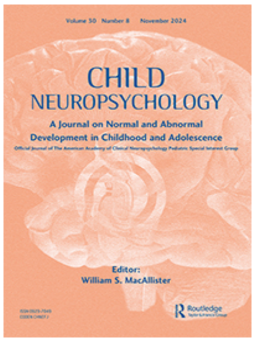

Routledge
Taylor & Francis Group

Child Neuropsychology

A Journal on Normal and Abnormal Development in Childhood and Adolescence

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/ncny20

How do children with Cerebral Visual Impairment (CVI)-related visual difficulties perform on key academic domains in grade 1?

Sara Monteiro, Pascale Esch, Géraldine Hipp & Sonja Ugen

To cite this article: Sara Monteiro, Pascale Esch, Géraldine Hipp & Sonja Ugen (21 Jan 2025): How do children with Cerebral Visual Impairment (CVI)-related visual difficulties perform on key academic domains in grade 1?, Child Neuropsychology, DOI: 10.1080/09297049.2025.2454450

To link to this article: https://doi.org/10.1080/09297049.2025.2454450

Published online: 21 Jan 2025.

CHILD NEUROPSYCHOLOGY
https://doi.org/10.1080/09297049.2025.2454450

How do children with Cerebral Visual Impairment (CVI)-related visual difficulties perform on key academic domains in grade 1?

Sara Monteiro [a], Pascale Esch [a], Géraldine Hipp [b] and Sonja Ugen [a]

[a]Luxembourg Centre for Educational Testing, University of Luxembourg, Esch-sur-Alzette, Luxembourg; [b]MENJE, Centre pour le Développement des Compétences relatives à la Vue, Bertrange, Luxembourg

ABSTRACT

Previous research estimated a prevalence of 3.4% Cerebral Visual Impairment (CVI)-related visual problems within primary school children, potentially compromising students' performance. This study aimed to clarify how CVI-related visual difficulties relate to academic performance in standardized achievement tests. As part of the Luxembourg school monitoring programme, 1129 first graders (mean age of 7 years) participated in three competence tests (mathematics, early literacy and listening comprehension) and in student and parent questionnaires (background information). The same children took part in a CVI-related visual difficulties screening (Evaluation of Visuo-Attentional abilities battery, optometric and orthoptic measures). The sample was divided post-screening into 38 children with potential CVI-related visual difficulties (18 females, 20 males, mean age 7y, range 6–8y) and 890 typically developing (TD) children (445 females, 430 males, 15 missing, mean age 7y, range 5–10y). Compared to the TD sample children with CVI-related visual difficulties significantly underperformed in early literacy and mathematics, but not in listening comprehension, even when controlling for background characteristics known to influence performance (gender, socio-economic status, migration background, parental education, home language, age). The results confirm the association of CVI-related visual difficulties with learning processes already at primary school level and emphasize the need to implement a systematic screening for CVI-related visual difficulties, as early as possible within the school path, to ensure adequate measures are employed to aid students at risk.

ARTICLE HISTORY
Received 17 April 2024
Accepted 12 January 2025

KEYWORDS
Cerebral Visual Impairment; large-scale screening; early literacy; mathematics; listening comprehension

Advances in medicine were followed by an increase of premature infants' survival rates, often associated with augmented visual processing deficits (E. L. Ortibus et al., 2011). Some of these deficits are linked to Cerebral Visual Impairment (CVI) (E. L. Ortibus et al., 2011; Philip & Dutton, 2014), a "visual dysfunction that cannot be attributed to disorders of the anterior visual pathways or any (. . .) co-occurring ocular impairment" (Sakki et al., 2018). CVI's clinical presentations are vast, and visual processing

CONTACT Sara Monteiro sara.monteiro@uni.lu Luxembourg Centre for Educational Testing, University of Luxembourg, Campus Belval MSH, 11 Porte des Sciences, Esch-sur-Alzette L-4366, Luxembourg

impairments often do not display in cerebral imageology (Fazzi et al., 2009), making diagnosis complex, possibly explaining the lack of agreed diagnostic protocols (McConnell et al., 2021). Diagnosis is typically done inferentially based on behavioral measures, with visual functions' limits assumed to link to cerebral structures' malfunction (Chokron & Dutton, 2023). Additionally, affected children frequently do not report nor are aware of their visual condition, which does not prompt complaints that could trigger subsequent investigation (Chokron et al., 2021; Lueck et al., 2019).

A recent study estimated, that 3.4% of primary school children are affected with CVI related vision problems (Williams et al., 2021). With an estimated prevalence of one child per classroom experiencing CVI-related visual difficulties (Williams et al., 2021), it is urgent to understand how visual vulnerability can impact academic performance. This insight will allow educators and practitioners to accurately identify and address these difficulties at their core (McDowell, 2023). CVI can impact academic achievement as for a child to succeed on scholastic tasks the integrity of different visual processing skills is necessary (Molloy et al., 2017), as shown in the overview by Philip and Dutton (2014). The impact that CVI may have on different visual functions required to academically succeed can be illustrated by Goodale and Milner's (1992; Goodale, 2013) proposal of vision organization in the brain. Their (Goodale, 2013; Goodale & Milner, 1992) dual-stream model is commonly accepted in research as the leading functional proposal of the visual system organization (Fazzi et al., 2009; Goodale, 2013). As opposed to a monolithic organization of vision, this model proposed two different computational pathways in the brain, one being responsible for identification and recognition and the other being responsible for motion and visually controlled action (Goodale & Milner, 1992). The dual-stream model proposal establishes a functional dichotomy between the ventral and dorsal stream projections with the dorsal being responsible for the "where" and "how" (a visual search and guided visual movement-based pathway) and the ventral being responsible for the "what" (a visual recognition-based pathway) in relation to a given visual target (Dutton, 2015; Goodale, 2013; Goodale & Milner, 1992). Dorsal stream impairments typically affect one or multiple visual functions, including visual search, visually guided movement, spatial mapping of the visual world, simultaneous processing of visual information and the capacity to visually apprehend information that is presented in a cluttered way (Barclay, 2015). Overall, dorsal stream level impairments are one of the most prevalent displays in childhood CVI (Chandna et al., 2021; Dutton, 2015; Lam et al., 2010; Merabet et al., 2023). Ventral stream impairments, on the other hand, typically display in impaired visual recognition (including facial and spatial recognition) and difficulties with visual memory (Barclay, 2015; Dutton, 2015). Reading and mathematics are particularly vulnerable to CVI's adverse effects (Williams et al., 2011), given their visual processing load. Specifically, early literacy competences such as decoding, i.e. the ability to make the connection between graphemes and phonemes, and thus establish sound-symbol correspondence, partially relies on intact visual recognition (Barclay, 2015). As a consequence, decoding is prone to be negatively affected by CVI, given that visual recognition is a visual function affected by certain CVI profiles (Barclay, 2015). Visual discrimination and the capacity to discriminate visual elements (e.g. letters) and to intelligibly interpret them when displayed together in a word, is an important early literacy skill which may also pose challenges for children with CVI, particularly children who struggle with the effects of crowding or visual clutter (Barclay, 2015;

McDowell, 2020, 2023; McDowell & Butler, 2023). In lateral homonymous hemianopia, a visual field disorder resulting from CVI, children consistently miss parts of the text on the counter lesioned side (Chokron & Dutton, 2023; Chokron et al., 2010, 2021; Philip & Dutton, 2014). Adults with a similar visual field deficit in a left-to-right reading context displayed reduced reading speed and impaired reading fluency (McDonald et al., 2006). Children with an analogous diagnostic profile display similar deficits (Chokron et al., 2010). Visual agnosia in adults translates in childhood to difficulties to interpret what is seen, often affecting written material, such as letter recognition (Chokron et al., 2010). The inability to recognize letters or words poses challenges (Cavézian et al., 2010), as decoding entails symbol recognition (Barclay, 2015). Visual attention also plays an important role in children's reading ability (Chokron et al., 2010). In this regard, dorsal stream dysfunctions damage the perception of visually loaded scenes as they interfere with global perception (Chokron et al., 2021; Dutton, 2003) which, in some children, affects the capacity to perceive groups of letters and words (Chokron & Dutton, 2023; Chokron et al., 2021; Philip & Dutton, 2014). Additionally, as children progress academically, the font size of written text grows smaller, leading to an increase of text crowding and associated difficulty level of reading tasks (Dutton, 2003; Philip & Dutton, 2014). Hence, children whose CVI profile affects dorsal stream are at risk of developing reading difficulties (Chokron & Dutton, 2023; Valdois, 2022). More concretely, the mastery of early literacy, as defined by the school curriculum, is linked with visual processing (MENFP, 2011a). Specifically, the capacity to build and use different codes of written language is assessed on the basis of different performance indicators including visual discrimination, the capacity to visually recognize and memorize images and the capacity to associate identical images or images that complete each other (MENFP, 2011a). These are all performance indicators that may be affected by visual vulnerabilities resulting from CVI (Barclay, 2015).

