform searches across a row of locations, and may choose to do it systematically (e.g., from left to right) or not. After a practice trial with three locations, number of locations was gradually increased in test trials. Testing was interrupted after two incorrect responses (missing at least of the locations at the end of the search or returning to an already visited location) on trials with the same number of locations. The largest number of items retrieved within a trial was recorded as the child's score (max. 9).

Head-Toes-Knees-Shoulders: This test was developed to measure child's shifting between perceptual (auditory) and functional (rule) dimensions of verbal instructions (McClelland et al., 2014). It has been suggested that the task provides a measurement of a

combination of inhibitory control, working memory and set-shifting (McClelland et al., 2014). At the beginning of the task, the child was asked to touch their own head or toes, following the experimenter's instruction (McClelland et al., 2014). After four practice trials, the child carried out ten test trials, in which the child was asked to perform an action that was opposite to the experimenter's instruction (e.g., touching their head in response to "toes", and touching toes in response to "head"). Children older than 36 months received an additional set of trials, involving knees/shoulders in addition to head/toes, following the same rules, and thereafter a set of trials with all four body parts (head, toes, knees, and shoulders). In each trial, the child received 2 points upon touching the "correct" body part (as per the opposite rule), and 1 point if the child needed to interrupt reaching for the incorrect body part before touching the correct one (max. 64 points).

Analogical Transfer: A transfer task was used, consisting of a source apparatus and a target apparatus that looked different but shared the same relational structure and so required a similar solution (Bobrowicz et al., 2020); cf. another, string-pulling task in (Chen et al., 1997). The target apparatus required mapping the relation between a given tool and functionally similar components of the source apparatus and employing the same motor action. Therefore, the target apparatus was of low surface similarity, but high structural and high procedural similarity to the source apparatus (cf. Chen, 1996).

Each task was presented as a puzzle box accompanied by three tools. The puzzle boxes were made of MDF, had a transparent plexiglass surface to allow peeking inside, and were covered with non-toxic paint to make the boxes seem "dirty". This was supposed to encourage the children to use the tools instead of bare hands when interacting with the puzzle boxes. The experimenter always wore gloves or used a paper towel to handle the boxes in order to reinforce their "dirtiness". Among the three tools, made of white FIMO clay, only one tool was functional. This tool had a functional element on both ends, which paired with a correct motor action on the child's part and applied to relevant components of the puzzle box, allowed for opening it. The other tools did not allow opening the box: (1) the first, "non-functional" tool had the same length and rigidity as the functional tool but lacked the functional ends; (2) the second, "useless" tool had a different length, shape and rigidity than the functional tool.

Seven sets of tasks were available in total (Fig. 1). Within each set, the source apparatus and the target apparatus required the same tool and the same motor action. Each child was tested with a set in which he/she was not able to solve the test task at baseline. Therefore, each child completed only one set of apparatuses.

5.3. Procedure

Children were tested individually at preschools after active, informed consent from their caregivers. Test leaders spent a day in each preschool to get acquainted with the children. Testing was carried out on two consecutive days, lasting 15–20 min per day. On the first day, children completed Word Recognition, Information, Find the Toy and Head-Shoulders-Knees-Toes, and, on the second day, Corsi Block Tapping and Find Them All. Only children interested in the tasks were tested, in a room arranged for the purposes of testing. All children received a small reward (a toy) at the end of testing.

The analogical transfer task comprised three phases: baseline, training and test. Baseline always commenced right after Word Recognition and Information. At baseline, the child received a single opportunity to interact with the target apparatus, from picking up a tool, through using it on the apparatus, to abandoning the tool, to ensure that he/she could not solve the apparatus spontaneously. All three tools were available. The child received the following instruction: "We will now do something with these three tools. Look at this box. Oh, it is dirty! Is it dirty? (pause) How lucky that we do not need to touch it, right? (pause) Look, there is a bee stuck there in the box! Do you think that you can help the bee to get out? We do not touch the box with our hands, but here are some tools that you can use to help the bee!". If the child chose the functional tool, used it in a correct way and opened the box, a target apparatus from another set was presented. Otherwise, the child heard "We will help this bee later, okay? Let us help another one first!", and immediately proceeded to training on the source apparatus from the same set. Delay between the training and the test was manipulated, as the child either received the test 5 min (short delay) or 24 h (long delay) after training on the source.

During training, two tools were available: functional and useless. Now, the child learned, with the help of the experimenter, how to use the functional tool to open the puzzle box. The child received the following instruction: "Let us help another bee now! This box is dirty, too, right? (pause) We do not touch it with hands. But we have to the bee somehow, so we can use this tool here to do so. Do you want to try first? (pause) This is fine, we can try together! Look, we can take this tool and use it like this to open the box and release the bee". Training was completed upon opening the box thrice without help. Right after training, all children proceeded to Find the Toy. Thereafter, children in the short-delay group received the test, followed by Head-Shoulders-Knees-Toes. Children in the long-delay group received only Head-Shoulders-Knees-Toes before completing Day 1 and attempted solving the test at the beginning of Day 2.

The target apparatus involved all three tools. The child received the following instruction: "Time to help the first bee! (short delay) / Do you remember this bee that we tried to help yesterday? (long delay) (pause) Now we will use these tools and we will not touch the box. Do you want to try? Here you go!". Children received three opportunities to interact with the task, from picking up a tool, through using it on the apparatus, to abandoning the tool. Independently of whether they solved the target apparatus, all children received stickers and age-appropriate toys as tokens of appreciation for their participation. All trials were video-recorded, capturing the experimental setup and the participant's hands.

Minimal overlap in the instruction was ensured when developing the test protocol. To prevent visual 1:1 overlap within the tool set in the training and in the test, an additional tool, which had not been shown in the source task, was introduced alongside the target task. Notably, the language demands of the instruction were considerably limited, compared to other analogical transfer experiments (e.g., entire stories used in (Brown et al., 1989); verbal a:b::c:d analogies in (Goswami & Brown, 1989)). The similarity of the instruction was also limited compared, e.g., to the a:b::c:d task, where the experimenter keeps asking the child "a is related to b as c is related to what?". Finally, the procedure involved single measurement of analogical performance because learning from single events is a