Like reading, mathematics is likely to be affected by CVI. Considering that vision is primordial in spatial cognition and that numbers are systematically visualized in space (Cappagli et al., 2022; Hubbard et al., 2005), it can be anticipated that visual difficulties interfering with visuo-spatial processing, as part of CVI profiles, will be detrimental for the performance in mathematics. An explicit example of the interplay between numbers and space is the spatial-numerical association or response codes' (SNARC) effect (Dahaene et al., 1993). The SNARC effect is usually assessed by parity judgment tasks (i.e. a task where subjects must judge if a number is odd or even). Typically, the SNARC effect for Arabic numbers is characterized by faster Reaction Times (RTs) when lower numbers are presented on the left side of space and, inversely, higher numbers tend to be associated with quicker RTs when presented on the right side of space. Thus, the SNARC effect allows to illustrate the association between space and numbers and even occurs in parity judgment tasks with no explicit relation to numerical magnitude (Hubbard et al., 2005). Children with low vision have been reported to present difficulties in locating numbers (Cappagli et al., 2022) or apprehending spatial concepts related to mathematics, such as data interpretation when the data is presented in a diagrammatic way (Barclay, 2015; Hyvärinen et al., 2012). Indeed, the development of visual functions requires specific visual experiences. For example, the capacity to see patterns requires the previous exposure and development of a visual representation of these same patterns (Roman-Lantzy, 2018). Children who are (partially) deprived of visual input have difficulties to mentally represent what they have never fully accessed visually (Roman-Lantzy, 2018). Additionally, many concepts in mathematics involve diagrammatic, pictorial, and graphic content that may be visually unintelligible or hard to access for children with CVI-related difficulties in visuospatial processing (Barclay, 2015). Additionally, visual recognition difficulties (Chokron, 2015a) may also affect numerical and symbolic content. Similarly, difficulties with visual form constancy can affect number recognition, in particular for numbers that are visually similar but reversed, such as 6 and 9 (Barclay, 2015). Since number knowledge is a strong predictor of mathematics performance in later years (Hornung et al., 2014), loss of visual recognition of symbolic and numerical material entails longitudinal costs. Mental imagery difficulties make liaisons between objects and their visual representations challenging. In other words, intact vision plays a crucial role in developing visual representations and, consequently, in categorizing different elements perceived visually (Fazzi et al., 2010). Therefore, children with limited visual experiences, due to visual impairments, are more likely to struggle with tasks that require object or figure identification because they may not have fully developed necessary levels of abstraction and categorization (Chokron et al., 2021). Additionally, individuals with CVI recognize objects less efficiently when they are depicted in an abstract manner (e.g. outlined or in a cartoon) compared to controls. Individuals with CVI seem to be more at ease when these same objects are presented in a way which is visually closer to their original presentation (e.g. closer to their colors and outlines) (Manley et al., 2023).

Dorsal stream impairments also impact mathematics leading to difficulties dealing with visually crowded material (Barclay, 2015). If the symbolic material presented in mathematics is not spaced, children might fail to single out elements or to conceive them separately. Children might equally struggle with complex arithmetic, especially considering its visual multi-step nature (Barclay, 2015).

As oral language precedes the acquisition of early literacy, audition presents a critical sensory modality that allows children with CVI to access school material and didactic content. More specifically, the development of early literacy skills is closely linked to listening skills, such as listening comprehension or phonological awareness (Barclay, 2015). However, the absence of intact visual representations (Fazzi et al., 2010) to pair with sounds, may hinder the development of a comprehensive auditory repertoire in these children. While listening comprehension can indeed support the academic success of children affected by CVI, the same cerebral structures underlying visual impairment may also affect auditory processing (Belote, 2020).

To sum-up, neurocognitive studies show the impact that CVI-related visual difficulties may have on different sub-processes connected to reading, mathematics and potentially listening comprehension. This study aims to explore to what extent CVI-related visual difficulties are associated with mastering precursor skills for key academic competences such as early literacy skills, mathematics and listening comprehension. The study was conducted in a representative cohort of first graders (mean age 7 years), assessed within the Luxembourg school monitoring programme (Fischbach et al., 2014), in a natural classroom setting. Considering previous research regarding the impact of CVI on reading and mathematics, it was hypothesized that children with CVI-related visual difficulties will have lower competences in early literacy (hypothesis 1) and mathematics (hypothesis 2), when compared to Typically Developing (TD) children.

The study refrains from formulating a specific hypothesis for listening comprehension as for this competence the material was presented auditorily, and the answer format was a closed multiple choice based on images, not requiring visual manipulation but sole image identification based on the auditorily presented content. Even though the visual load was lower than for the other two competence domains, it was not inexistent. Listening comprehension outcomes might, therefore, go two-fold: CVI-related visual difficulties might have a relation to performance, as there is some visual processing involved in task completion, or, instead, the heavier load on senses alternative to vision might result in similar group performances. Therefore, this study aims to investigate group differences in performance for listening comprehension.

Materials and methods

Participants

The study's sample included 1129 children ($M = 7$ years; $SD = 4$ months) who were representative of the whole grade 1 cohort in terms of gender and socio-economic status (532 girls, 580 boys). This sample was drawn from the full grade 1 cohort ($N = 5536$) that participated in the Luxembourg school monitoring programme, a standardized nationwide large-scale assessment evaluating whether the precursors to key academic competences were achieved (Fischbach et al., 2014; Martin et al., 2015). The students participated in the school monitoring programme at the very beginning of grade 1, after eight weeks of fundamental education, with the tests taking place during the month of November. The children were assessed in three competence areas: mathematics, early literacy and listening comprehension. In a second step, the same children's neurovisual and visual functions were individually assessed as part of a countrywide screening of CVI-related visual difficulties at school. The individual assessments of CVI-related visual difficulties in school were organized between the months of January and July. To enable the exploration of the relation between having CVI-related visual difficulties and mastery of precursor skills, the school monitoring and the neurovisual screening data were matched through a trusted third party, to comply with data protection regulations. Children's background variables were gathered through a questionnaire filled out by children and their legal guardians as part of the assessment. Ethical approval from the University was not required for this study as the school monitoring programme is legally approved by the national committee for data protection. Furthermore, to adhere to European Data Protection Regulations, the analyses used an anonymized dataset. Children and their legal guardians were informed and given the option to opt-out before data collection. They could also omit questionnaire parts if uneasy or unsure, which explains missing data (Table 1).

Instruments

Competence measures

The early literacy competence test (30 items) targeted the ability to construct and use written language units, including the sub-skills of phonological awareness, visual discrimination, and alphabetic principle's understanding. The mathematics competence test (60 items) covered the domains of numbers and operations, space and shapes and

Table 1. Children's background characteristics: age, gender, SES, migration background, home language, and parental education of TD and CVI children.

		Groups				
		TD		CVI		
Background variable		N	M (SD)	N	M (SD)	*t-test*
Age in months		890	84.204 (5.361)	38	86.042 (4.979)	.038*
SES (HISEI)		739	50.160 (15.813)	30	47.000 (16.110)	.283
		N	%	N	%	χ^2
Gender	Female	445	50.9	18	47.4	.674
	Male	430	49.1	20	52.6	
Migration background	Native	380	50	18	58.1	.379
	Non-native	380	50	13	41.9	
Home language	Luxembourgish/German	511	57.4	24	63.2	.483
	Other	379	42.6	14	36.8	
Parental education	Low	265	35.3	10	37.0	.856
	High	485	64.7	17	63.0	

The *p*-values come from chi-squares of variable independency and two-tailed independent t-tests of mean difference between groups.

dimensions and measures. The listening comprehension test (31 items) assessed the ability to identify and understand information in orally presented materials (e.g. stories) as well as the capacity to build information and activate listening strategies. A teacher administered the test booklets in the classroom. For the early literacy and listening comprehension tests an audio file was provided to the teachers. Each item was displayed on a single page. Detailed instruction and scoring manuals were provided. The scoring was dichotomous, coded as right or wrong. These raw scores were scaled with item response theory models to provide one competence measure scale for each test (Fischbach et al., 2014). The scores were transformed to a scale with $M = 500$ and $SD = 100$.