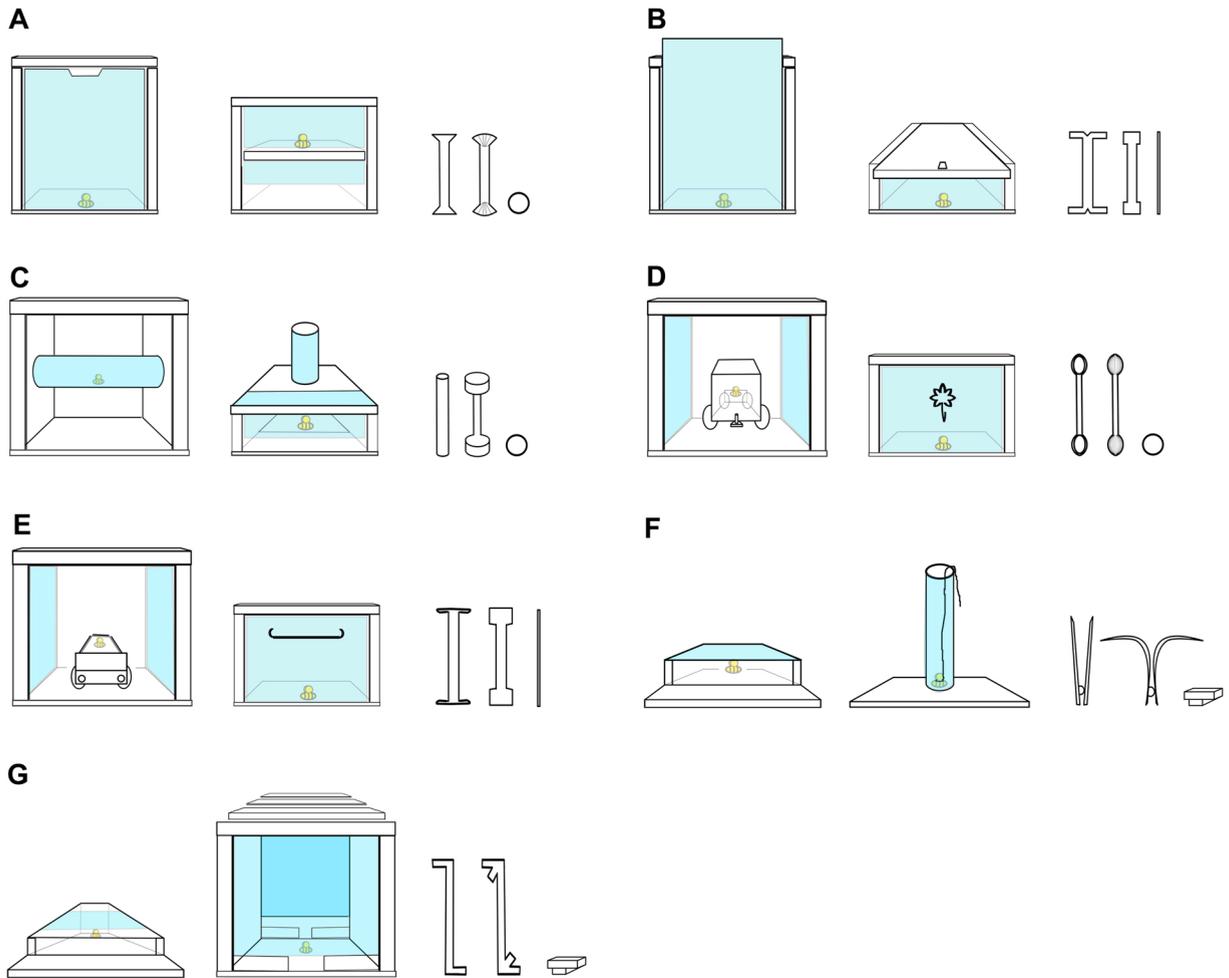


Fig. 1. An overview of all sets of apparatuses and tools used in the study. Each child completed only one set of apparatuses (one among the A-G sets). Within each set of apparatuses, the source apparatus is depicted to the left and the target apparatus to the right. Among the three tools represented alongside each set, the left one was “functional”, the middle one was “nonfunctional”, and the right one was “useless”. Simple motor actions were required to open each box: (A) inserting the tip of the tool into a gap and lifting the tool’s handle; (B) hooking the tip of the tool and pulling the tool’s handle; (C) inserting the tip and pushing the tool’s handle; (D) casting the loop-like tip and pulling the tool’s handle; (E) casting the rake-like tip and pulling the tool’s handle; (F) inserting the tips of the tweezers-like tool and pulling it; (G) inserting the tip of the hockey-bat-like tool, and raking.

hallmark of analogical transfer (Gick & Holyoak, 1980, 1983), and, further, testing the child on several pairs of apparatuses would increase the likelihood of transfer across the sets, confounding transfer within the set.

5.4. Coding and statistical analysis

Trials of Corsi Block Tapping and Find Them All were video recorded, capturing the experimental setup and the participant’s hands. Results of the other trials were recorded in a paper-and-pencil manner by the experimenter in real time.

5.4.1. Variables

Nine variables were used in the analysis. All variables were continuous. The variables comprised scores on Word Recognition, Information, Corsi Block Tapping, Find the Toy, Find Them All, Head-Shoulders-Knees-Toes, Age in months, Preschool, Delay between baseline and test, as well as binary Outcome of the analogical transfer task.