Neurovisual measure

The neurovisual measure used was the Evaluation of Visuo-attentional Abilities (EVA) battery (Cavézian et al., 2010), a 20-minute behavioral test battery to screen for CVI-related visual difficulties in children aged four to six years old. Dorsal-stream difficulties are known to be the most prevalent symptoms of childhood CVI, with visual search and visuo-attentional skills being the most affected (Chandna et al., 2021; Dutton, 2015; Lam et al., 2010; Merabet et al., 2023). As both domains are assessed by the EVA (Cavézian et al., 2010) this tool appeared to be a suitable option to screen for CVI-related visual difficulties in grade 1 children. The EVA administration was done at school, on a one-to-one basis by a specialized clinician and included all nine subtests which focused on different neurovisual functions: gaze fixation, visual field, visual extinction, binocular visual pursuit, visual memory, a teddy bear cancellation task (Laurent-Vannier et al., 2006), a letter cancellation task (Corkum et al., 1995), an embedded figures test and a matching test. The EVA (Cavézian et al., 2010) was developed considering a CVI prevalence of 3 to 5% within the general population (Chokron, 2007). The original norming cohort for this battery consisted of 450 kindergarten children (Cavézian et al., 2010; Chokron, 2015b). Following an estimated prevalence of 3–5% for CVI among children, a 5% threshold was admitted to screen effectively for these cases. To analyze performance, the lowest 5% of scores – or the closest value to 5% – from the norming cohort were evaluated separately for each age group (4–5 years and 5–6 years respectively). The total score for each child was calculated by counting the number of subtests they completed successfully (Chokron, 2015b). A subtest was completed successfully if the performance was above the lowest 5% of scores within the norming cohort, and each subtest received a score of 1 (if successful) or 0 (if unsuccessful). The cutoff score for identifying CVI-related visual difficulties was then determined by considering the distribution of total scores for the entire battery. For the 5–6-years age group, a child was considered having CVI-related visual difficulties if they failed two or more of the nine subtests (Chokron, 2015b). However, because the children in this study were older (7–8 years) than those in the original norming sample, stricter cutoffs were applied with a 7–8-year-old child being flagged for CVI-related difficulties if they failed just one of the nine subtests. This was decided by expert judgment consensus, which included the clinical team of neuropsychologists, optometrists and orthoptists who individually assessed the children at school. If the children performed below the adapted cutoff, a CVI-related visual difficulties clinical outcome was attributed post screening.

Visual measures

Additional visual measures were collected by the optometrists and orthoptists aimed to identify children at risk of ophthalmological difficulties. The set of measures were applied by either an optometrist or an orthoptist, at school, in an individualized setting. The measures aimed to collect low-level visual processing information. They included an assessment of monocular visual acuity for far vision (for both left and right eyes), an assessment of binocular visual acuity for near vision as well as an assessment of binocular low contrast sensitivity (in near vision. The acuity measures used the LEA symbols optotypes (Hyvärinen et al., 1980). Furthermore, an assessment of color vision was performed (Ishihara, 1917), as well as a binocular vision assessment comprising a convergence test, a cover test, an ocular motility test and an assessment of stereo acuity (stereopsis). Children who failed one of these assessments were referred to an ophthalmologist for further investigation and for necessary correction. Considering that the focus of this manuscript were dorsal-stream difficulties (i.e. visuo-attentional difficulties), children flagged by the visual measures were excluded from the group with CVI-related visual difficulties and composed the ophthalmological group, as no conclusions could be made regarding their visuo-attentional processing prior to adequate intervention. It is still worth noting that optometric and orthoptic difficulties are well documented in CVI children (Boonstra et al., 2022; Fazzi et al., 2007; V. Good et al., 1994; W. V. Good et al., 2001; Philip & Dutton, 2014).

Background data

Regarding children's background characteristics, the International Socio-Economic Index of Occupational Status (Ganzeboom, 2010; Ganzeboom & Treiman, 1996)(ISEI) was used as a scale for the parents' occupational status. Children's Socio-Economic Status (SES) was derived from the highest ISEI in the household (HISEI). The categorical background variables were arbitrarily dummy coded to enter the regression analysis. Gender was treated in a dichotomous format (female/male), with female being the reference category. The sample was divided into two language groups: children speaking

Luxembourgish or German at home and those who did not speak these languages at home. Considering that only a third of the school population speaks Luxembourgish as a first language (SCRIPT, MENJE, 2022) and that Luxembourgish is linguistically close to German, which is the language of literacy acquisition, speaking German could enhance academic performance in the language competence tests (Hornung et al., 2015). Speaking Luxembourgish or German at home was used as the reference category (0). Regarding the migration profile, children with at least one parent born in Luxembourg were considered native and constituted the reference category for this dummy variable coding (0). Regarding parental education, the sample was divided into lower (i.e. no diploma or technical secondary education) and higher education (i.e. secondary education, craftsman diploma, non-university degree, university degree) With lower education being the reference category (0).*Statistical analyses*

To answer the research question and test hypotheses 1 and 2, stepwise regression models were computed. Model 1 and 2 considered early literacy test scores as the outcome, model 3 and 4 considered mathematics test scores as the outcome and finally, model 5 and 6 addressed the scores of listening comprehension as the outcome. Models 1, 3 and 5 used group affiliation (TD vs. CVI-related visual difficulties) as single predictor of performance. In a second step, we controlled for background variables that are known to influence academic performance (Agirdag & Vanlaar, 2016; Colling et al., 2024; Duong et al., 2016; Hornung et al., 2015) (gender, parental education, home language, migration status, SES and age).

Results

Data analyses were done with the software IBM SPSS Statistics (Version 27). Descriptive statistics were computed for all background (Table 1) and performance variables (Table 2).

Altogether 38 children performed below cutoff on the EVA battery (average age 7 years, SD = 4 months). These children were solely flagged on this tool, displaying TD-like performances in optometric and orthoptic measures. Children who struggled in the additional optometric and orthoptic measures were not considered for the purpose of this study ($n = 189$) and were excluded from the sample, given that the study targeted dorsal-stream difficulties which were addressed by the EVA battery. Children with a combination of ophthalmological and CVI-related visual difficulties issues ($n = 12$) were equally excluded from the sample, given their heterogeneous clinical presentation. The remaining 890 children, not flagged in any of the clinical screening instruments, were classified as TD (average 7 years, SD = 5 months).

Table 2. Means and standard deviations of scores on competence measures per group.

Competence Test	Group	N	Mean	SD
Early Literacy	TD	817	512.08	113.61
	CVI	37	454.37	118.41
Mathematics	TD	871	517.93	86.87
	CVI	38	470.86	98.04
Listening comprehension	TD	825	505.80	104.45
	CVI	37	471.58	126.88

For all the analyses, a significance cutoff of $p < .05$ was used to determine statistical significance. There were no significant differences between groups for the background variables gender, SES, migration background, home language and parental education, except for age. Children with CVI-related visual difficulties were slightly older than TD children (see Table 1). As for the group differences in the main outcomes, independent samples t-tests were computed per competence domain. The 871 TD children who participated in the mathematics test ($M = 518$, $SD = 87$), demonstrated significantly higher scores in this competence domain $t(907) = 3.25$, $p = .001$, when compared to the 38 children with CVI-related visual difficulties ($M = 471$, $SD = 98$). The effect size for the difference between samples was calculated with Cohen's d, resulting in a value of 0.54, which is considered moderate. The 817 TD children who participated in the early literacy test ($M = 512$, $SD = 114$), demonstrated significantly higher scores in this competence domain $t(850) = 2.94$, $p = .003$, when compared to the 35 children with CVI-related visual difficulties ($M = 454$, $SD = 118$). The effect size for the difference between samples was calculated with Cohen's d, resulting in a value of 0.51, considered to be a moderate effect. The 825 TD children who participated in the Luxembourgish listening comprehension test ($M = 506$, $SD = 104$), did not demonstrate a significant difference in scores for this competence domain $t(860) = 1.9$, $p = .054$, when compared to the 37 children with CVI-related visual difficulties ($M = 472$, $SD = 127$). The effect size for the difference between samples was calculated with Cohen's d, resulting in a value of 0.32, considered a small effect.

Subsequently, as a first step, we performed a single regression analysis with children's clinical outcome as a function of each performance domain. The first stepwise regression models were computed to address hypotheses 1 and 2 and test the research question (models 1, 3 and 5, respectively). According to hypothesis 1 lower performances in the group with CVI-related visual were associated with difficulties in the competence of early literacy. Indeed, the results indicated a significant association between a lower test score for early literacy (model 1) and having CVI-related visual difficulties ($\beta = -62.857$, $p = .006$). Hypothesis 2 predicted an association between having CVI-related difficulties and lower performances in mathematics. Respectively, the results showed a significant association between a lower test score for mathematics (model 3) and having CVI-related visual difficulties ($\beta = -47.344$, $p = .005$). Research question 1 aimed to investigate whether there was a relationship between having CVI-related visual difficulties and performing in listening comprehension. The results of regression model 5 (Table 5) did not indicate a significant association between having CVI-related visual difficulties and performing in listening comprehension ($\beta = -23.319$, $p = .153$), thus suggesting that there is no significant difference between the allocation to either of the two clinical outcomes (i.e. TD or CVI-related visual difficulties) and performance in this competence domain.

As a second step, we performed a multiple regression analysis with children's clinical outcome as a function of each performance domain whilst controlling for background variables known to influence performance (including age) (Agirdag & Vanlaar, 2016; Colling et al., 2024; Duong et al., 2016; Hornung et al., 2015). With respect to hypothesis 1, a significant association was observed between CVI-related visual difficulties and early literacy performance ($\beta = -57.687$, $p = .008$). TD children significantly outperformed peers with CVI-related visual difficulties. The individual parameters of model 2

Table 3. Parameter estimates (β) for associations between early literacy skills, diagnosis, age and background variables.

Outcome	Predictors	Model	Unstandardized coefficients			Standardized coefficients	R Square
			β	Std. Error	*p*		.011
Early literacy	(Constant)	1	523.505	4.339	.000		
	CVI		−62.857	22.976	.006	−.105	
	(Constant)	2	468.130	68.901	.000		.136
	CVI		−57.687	21.688	.008	−.096	
	Age		−.299	.792	.706	−.014	
	Gender		−17.341	8.057	.032	−.078	
	Parental education		23.364	9.469	.014	.100	
	Home language		20.612	10.031	.040	.093	
	Migration status		−23.596	10.118	.020	−.106	
	SES		1.470	.292	.000	.207	

(Table 3) were examined further and indicated that, other than having CVI-related visual difficulties, SES was a significant predictor for performance in early literacy ($\beta = 1.470$, $p = .000$). An increase in SES is, therefore, significantly associated with an increase in early literacy performance. Gender was also significantly associated with early literacy performance ($\beta = -17.341$, $p = .032$), with girls significantly outperforming their male peers. Children who spoke Luxembourgish or German at home had higher scores in this competence than their peers ($\beta = 20.612$, $p = .040$). The same observation was made for children without a migration background outperformed their peers ($\beta = -23.596$, $p = .020$) and for higher levels of parental education ($\beta = 23.364$, $p = .014$). Overall, the amount of explained variance is higher in the multiple regression model 2, when compared to the single regression model 1 (Table 3), making it a better fit to explain our results and therefore account for the influence of CVI-related visual difficulties even when controlling for background variables including age (Table 3). This result highlights the contribution of CVI-related visual difficulties and also shows its independence from these socio-demographic factors (including age). The same applied to hypothesis 2, as children with CVI-related visual difficulties scored significantly lower in mathematics than TD children ($\beta = -46.701$, $p = .004$), even when controlling for background variables (Table 4). The individual predictors of model 4 (Table 4) were further examined and the results suggested that, other than having CVI-related visual difficulties, having a higher SES ($\beta = .916$, $p = .000$), speaking Luxembourgish or German at home ($\beta = 19.839$, $p = .009$) and having higher levels of parental education ($\beta = 22.216$, $p = .002$) were

Table 4. Parameter estimates (β) for associations between mathematics performance, diagnosis, age and background variables.

Outcome	Predictors	Model	Unstandardized coefficients			Standardized coefficients	R Square
			β	Std. Error	*p*		.011
Mathematics	(Constant)	3	527.646	3.226	.000		
	CVI		−47.344	16.884	.005	−.105	
	(Constant)	4	431.092	52.499	.000		.105
	CVI		−46.701	16.212	.004	−.103	
	Age		.316	.602	.600	.019	
	Gender		7.261	6.094	.234	.043	
	Parental education		22.216	7.133	.002	.125	
	Home language		19.839	7.618	.009	.117	
	Migration status		−7.692	7.688	.317	−.045	
	SES		.916	.220	.000	.169	

Table 5. Parameter estimates (β) for associations between listening comprehension performance, diagnosis, age and background variables.

Outcome	Predictors	Model	Unstandardized coefficients			Standardized coefficients	R Square
			β	Std. Error	*p*		.002
Listening comprehension	(Constant)	5	520.308	3.915	.000		
	CVI		−23.319	20.375	.253	−.044	
	(Constant)	6	635.029	55.069	.000		.320
	CVI		−22.252	16.982	.191	−.042	
	Age		−2.046	.633	.001	−.105	
	Gender		−7.581	6.422	.238	−.038	
	Parental education		26.507	7.529	.000	.126	
	Home language		36.345	7.969	.000	.182	
	Migration status		−61.446	8.055	.000	−.307	
	SES		1.078	.232	.000	.169	

significantly associated with increased performances in the mathematics competence test. Similarly to early literacy, the amount of explained variance was higher for the model including background variables (model 4) when compared to the single regression model 3 (Table 4) thus making it a better fit to explain our results. Lastly, to address the manuscript's research question, the results of model 6 suggested that being identified with CVI-related visual difficulties was not a significant predictor for listening comprehension thus indicating that children with and without CVI-related visual difficulties obtain similar scores after controlling for background characteristics (including age). Other parameters were significantly associated with the performance in listening comprehension including a higher SES ($\beta = 1.078$, $p = .000$), age ($\beta = -2.046$, $p = .001$), speaking Luxembourgish or German at home ($\beta = 36.345$, $p = .000$), a higher level of parental education ($\beta = 26.507$, $p = .000$) as well as the absence of migration status ($\beta = -61.446$, $p = .000$). These variables seemed to better predict the performance in listening comprehension than having been identified with CVI-related visual difficulties. Figure 1 illustrates the group differences in performance for each competence domain controlling for background variables.

Discussion

This study, reporting on a national representative cohort of first graders in Luxembourg (mean age 7 years), explored the relationship between CVI-related visual difficulties and precursors to key academic competences at the beginning of formal schooling, within a natural setting (classroom). The results aim to address the lack of research investigating the relation between impaired visual processes and precursors to key academic skills as early as the beginning of grade 1, within a natural environment (classroom).

The standardized competence tests used provided results as a one-scale value, as they primarily aim to evaluate the educational system. The use of competence tests in association with a visual profile constituted a secondary use of the school monitoring tool. Therefore, the way the test material was presented was strictly connected to the way its assessment has been formulated within the national school curriculum (Fischbach et al., 2014). Consequently, there were some restrictions in terms of visual presentation of

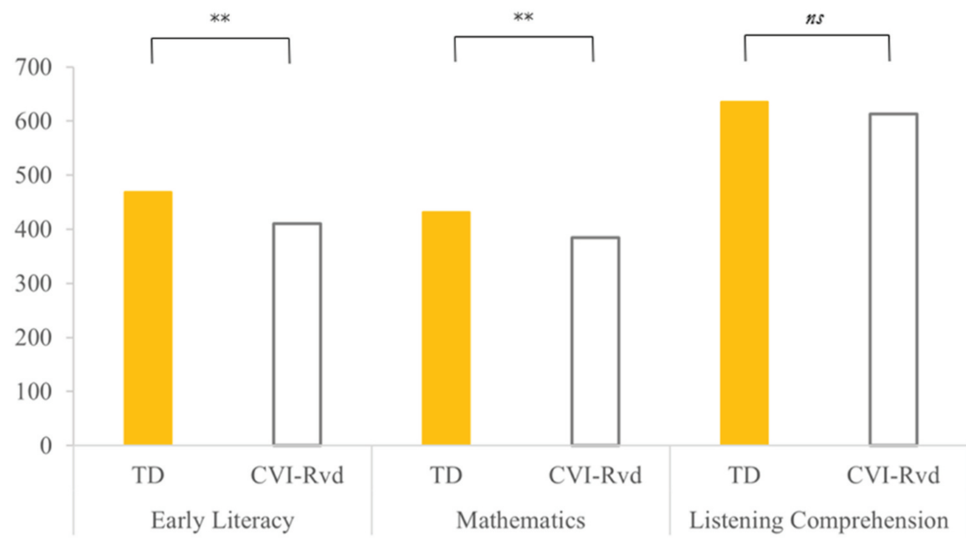

Figure 1. Association between CVI-related visual difficulties and academic achievement.