5.4.2. Statistics

All analyses were conducted in R (v.3.5.1, the R Foundation for Statistical Computing; <http://www.R-project.org>; see Appendix 1). Significance level was set at 0.05. Missing data was little, and completely random (MCAR, analyzed with “missing pairs” and “missing compare” functions from finalfit package; Word Recognition: 0%, Information: 0%, Corsi Block Tapping: 2.32%, Find the Toy: 0%,

Find Them All: 13.95%, Head-Shoulders-Knees-Toes: 9.3%). Before the analysis, the dataset was imputed (mice package, van Buuren and Groothuis-Oudshoorn, 2011) with multiple imputations for multivariate missing data. The number of multiple imputations was set at 25, and the number of imputations at 40. Parallel analysis and scree plots were computed before the number of factors in EFA was determined (“fa.parallel” function in psych package; Revelle, 2013).

To address H1, a generalized linear model was fitted (“glm” in lme4 package; Bates et al., 2015) with Outcome in the analogical transfer test as a response (0 if all three attempts at solution failed; 1 if any attempt led to a solution) and Age in months and Delay as a predictor. “Binomial” family was used.

To address H2, Exploratory Factor Analysis (EFA) using “fa.diagram” function in psych package (Revelle, 2013) was carried out. Based on this analysis, Confirmatory Factor Analysis (CFA) was performed with the Lavaan package (Rosseel, 2012). Latent factors were thereafter extracted and served as response variables in general linear models with Age (months) as a predictor. “Gamma” family was used for Factor 1, and “gaussian” family was used for Factor 2. Thereafter, a generalized linear model was computed to estimate the main effect of each Factor on the Outcome of the analogical transfer test, controlling for Age in months, Preschool and Delay. Thereafter, to determine which tasks explained a statistically significant amount of variance in the Outcome of the analogical transfer test, sequential nested regression models were built and compared with anova function for comparisons of nested models from “lmtest” package in R (“Chisq” family; Zeileis & Hothorn, 2002), controlling for Age in months, Preschool and Delay. Finally, the main effect of each measure was estimated on the Outcome of the analogical transfer test, again controlling for Age in months, Preschool and Delay.

6. Results

6.1. Descriptive statistics

For an overview of descriptive statistics on all variables except for outcome of the analogical transfer task see Table 1. Among children who received training (experimental group, $n = 86$), 45.35% ($n = 39$) solved the test. Among children who solved the target apparatus, 59% ($n = 23$) solved it after the short delay. Among children who received short delay, 50% ($n = 46$) solved the test, and among children who received long delay, 40% ($n = 16$) solved the test.

6.2. (H1) The effect of Age on Analogical Transfer

A generalized linear model was fitted to determine the effect of Age (in months) and Delay on Outcome of the test. The likelihood of solving the test did not vary with Age, $\chi^2(1) = 0.093$, $p = 0.761$, or Delay, $\chi^2(1) = 0.643$, $p = 0.423$.

6.3. (H2) The role of world knowledge and EFs for Analogical Transfer

Structure of EFs. Correlation Matrix showed that several correlation coefficients exceeded 0.3 (Table 2). The KMO (overall: 0.78; Word Recognition: 0.73; Information: 0.72; CB: 0.85; FTT: 0.83; FTA: 0.88; HTKS: 0.84) and Bartlett’s Test of Sphericity indicated that the set of variables was adequately related for factor analysis, $\chi^2(15) = 124.13$, $p < 0.001$.

Table 1

Descriptive Statistics of Measures Used in the Current Study $N = 86$ (30–36: 22, 37–43: 29, 44–49: 28; 50–55: 7).

Measure	Age group	Lowest score	Highest score	Mean	SD
Word Recognition	30 – 36	0	24	13.09	5.8
	37 – 43	1	26	14.93	6.45
	44–49	8	29	18.89	4.37
	50 – 55	10	27	19.86	5.46
Information	30 – 36	3	16	8.72	4.37
	37 – 43	4	17	11.66	4.2
	44–49	7	21	14.96	3.05
Corsi Block Tapping	50 – 55	11	19	16.14	2.79
	30 – 36	0	3	1.47	1.02
	37 – 43	0	4	1.54	1.43
Find the Toy	44–49	0	5	2.56	1.67
	50 – 55	0	7	3.29	2.43
	30 – 36	0	12	6.73	3.41
	37 – 43	1	11	5.35	2.58
Find Them All	44–49	0	11	5.96	3.23
	50 – 55	0	12	7	4.65
	30 – 36	4	9	7.5	1.61
	37 – 43	4	9	7.875	1.7
Head-Shoulders-Knees-Toes	44–49	6	9	8.74	0.69
	50 – 55	8	9	8.57	0.53
	30 – 36	0	20	1.26	5
	37 – 43	0	46	10.36	15.3
	44–49	0	51	17.33	17.03
	50 – 55	0	22	10.86	8.71

Table 2
Correlations among world knowledge and self-regulation measures (zero-order). N = 86.

	INFO	CB	FTT	FTA	HTKS
WR	0.7 ^a	0.48 ^a	0.16	0.32 ^b	0.34 ^c
INFO		0.52 ^a	0.16	0.34 ^c	0.4 ^a
CB			0.15	0.32 ^a	0.42 ^a
FTT				0.19	0.06
FTA					0.26 ^b

Note: WR = Word Recognition and INFO = Information (both WPPSI). CB = Corsi Block Taping. FTT = Find the Toy. FTA = Find Them All. HTKS = Head-Shoulders-Knees-Toes.

^a p < 0.001;

^b p < 0.05;

^c p < 0.01.

Examination of scree plots revealed that either a one- or a two-factor model could be a good fit for the data. Thereafter, two EFAs were run, testing the two-factor and one-factor models, respectively, for appropriateness for the sample. The two-factor model was selected as more appropriate, as it explained 39.2% of variance (one-factor: 37%), with lower RMSR (0.02, compared to 0.04 for one-factor), lower BIC (-16.82, compared to -32.83 for one-factor) and higher TLI (1.106, compared to 1.027 for one-factor; for full outputs see Appendix 1). Factor 1 comprised two items and explained 20.4% of the variance. Factor 2 comprised of two items and explained 18.8% of the variance (see Table 3). Furthermore, Factor 1 correlated with Factor 2 (0.7). Find the Toy did not load on any of these Factors.

CFA, using a Structured Equation Model, revealed an acceptable fit for the model, with a TLI of 1.076 and RMSEA of 0%CI (0, 0) (see Fig. 2). All indicators showed positive factor loadings (see Table 4). The CFA model confirmed a significant positive correlation between Factor 1 (Knowledge) and Factor 2 (Executive Functions, $r = .803, p < 0.001$).

6.4. The effect of Age on measures of Knowledge and Executive Functions

Two general linear models were fitted to determine the effect of Age in months on Knowledge and Executive Functions, and both factors correlated with Age (Knowledge: $\beta = 0.042, SE = 0.007, t = 6.502, p < 0.001$; EFs: $\beta = 0.084, SE = 0.012, t = 7.009, p < 0.001$).

Table 3
Exploratory Factor Analysis. N = 86.

Measure	Factor	
	1	2
Word Recognition	0.939	
Information	0.555	
Find The Toy		
Corsi Block Tapping		0.608
Find Them All		0.671
Head-Shoulders-Knees-Toes		0.453

Note. OLS extraction method and oblique rotation was used. Cut off was set at 0.4. Values < 0.4 were removed from the table. The root mean square of residuals (RMSR) = 0.02. Tucker Lewis Index of factoring reliability = 1.106. RMSEA index = 0.