the material and performance score calculation. Although there is only one general score per domain, this study assumes, in line with previous research (Chokron & Dutton, 2023; Chokron et al., 2010, 2021; Fazzi et al., 2009; Lueck et al., 2019; Molloy et al., 2017; Philip & Dutton, 2014), that different subprocesses necessary to complete the tasks within each domain are affected in the subsample with CVI-related visual difficulties. Additionally, even though neurocognitive studies often look at subprocesses of reading and mathematics separately, difficulties detected for one of these domains will likely impact both. Indeed, the results of this study showed that TD children outperformed peers with CVI-related visual difficulties in early literacy and mathematics. This aligns with difficulties inherent to a profile with CVI-related visual difficulties that has been identified in previous research and that impacted visual functions required to succeed in academic contexts (Barclay, 2015; Chokron & Dutton, 2023; Chokron et al., 2010, 2021; Williams et al., 2021). More precisely, in the early literacy and mathematics tests, the instructions were presented auditorily and provided an explanation on how the task should be completed. Children had to visually analyze each item, decode the visual information presented and visually process it. It can be hypothesized that the load of visual content to be processed is fundamentally higher for early literacy and mathematics when compared to listening comprehension, thus resulting in significantly lower performances for children with CVI-related difficulties when compared to their TD-peers.

Looking into each domain in isolation, this study set off from the hypothesis that the subsample with CVI-related visual difficulties would display a lower performance in the domain of early literacy, when compared to the TD children. The early literacy measure sampled the curriculum domains of phonological awareness (via grapheme recognition), visual discrimination, and word segmentation. Research exploring the profile of CVI children stresses how both ventral and dorsal stream impairments negatively impact areas linked with reading (Chokron & Dutton, 2023; Chokron et al., 2021; Philip & Dutton, 2014). Hence, crowding is a frequent challenge for children presenting with dorsal stream disfunction (Philip & Dutton, 2014), and is often transposed to reading, as visual symbols (letters) are presented simultaneously and require concurrent visual processing. This difficulty might have affected children's ability to solve items that require visual discrimination, such as letter cancellation tasks where multiple elements are presented in a line, and some must be singled out as targets. It should be noted that the EVA battery (Cavézian et al., 2010) has different subtests (e.g. tangled figures subtest; cancellation tasks) which directly or indirectly address the perception of multiple elements simultaneously. Therefore, children who performed below cutoff in these subtests may have been particularly prone to difficulties with the tasks of the school monitoring that require intact perception of visual elements' crowding. Difficulties relating to visual recognition, that can also manifest when coping with written material, thus inducing a vulnerability which will closely connect with early literacy skills' mastery (Chokron, 2015a). Concretely, this difficulty affects the capacity to recognize words or syllables (Chokron, 2015a). We infer from our results that fully functional higher order visual processing is required to complete different test items successfully. These difficulties are not based on children's language proficiency, as this background characteristic was controlled for in all six models (Tables 3–5). Therefore, the lower performances of children with CVI-related visual difficulties, when compared to TD peers, are most probably associated with their visual profile.

As in early literacy, the mathematics test also sampled school curriculum domains, namely numbers and operations, space and shapes as well as dimensions and measures. Previous empirical research (Barclay, 2015; Chokron & Dutton, 2023) showed that multi-digit calculations and the systems in which numbers are represented rely on visuo-spatial cognition (e.g. number line). If CVI affects aspects of the dorsal stream, it will most likely affect visual processes required for the domain of numbers and operations, such as the organization of a calculation on a sheet of paper or the capacity to spatially differentiate magnitudes. The capacity to align numbers might equally be impaired (Chokron & Dutton, 2023). Figure-ground discrimination or impaired perception at global and local levels of processing might also affect the way children distinguish different shapes or objects and accurately see the full content in exercises requiring intact shape perception. Mental imagery difficulties make the liaisons between an object and its visual representation an endeavor. Tasks relying on object or geometric figure's identification may be extremely difficult (Chokron, 2015a) as might be the capacity to access symbolic (often numeric) content from a piece of paper (Philip & Dutton, 2014). Similarly, tasks requiring higher order visual processing, such as mental figure manipulations (e.g. rotation), might be a challenge for children struggling to mentally represent them. As these mechanisms are to some extent employed in the completion of the mathematics' items used in the standardized competence test (MENFP, 2011a, 2011b), the significantly lower performance of the sample with CVI-related visual difficulties translates these mechanisms' vulnerability. However, in-depth analysis of item content would have to be pursued to confidently identify the domains in which these children mostly failed.

Additionally, this study aimed to investigate whether there were group differences in listening comprehension performance. Unlike early literacy and mathematics, the performances of children with CVI-related visual difficulties and TD children did not significantly differ. The competence domain of listening comprehension targeted first graders' oral comprehension skills (Fischbach et al., 2014; MENFP, 2011a). The materials in this competence were presented orally, thus considerably decreasing the visual load with which children with CVI-related visual difficulties would have to cope successfully. Additionally, in the listening comprehension test, the answer format consisted of a cross-sensory matching task whereas, for early literacy and mathematics, children had to actively process and mentally manipulate the visual content presented. In other words, the instructions in the listening comprehension test included the targeted answer that children had to auditory apprehend and then match to its visual referent. Thus, the visual load here was fundamentally lower than for the tests of early literacy and mathematics. Furthermore, previous research showed that children with CVI-related visual difficulties tend to develop sensory modalities that are not visual as compensation strategies (Barclay, 2015; Philip & Dutton, 2014). In fact, research on cross-modal plasticity emphasized the role that sense modalities deploy, especially via their ability of enhancement, to compensate for a lack of vision (Collignon et al., 2009). We believe that the absence of group differences in this competence domain relies on both the decrease in visual load, as the material is presented via an audio file (e.g. stories), and on the use of audition as a compensation strategy. Considering that other academic areas imply listening comprehension mastery (Barclay, 2015), it is important to consider the format in which learning materials are presented and its relation to children's academic success.

It is also worth noting that, children who were flagged in the visual measures applied by orthoptists and optometrists, also displayed significant performance differences when compared to their TD-peers (Monteiro et al., 2024). The ophthalmological subsample significantly underperformed their TD-peers in the domains of mathematics, early literacy and, as opposed to children with CVI-related visual difficulties, also in the domain of listening comprehension. These results thus suggest a vulnerability that extends beyond the visual load of the test material and that may not be compensated by using alternative sensory input modalities.

Lastly, the phenotypical similarities between CVI and other neurodevelopmental disorders should be discussed. This is especially important, as underperformances in the EVA battery may result from other developmental conditions, such as Autism Spectrum Disorder (ASD) and Attention-Deficit Hyperactivity Disorder (ADHD). Indeed, some diagnostic criteria for ASD as mentioned in the diagnostic and statistical manual of mental disorders' (DSM-5) match those of children with visual impairment, such as lack of eye contact, the presence of stereotypical behaviors, or reactions to stimuli (e.g. side tracking by unimportant stimuli) (Fazzi et al., 2019; Molinaro et al., 2020). This aligns with Fazzi et al. (Fazzi et al., 2019) who observed that the prevalence of ASD was higher among children with visual impairment than at population level. Consequently, potential comorbidities or similarities between symptoms should be reflected upon carefully. Another neurodevelopmental disorder to address is ADHD, especially when considering that the EVA (Cavézian et al., 2010) addresses visuo-attentional difficulties. Indeed, the attentional overlap between CVI and ADHD has been previously reported (Chokron & Dutton, 2023; Hokken et al., 2023; Lueck et al., 2019) and implies a serious challenge for setting up differential diagnosis. Thus, it cannot be excluded that some of the profiles identified by the EVA may also relate to those of ADHD children, and therefore some caution should be taken when interpreting a performance below the EVA cutoff as exclusively relating to visual disorders.

Limitations

Some limitations to this study must be acknowledged. The EVA battery (Cavézian et al., 2010) targets a limited set of visual functions, with special emphasis on visual attention. Therefore, the group with CVI-related visual difficulties might be underestimated as there may be unflagged children within the TD sample who display other profiles consistent with CVI-related visual difficulties. However, we can confidently say that, within our nationally representative sample, children with profiles of visuo-attentional difficulties displayed lower academic performances in mathematics and early literacy when compared to their TD peers.