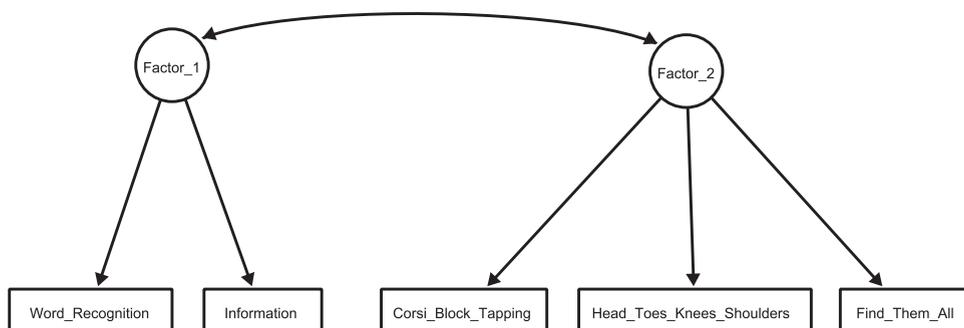


Fig. 2. Confirmatory Factor Analysis model of Knowledge (Factor 1) and Executive Functions (Factor 2).

Table 4
Factor Loadings in the Structured Equation Model.

Latent factor	Indicators	Estimate	SE	z	p	Beta
Factor 1 (Knowledge)	Word Recognition	3.814	0.438	8.706	0	0.879
	Information	4.813	0.616	7.820	0	0.799
Factor 2 (Executive Functions)	CB	1.209	0.191	6.335	0	0.726
	FTA	0.689	0.157	4.396	0	0.514
	Head-Toes-Knees-Shoulders	0.762	0.166	4.58	0	0.533

6.5. The effect of Knowledge and Executive Functions on Analogical Transfer

A generalized linear nested model was fitted, with Knowledge and Executive Functions, controlling for Age in months, Preschool and Delay. The likelihood of solving the test significantly increased with Knowledge, $\beta = 1.237$, $SE = 0.589$, $z = 2.099$, $p = 0.036$, and non-significantly with Executive Functions, $\beta = -1.12$, $SE = 0.614$, $z = -1.822$, $p = 0.069$.

6.6. The effect of Word Recognition and Corsi Block Tapping on Analogical Transfer

In order to determine the tasks that specifically explained a statistically significant amount of variance in analogical transfer, a sequence of models was built. Model 1 contained no predictors. Age in months, Preschool and Delay were predictors in model 2, while each of the individual task variables were added sequentially to the next models (model 3: + Word Recognition, model 4: + Information, model 5: + CB, model 6: + HTKS, model 7: + FTA). Hierarchical regression showed that Word Recognition (model 3; $SS\ Residual = 112.95$, $SS\ Difference = 5.523$, $p = 0.019$), and thereafter Corsi Block Tapping (model 5; $SS\ Residual = 103.24$, $SS\ Difference = 7.644$, $p < 0.001$) significantly improved the model. By adding Word Recognition, R^2 increased by 0.05 ($f^2 = 0.053$), and by adding Corsi Block Tapping, R^2 increased further by 0.065 ($f^2 = 0.07$).

Finally, a generalized linear model was run to pinpoint whether Word Recognition and Corsi Block Tapping correlated with analogical transfer, controlling for Age in months and Preschool. The likelihood of solving the test increased with score on Word Recognition, $\beta = 0.166$, $SE = 0.052$, $z = 3.185$, $p = 0.001$, a measure of world knowledge, and score on Corsi Block Tapping, $\beta = -0.496$, $SE = 0.174$, $z = -2.845$, $p = 0.004$, a measure of working memory. Effect size of the model equaled 0.148 (f^2 , moderate effect size).

7. Discussion

The present research addressed the predictive value of world knowledge, executive functions (EFs), age and delay for analogical transfer in 2.5- to 4.5-year-olds. For the first time, we assessed whether single-event analogical transfer in such young children depended on world knowledge and cognitive aspects of self-regulation. Analogical transfer depended on Word Recognition, a measure of world knowledge from the WPPSI-IV battery, and Corsi Block Tapping, a measure of visuospatial working memory. Interestingly, children were equally likely to succeed in the analogical transfer task regardless of age and delay between the source and the target problem. None of the other behavioral measures of world knowledge, working memory and shifting were linked to analogical transfer.