This study analyzed performance differences between children with CVI-related visual difficulties and their TD-peers through a secondary use of the national school monitoring program. Repurposing the school monitoring program for the scope of this study also implied a limitation as procedures of item design and test administration had to be respected. In fact, this study's preliminary results suggest that the complementary employment of distinct sensory modalities may have aided the intelligibility and accessibility of the tasks in listening comprehension. The use of both visual and auditory input may thus have supported the performance of children with CVI-related visual difficulties, who constitute a group repeatedly identified in research as being academically at-risk (Lueck & Dutton, 2015; Molloy et al., 2017; Pawletko et al., 2015; Williams et al., 2011). It can be hypothesized that the observed performance differences in early literacy and mathematics may also partially relate to the presentation format of the test material and to the extent of visual operations at varying levels to be able to successfully complete the tasks of these two competence tests. Further studies assessing mathematics and early literacy in a similar format to listening comprehension would be important to best clarify the extent to which the material presentation may contribute to performance differences between samples. However, it is important to consider that the test material used to assess these competence domains was designed in accordance with the didactic material used at school and that it reflects the children's traditional learning environment. Moreover, difficulties associated with lower-level visual processing (i.e. acuity, contrast, color sensitivity, depth perception) were excluded within the sample of children with CVI-related visual difficulties thus presuming that, to a certain extent, their central visual function was preserved and did not compromise access to the test material.

Even though research recommends integrating multiple sources of information for a valid CVI diagnosis (Lueck & Dutton, 2015; Lueck et al., 2019; E. Ortibus et al., 2011; Pilling et al., 2022), in this study the use of the EVA was not intended for profiling nor for diagnostic purposes. The tool was used as a preliminary screening instrument, and adaptations to the cutoffs were needed to target the mean age of our study sample (7 years). Therefore, those identified as at-risk by the EVA (using more stringent and modified cutoff scores) were invited for an in-depth assessment involving a broader set of neuropsychological tools, as well as an anamnesis (including medical risk factors, such as prematurity or birth weight). This second phase of the process aimed to create a more detailed profile of the child's difficulties from a CVI perspective. Although this in-depth assessment was not the primary focus of this manuscript, it is essential to mention it considering that it may help address some of the study's limitations. More specifically, this phase ensured that the difficulties identified through the initial screening were validated by other tools assessing the same (or alternative) visual processes. Data on medical risk factors would have provided useful information to improve the analyses computed in this study. Indeed, considering the widely reported associations between premature birth and CVI-related difficulties (Dutton, 2013; Khetpal & Donahue, 2007) information on the child's gestational age would have offered an interesting outlook. However, collecting this kind of sensitive data is not covered by the mission and scope of the school monitoring (Martin et al., 2015).

Additionally, although the EVA battery's cutoffs were adjusted, other optometric and orthoptic measures were used to differentiate between children with CVI-related visual difficulties and children with ophthalmological difficulties. The alterations should, nonetheless, be statistically validated in future studies. It is also important to mention that other neurodevelopmental disorders may be associated with the observed under performance in the EVA battery. Indeed, previous research on the phenotypical overlap between neurodevelopmental disorders such as ASD and ADHD with CVI (Chokron & Dutton, 2016, 2023; Chokron et al., 2020, 2021; Fazzi et al., 2019; Hokken et al., 2023; Hokken, Stein, et al., 2024; Hokken, van der Zee, et al., 2024; Lueck et al., 2019; Micheletti et al., 2021; Molinaro et al., 2020). However, as the focus of this study was to screen for CVI-related visual difficulties, a differential diagnosis as well as a visuo-attentional profiling were established at a later stage of the diagnostic process, with all children who had been flagged by the EVA attending a more in-depth clinical assessment. Furthermore, as the study uses standardized large-scale global competence scores, it is not possible to draw conclusions on specific subprocesses (e.g. arithmetic or counting for mathematics).

Strengths and conclusions

Nationally representative data regarding the relation of CVI-related visual difficulties with key precursors to academic performances is a strength of this paper. The prevalence rates identified within our sample go in a similar direction of recently published findings (of 3.4%), under a different methodological approach (Williams et al., 2021). The group with CVI-related visual difficulties performed significantly below the TD group in early literacy and mathematics. The significantly lower performances show as early as the very beginning of grade 1. The results stress the association of CVI-related visual difficulties in the educational context and show that children with CVI-related visual difficulties have not met the minimum standard in terms of their previous learning cycle, when compared to their TD-peers. The results thus emphasize the need for an early systematic screening that goes beyond the universally established assumption that acuity assessment would suffice as a measure of visual integrity. Further research could target finer-grain analyses on item-level to specify which sub-domains are impacted by CVI-related visual difficulties. However, children with CVI-related visual difficulties perform similarly to their TD peers in listening comprehension. This result provides insight on how to build on these children's strengths by using sense modalities alternative to vision to support them in their academic learning.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

The author(s) reported there is no funding associated with the work featured in this article.

ORCID

Sara Monteiro http://orcid.org/0009-0002-6759-714X
Pascale Esch http://orcid.org/0000-0002-0892-9960
Géraldine Hipp http://orcid.org/0009-0002-0037-6887
Sonja Ugen http://orcid.org/0000-0002-0174-8091

References

Agirdag, O., & Vanlaar, G. (2016). Does more exposure to the language of instruction leads to higher academic achievement? A cross-national examination. *International Journal of Bilingualism*, *22*(1), 1–15. https://doi.org/10.1177/1367006916658711

Barclay, L. A. (2015). Assessments linked to interventions: Literacy and math. In A. H. Lueck & G. N. Dutton (Eds.), *Vision and the brain: Understanding cerebral visual impairment in children* (pp. 411–434). AFB Press American Foundation for the Blind.

Belote, M. (2020). Central auditory processing disorder: The hearing equivalent of CVI. Risk factors, features and strategies. *Deaf and Hard of Hearing Services California*, *25*(1), 12–15.

Boonstra, F. N., Bosch, D. G. M., Geldoff, C. J. A., Stellingwerf, C., & Porro, G. (2022). The multidisciplinary guidelines for diagnosis and referral in cerebral visual impairment. *Frontiers in Human Neuroscience*, *16*, 1–24. https://doi.org/10.3389/fnhum.2022.727565

Cappagli, G., Cuturi, L. F., Signorini, S., Morelli, F., Cocchi, E., & Gori, M. (2022). OPEN early visual deprivation disrupts the mental representation of numbers in visually impaired children. *Scientific Reports*, *12*(1), 1–8. https://doi.org/10.1038/s41598-022-25044-1

Cavézian, C., Vilayphonh, M., de Agostini, M., Vasseur, V., Watier, L., Kazandjian, S., Laloum, L., & Chokron, S. (2010, September). Assessment of visuo-attentional abilities in young children with or without visual disorder: Toward a systematic screening in the general population. *Research in Developmental Disabilities*, *31*(5), 1102–1108. https://doi.org/10.1016/j.ridd.2010.03.006

Chandna, A., Ghahghaei, S., Foster, S., & Kumar, R. (2021, November 16). Higher visual function deficits in children with cerebral visual impairment and good visual acuity. *Frontiers in Human Neuroscience*, *15*, 711873. https://doi.org/10.3389/fnhum.2021.711873

Chokron, S. (2007). Troubles neurovisuels d'origine centrale chez l'enfant: vers un diagnostique et une prise en charge précoce. *Ophthalmologies*, *1*(5), 94–98.

Chokron, S. (2015a). Approche neuropsychologique des troubles neurovisuels chez l'enfant. *Revue de neuropsychologie*, *7*(1), 41. https://doi.org/10.3917/rne.071.0041

Chokron, S. (2015b). Evaluation of visuo-attentional abilities (EVA): A simple and rapid battery to screen for CVI in young children. In A. H. Lueck & G. N. Dutton (Eds.), *Vision and the brain: Understanding cerebral visual impairment in children* (pp. 385–390). AFB Press American Foundation for the Blind.

Chokron, S., Cavézian, C., & de Agostini, M. (2010). Troubles neurovisuels chez l'enfant : Sémiologie, retentissement sur les apprentissages et dépistage. *Développements*, *n° 6*(3), 17. https://doi.org/10.3917/devel.006.0017

Chokron, S., & Dutton, G. N. (2016, October 4). Impact of cerebral visual impairments on motor skills: Implications for developmental coordination disorders. *Frontiers in Psychology*. *7*. https://doi.org/10.3389/fpsyg.2016.01471
Chokron, S., & Dutton, G. N. (2023, December 22). From vision to cognition: potential contributions of cerebral visual impairment to neurodevelopmental disorders. *Journal of Neural Transmission*. *130*(3), 409–424. https://doi.org/10.1007/s00702-022-02572-8
Chokron, S., Kovarski, K., & Dutton, G. N. (2021, October 13). Cortical visual impairments and learning disabilities. *Frontiers in Human Neuroscience*, *15*, 713316. https://doi.org/10.3389/fnhum.2021.713316
Chokron, S., Kovarski, K., Zalla, T., & Dutton, G. N. (2020, July). The inter-relationships between cerebral visual impairment, autism and intellectual disability. *Neuroscience & Biobehavioral Reviews*, *114*, 201–210. https://doi.org/10.1016/j.neubiorev.2020.04.008
Collignon, O., Voss, P., Lassonde, M., & Lepore, F. (2009, January). Cross-modal plasticity for the spatial processing of sounds in visually deprived subjects. *Experimental Brain Research*, *192*(3), 343–358. https://doi.org/10.1007/s00221-008-1553-z
Colling, J., Hornung, C., Esch, P., Keller, U., Hellwig, A. L., & Ugen, S. (2024). Literacy acquisition in German or French in the pilot project "zesumme wuessen!" - Preliminary épstan results of student characteristics, achievement, motivation, and parental support. *Luxembourg Centre for Educational Testing (LUCET)*. https://orbilu.uni.lu/handle/10993/61424
Corkum, V., Byrne, J. M., & Ellsworth, C. (1995, April). Clinical assessment of sustained attention in preschoolers. *Child Neuropsychology*, *1*(1), 3–18. https://doi.org/10.1080/09297049508401338
Dahaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General*, *122*(3), 371–396. https://doi.org/10.1037/0096-3445.122.3.371
Duong, M. T., Badaly, D., Liu, F. F., Schwartz, D., & McCarty, C. A. (2016). Generational differences in academic achievement among immigrant youths: A Meta-analytic review. *Review of Educational Research*, *86*(1), 3–41. https://doi.org/10.3102/0034654315577680
Dutton, G. N. (2003, April). Cognitive vision, its disorders and differential diagnosis in adults and children: Knowing where and what things are. *The Eye*, *17*(3), 289–304. https://doi.org/10.1038/sj.eye.6700344
Dutton, G. N. (2013, August). The spectrum of cerebral visual impairment as a sequel to premature birth: An overview. *Documenta Ophthalmologica*, *127*(1), 69–78. https://doi.org/10.1007/s10633-013-9382-1
Dutton, G. N. (2015). The brain and vision. In A. H. Lueck & G. N. Dutton (Eds.), *Vision and the brain: Understanding cerebral visual impairment in children* (pp. 411–434). AFB Press American Foundation for the Blind.
Fazzi, E., Bova, S., Giovenzana, A., Signorini, S., Uggetti, C., & Bianchi, P. (2009, December). Cognitive visual dysfunctions in preterm children with periventricular leukomalacia. *Developmental Medicine & Child Neurology*, *51*(12), 974–981. https://doi.org/10.1111/j.1469-8749.2009.03272.x
Fazzi, E., Micheletti, S., Galli, J., Rossi, A., Gitti, F., & Molinaro, A. (2019, October). Autism in children with cerebral and peripheral visual impairment: Fact or artifact? *Seminars in Pediatric Neurology*, *31*, 57–67. https://doi.org/10.1016/j.spen.2019.05.008
Fazzi, E., Signorini, S. G., Bova, S. M., La Piana, R., Ondei, P., Bertone, C., Misefari, W., & Bianchi, P. E. (2007, March). Spectrum of visual disorders in children with cerebral visual impairment. *Journal of Child Neurology*, *22*(3), 294–301. https://doi.org/10.1177/08830738070220030801
Fazzi, E., Signorini, S. G., & Lanners, J. (2010). The effect of impaired vision on development. In G. N. Dutton & B. Martin (Eds.), *Visual impairment in children due to damage to the brain* (pp. 83–104). MacKeith Press.
Fischbach, A., Ugen, S., & Martin, R. (2014). *Épstan technical report* [Internet]. 1–31. University of Luxembourg, ECCS research unit/LUCET. http://www.epstan.lu
Ganzeboom, H. B. G. (2010). A new International Socio-Economic Index (ISEIO of Occupational Status for the International Standard Classification of Occupation (ISCO-08) Constructed with

DATA from the ISSP 2002–2007; with an Analysis of Quality of Occupational Measurement in ISSP. [Internet]. Annual Conference of International Social Survey Programme, Lisbon. http://www.ilo.org/public/english/bureau/stat/isco/index.htm?

Ganzeboom, H. B. G., & Treiman, D. J. (1996, September). Internationally comparable measures of occupational status for the 1988 international standard classification of occupations. *Social Science Research*, *25*(3), 201–239. https://doi.org/10.1006/ssre.1996.0010

Good, V., Jan, J. E., Barrovich, A. J., & Hoyt, S. (1994). Cortical visual impairment in children. *Survey of Ophthalmology*, *38*(4), 351–364. https://doi.org/10.1016/0039-6257(94)90073-6

Good, W. V., Jan, J. E., Burden, S. K., Skoczenski, A., & Candy, R. (2001, February 14). Recent advances in cortical visual impairment. *Developmental Medicine & Child Neurology*, *43*(1), 56. https://doi.org/10.1111/j.1469-8749.2001.tb00387.x

Goodale, M. A. (2013, November). Separate visual systems for perception and action: A framework for understanding cortical visual impairment. *Developmental Medicine & Child Neurology*, *55*(s4), 9–12. https://doi.org/10.1111/dmcn.12299

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in Neurosciences*, *15*(1), 20–25. https://doi.org/10.1016/0166-2236(92)90344-8

Hokken, M. J., Krabbendam, E., van der Zee, Y. J., & Kooiker, M. J. G. (2023, April 3). Visual selective attention and visual search performance in children with CVI, ADHD, and dyslexia: A scoping review. *Child Neuropsychology*, *29*(3), 357–390. https://doi.org/10.1080/09297049.2022.2057940

Hokken, M. J., Stein, N., Pereira, R. R., Rours, I. G., Frens, M. A., van der Steen, J., Pel, J. J., & Kooiker, M. J., (2024, August). Eyes on CVI: Eye movements unveil distinct visual search patterns in cerebral visual impairment compared to ADHD, dyslexia, and neurotypical children. *Research in Developmental Disabilities*, *151*, 104767. https://doi.org/10.1016/j.ridd.2024.104767

Hokken, M. J., van der Zee, Y. J., van der Geest, J. N., & Kooiker, M. J. G. (2024, March 19). Parent-reported problems in children with cerebral visual impairment: Improving the discriminative ability from ADHD and dyslexia using screening inventories. *Neuropsychological Rehabilitation*, 1–21. https://doi.org/10.1080/09602011.2024.2328875

Hornung, C., Schiltz, C., Brunner, M., & Martin, R. (2014, April 4). Predicting first-grade mathematics achievement: The contributions of domain-general cognitive abilities, nonverbal number sense, and early number competence. *Frontiers in Psychology*. *5*. http://journal.frontiersin.org/article/10.3389/fpsyg.2014.00272/abstract

Hornung, C., Wollschläger, R., Keller, U., Esch, P., Muller, C., & Fischbach, A. (2015. Report No.: Nouveaux résultats longitudinaux issus du monitoring scolaire national ÉpStan en première et troisième année scolaire (cycles 2.1 et 3.1) : tendance négative au niveau du développement des compétences et redoublements inefficaces. *Nouveaux résultats longitudinaux issus du monitoring scolaire national ÉpStan en première et troisième année scolaire (cycles 2.1 et 3.1) : tendance négative au niveau du développement des compétences et redoublements inefficaces* [Internet]. LUCET & SCRIPT. https://doi.org/10.48746/bb2021lu-fr-14

Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005, June 1). Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience*, *6*(6), 435–448. https://doi.org/10.1038/nrn1684

Hyvärinen, L., Näsänen, R., & Laurinen, P. (1980, August). New visual acuity test for pre-school children. *Acta Ophthalmologica*, *58*(4), 507–511. https://doi.org/10.1111/j.1755-3768.1980.tb08291.x

Hyvärinen, L., Walthes, R., Freitag, C., & Petz, V. (2012, June). Profile of visual functioning as a bridge between education and medicine in the assessment of impaired vision. *Strabismus*, *20*(2), 63–68. https://doi.org/10.3109/09273972.2012.680235

Ishihara, S. (1917). *Tests for Colour-Blindness*. Hongo Harukicho.