7.1. Age did not correlate with single-event analogical transfer in 2.5- to 4.5-year-olds

Success rates among 2.5- to 4.5-year-olds were similar, suggesting that the child's age was not a relevant predictor of single-event analogical transfer in toddlerhood and early preschool, and on the task used in the current study. Previously, [Simms and colleagues \(2018\)](#) found that age predicted success rates on an analogical mapping task, but their participant group comprised children 5- to 11-year-old, representing a much wider age-range. In addition, their analogical transfer task required operating on up to two competing distractors and up to two relations between objects. Although the task in the present study likewise required inhibiting irrelevant features of the source and the target problems, it was arguably simpler, requiring only one relation: between the functional tool and a functionally relevant part of the problem.

Although child age was not predictive of analogical transfer in the current study, both world knowledge and executive functions (working memory and shifting) were significantly stronger among the older children. As there are large individual differences in developmental trajectories, age per se may not be an optimal statistical proxy for developmental capacity when specific capacities are also available.

7.2. Working memory, shifting and world knowledge

Although working memory, inhibition and shifting emerge later in development as separate components, they frequently form a unitary cluster in toddlerhood ([Carlson et al., 2013](#); [Lensing & Elsner, 2018](#)). In line with previous studies, working memory and shifting indeed loaded on a single factor in the current study. Interestingly, in line with Simms and colleagues' study (2018), working memory predicted analogical transfer in 2.5- to 4.5-year-olds while shifting did not. Among working memory measures, only Corsi Block Tapping was a significant predictor of analogical transfer in our study. Find Them All, although loading on the same factor as

Corsi Block Tapping and Heads-Shoulders-Knees-Toes and, in theory, measuring working memory, did not predict analogical transfer. Find Them All may have been a poor measure of working memory because, contrary to Corsi Block Tapping, it allowed the child to resort to simpler solutions than relying on working memory (e.g., uncovering boxes in a fixed order, from left to right). To our surprise, Find The Toy, a task that supposedly measures working memory (Bernier et al., 2010; Pauen & Bechtel-Kuehne, 2016), did not load on the same factor as other working memory measures. We conclude that this task may in fact not measure working memory, but rather short-term memory, as it only requires holding information in mind, not working with it. Indeed, working and short-term memory tasks often load on separate factors in children, adolescents and adults (Alloway et al., 2004; Diamond, 2012).

Scores on WPPSI-IV subscales Word Recognition and Information loaded on another factor, but only Word Recognition was predictive of success on our analogical transfer task. Scores on both Word Recognition and Information could be relevant for analogical transfer because analogical transfer builds on a well-developed knowledge base (Vosniadou, 1989). It is, therefore, somewhat surprising that scores on Information were not predictive of success on our analogical transfer task. Information demands better verbal comprehension as it requires answering a series of full-sentence questions, contrary to Word Recognition that demands pointing to a correct picture, representing a given word. Higher verbal demands of Information, compared to Word Recognition, might have limited its predictive value for analogical performance in the current study.

That analogical transfer depends on knowledge and working memory is not surprising. The impact of child's knowledge on child's capacity for holding and manipulating of such pieces is twofold. First, applicable representations are not available unless they belong to the child's knowledge (Goswami, 1991), and second, the information cannot be held and manipulated efficiently if the child does not have access to previously acquired strategies of doing so. Such strategies allow for automatizing some components of cognitive processing and releasing cognitive resources, thereby supporting analogical transfer (Megalakaki, 2016). Even if our task tapped rather into perceptual than verbal analogical reasoning, these two domains of analogical reasoning were previously found to correlate with one another in 5- to 7-year-olds, suggesting that even essentially non-verbal tasks may tap into cognitive resources shared by perceptual and verbal analogical reasoning (Nippold & Sullivan, 1987).