Khetpal, V., & Donahue, S. P. (2007, June). Cortical visual impairment: Etiology, associated findings, and prognosis in a tertiary care setting. *Journal of American Association for Pediatric Ophthalmology and Strabismus*, *11*(3), 235–239. https://doi.org/10.1016/j.jaapos.2007.01.122

Lam, F. C., Lovett, F., & Dutton, G. N. (2010, October). Cerebral visual impairment in children: A longitudinal case study of functional outcomes beyond the visual acuities. *Journal of Visual Impairment and Blindness*, *104*(10), 625–635. https://doi.org/10.1177/0145482X1010401008

Laurent-Vannier, A., Chevignard, M., Pradat-Diehl, P., Abada, G., & De Agostini, M. (2006, February). Assessment of unilateral spatial neglect in children using the teddy bear cancellation test. *Developmental Medicine & Child Neurology*, *48*(2), 120–125. https://doi.org/10.1017/S0012162206000260

Lueck, A. H., & Dutton, G. N. (2015). *Vision and the brain understanding cerebral visual impairment in children*. AFB Press American Foundation for the Blind.

Lueck, A. H., Dutton, G. N., & Chokron, S. (2019, October). Profiling children with cerebral visual impairment using multiple methods of assessment to aid in differential diagnosis. *Seminars in Pediatric Neurology*, *31*, 5–14. https://doi.org/10.1016/j.spen.2019.05.003

Manley, C. E., Walter, K., Micheletti, S., Tietjen, M., Cantillon, E., Fazzi, E. M., Bex, P. J., & Merabet, L. B. (2023, September). Object identification in cerebral visual impairment characterized by gaze behavior and image saliency analysis. *Brain & Development*, *45*(8), 432–444. https://doi.org/10.1016/j.braindev.2023.05.001

Martin, R., Ugen, S., & Fischbach, A. (Eds.). (2015). *Épreuves Standardisées - Bildungsmonitoring für Luxembourg*. LUCET.

McConnell, E. L., Saunders, K. J., & Little, J. (2021, March). What assessments are currently used to investigate and diagnose cerebral visual impairment (CVI) in children? A systematic review. *Ophthalmic & Physiological Optics*, *41*(2), 224–244. https://doi.org/10.1111/opo.12776

McDonald, S. A., Spitsyna, G., Shillcock, R. C., Wise, R. J. S., & Leff, A. P. (2006, January 1). Patients with hemianopic alexia adopt an inefficient eye movement strategy when reading text. *Brain A Journal of Neurology*, *129*(1), 158–167. https://doi.org/10.1093/brain/awh678

McDowell, N. (2020). A pilot study of the austin playing card assessment: A tool to detect and find the degree of visual perceptual difficulties related to clutter. *The British Journal of Visual Impairment*, *38*(2), 118–136. https://doi.org/10.1177/0264619619896008

McDowell, N. (2023, December 14). Children with cerebral visual impairment related visual issues in the classroom. *Kairaranga*, *24*(2), 15–29. https://doi.org/10.54322/kairaranga.v24i2.365

McDowell, N., & Butler, P. (2023, November). Validation of the austin assessment: A screening tool for cerebral visual impairment related visual issues. *PLOS ONE*, *18*(11), 1–20. https://doi.org/10.1371/journal.pone.0293904

MENFP. (2011a). *Plan d'études école fondamentale*. Ministère de l'Éducation nationale et de la Formation professionnelle.

MENFP. (2011b). *The levels of competence - cycles 1-4* [Internet]. https://men.public.lu/en/publications/enseignement-fondamental/informations-generales/niveaux-competence-cycles-1-4.html

Merabet, L. B., Mayer, D. L., Bauer, C. M., Wright, D., & Kran, B. S. (2023). Motion and form coherence processing in individuals with cerebral visual impairment. *Developmental Medicine & Child Neurology*, *65*(10), 1379–1386. https://doi.org/10.1111/dmcn.15591

Micheletti, S., Corbett, F., Atkinson, J., Braddick, O., Mattei, P., Galli, J., Calza, S., & Fazzi, E. (2021, November 24). Dorsal and ventral stream function in children with developmental coordination disorder. *Frontiers in Human Neuroscience*, *15*, 703217. https://doi.org/10.3389/fnhum.2021.703217

Molinaro, A., Micheletti, S., Rossi, A., Gitti, F., Galli, J., Merabet, L. B., & Fazzi, E. M. (2020, August 1). Autistic-like features in visually impaired children: A review of literature and directions for future research. *Brain Sciences*, *10*(8), 507. https://doi.org/10.3390/brainsci10080507

Molloy, C. S., DiBattista, A. M., Anderson, V. A., Burnett, A., Lee, K. J., Roberts, G., Cheong, J. L., Anderson, P. J., & Doyle, L. W. (2017, April 3). The contribution of visual processing to academic achievement in adolescents born extremely preterm or extremely low birth weight. *Child Neuropsychology*, *23*(3), 361–379. https://doi.org/10.1080/09297049.2015.1118024

Monteiro, S., Esch, P., Engel, P. J., & Ugen, S. (2024). *Visuelle Beeinträchtigungen im Kindesalter: Früherkennung mit dem nationalen Bildungsmonitor Épstan*. SCRIPT & University of Luxembourg.

Ortibus, E., Laenen, A., Verhoeven, J., De Cock, P., Casteels, I., Schoolmeesters, B., Buyck, A., & Lagae, L. (2011, August). Screening for cerebral visual impairment: Value of a CVI questionnaire. *Neuropediatrics*, *42*(4), 138–147. https://doi.org/10.1055/s-0031-1285908

Ortibus, E. L., De Cock, P. P., & Lagae, L. G. (2011, July). Visual perception in preterm children: What are we Currently measuring? *Pediatric Neurology*, *45*(1), 1–10. https://doi.org/10.1016/j.pediatrneurol.2011.02.008

Pawletko, T., Chokon, S., & Dutton, G. N. (2015). Considerations in the behavioral diagnosis of CVI: issues, cautions, and potential outcomes. In A. H. Lueck & G. N. Dutton (Eds.), *Vision and the brain: understanding cerebral visual impairment in children* (pp. 145–173). AFB Press.

Philip, S. S., & Dutton, G. N. (2014, May 1). Identifying and characterising cerebral visual impairment in children: A review. *Clinical and Experimental Optometry*, *97*(3), 196–208. https://doi.org/10.1111/cxo.12155

Pilling, R. F., Allen, L., Bowman, R., Ravenscroft, J., Saunders, K. J., & Williams, C. (2022, October 18). Clinical assessment, investigation, diagnosis and initial management of cerebral visual impairment: A consensus practice guide. *The Eye*. https://www.nature.com/articles/s41433-022-02261-6

Roman-Lantzy, C. (2018). Cortical visual impairment: An overview. In C. Roman-Lantzy (Ed.), *Cortical visual impairment: An approach to assessment and intervention* (pp. 7–18). AFB Press American Foundation for the Blind.

Sakki, H. E. A., Dale, N. J., Sargent, J., Perez-Roche, T., Bowman, R. (2018, April). Is there consensus in defining childhood cerebral visual impairment? A systematic review of terminology and definitions. *British Journal of Ophthalmology*, *102*(4), 424–432. https://doi.org/10.1136/bjophthalmol-2017-310694

SCRIPT, MENJE. (2022). Enseignement fondamental: Statistiques globales et analyse des résultats scolaires, Année scolaire 2020/2021. *Luxembourg: Official Journal of the European Union*, 1–79.

Valdois, S. (2022, November). The visual-attention span deficit in developmental dyslexia: Review of evidence for a visual-attention-based deficit. *Dyslexia*, *28*(4), 397–415. https://doi.org/10.1002/dys.1724

Williams, C., Northstone, K., Sabates, R., Feinstein, L., Emond, A., & Dutton, G. N. (2011, March 21). Visual perceptual difficulties and under-achievement at school in a large community-based sample of children. *PLOS ONE*, *6*(3), e14772. https://doi.org/10.1371/journal.pone.0014772

Williams, C., Pease, A., Warnes, P., Harrison, S., Pilon, F., Hyvarinen, L., West, S., Self, J., & Ferris, J. (2021, June). Cerebral visual impairment-related vision problems in primary school children: A cross-sectional survey. *Developmental Medicine & Child Neurology*, *63*(6), 683–689. https://doi.org/10.1111/dmcn.14819