In the current setup, shifting, as measured by Head-Toes-Knees-Shoulders, did not correlate with analogical performance. This result may be partly explained by high task difficulty for several children. However, if children as young as 2.5 could achieve analogical performance comparable to older children, shifting, shown to improve between 3 and 4.5 (Chevalier et al., 2012; Jacques & Zelazo, 2001), may not be prerequisite for the setup used in this study.

7.3. Analogical transfer after delays

In the present study, we manipulated the delay between the source and the target problem and, contrary to our predictions, children were equally successful in analogical transfer after a short or a long delay. Perhaps analogical transfer of short-term representations is as effective as of long-term ones, in line with previous studies demonstrating that tasks requiring shorter-term representations involved the same areas of the prefrontal cortex as tasks requiring longer-term memories (Speed, 2010). As the prefrontal cortex is also involved in analogical reasoning (Boroojerdi et al., 2001), perhaps analogical transfer is independent from the representations' age. This would be adaptive, as most everyday problems require generalization from past, not immediately preceding, experiences.

7.4. Limitations

Although the cross-sectional design of the current study allowed for answering research questions posed in the study, it only captured children's level of performance at a single point in time. In order to determine if improvements in analogical performance depend on world knowledge and executive functions, longitudinal designs must be employed. In the future, a longitudinal study, starting at 2.5 years and ending at 4.5 could demonstrate whether the relationships found in this study hold when the same children are followed for 2 years. This, however, would require repeated measurement, e.g., on the analogical transfer task and learning effects could confound the influence of self-regulation development on the development of analogical transfer.

Furthermore, in this study, children in a large age span, ranging from 30 to 55 months, were tested with the same measures of EFs. This facilitated comparing children's scores across age groups, but the behavioral measure of shifting used in the study, namely Head-Toes-Knees-Shoulders, may have been relatively difficult for several children, leading to a floor effect and perhaps masking the influence of shifting on children's analogical performance. In the future, the recently revised version of this task (HTKS-R: Gonzales et al., 2021; McClelland et al., 2021) or other, age-adjusted tasks could be introduced instead (Carlson, 2005).

It must be noted that, as working memory, inhibition and shifting frequently form a unitary cluster in toddlerhood (Carlson et al., 2013; Lensing and Elsner, 2018), all behavioral measures used to test child executive functions in this study engaged, albeit to varying extent, inhibition, working memory and shifting. Therefore, our results must be treated with caution, with awareness that they are related to specific tasks.

8. Conclusions

Analogical transfer plays a pivotal role in development, as it is important for fast and flexible learning from single events, both inside and outside of the schooling system. Supporting the development of analogical transfer may stimulate drawing accurate analogies on more abstract levels and would, therefore, facilitate children's critical thinking. Thus, it may be beneficiary to establish methods of training analogical transfer in early preschool years. Early non-verbal trainings of analogical transfer, based on simple

setups like the one used in the present study, could be applied in preschool settings to boost child's analogical reasoning skills. Finally, because our analogical transfer task has minimum language demands, materials and findings from the present study may be relevant for populations with speech and/or hearing impediments.

Ethics approval and consent to participate

This research was approved by Swedish Ethical Review Authority in Lund (DRN 2018/572, PI Psouni). No sensitive data about participants were gathered, and only those children, whose parents submitted a written consent, either on paper or digitally, were included in the study.

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CRedit authorship contribution statement

Katarzyna Bobrowicz: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Visualization, Funding acquisition; **Johan Sahlström:** Methodology, Investigation, Data curation; **Klara Thorstensson:** Methodology, Investigation, Data curation. **Brigitta Nagy:** Methodology, Investigation, Data curation. **Elia Psouni:** Conceptualization, Methodology, Writing – original draft, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Declaration of Competing Interest

We have no known conflict of interest to disclose.

Data Availability

All relevant data are within the manuscript and its Online Supplemental Material.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.cogdev.2022.101181](https://doi.org/10.1016/j.cogdev.2022.101181).

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