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Developmental coordination disorder and cerebral visual impairment: What is the association?

Serena Micheletti [a,*,1], Marika Vezzoli [b,2], Jessica Galli [a,c,3], Paola Mattei [a], Andrea Rossi [a], Giulia Paderni [a], Lotfi B. Merabet [d,4,5], Elisa Fazzi [a,c,4,6]

[a] Unit of Child Neurology and Psychiatry, ASST Spedali Civili of Brescia, Brescia, Italy
[b] Unit of Biostatistics and Bioinformatics, Department of Molecular and Translational Medicine, University of Brescia, Brescia, Italy
[c] Department of Clinical and Experimental Sciences, University of Brescia, Brescia, Italy
[d] The Laboratory for Visual Neuroplasticity, Department of Ophthalmology, Massachusetts Eye and Ear, Harvard Medical School, Boston, MA, USA

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ABSTRACT

Introduction: Children with Developmental Coordination Disorder (DCD) experience impairments beyond motor planning, affecting visual perceptual and visual-motor integration abilities, similar to children with Cerebral Visual Impairment (CVI), making it challenging to distinguish between the two conditions. This study aimed to identify convergences and divergences in the clinical, neuropsychological, and functional vision-related skills of children with DCD and CVI.

Methods: An assessment of the neuropsychological profile (cognitive, visual cognitive, and motor coordination skills) and visual acuity were conducted on 65 children with DCD (mean age: 8 years, 1 month; SD: 1 year, 6 months) and 35 children with CVI (mean age: 8 years, 5 months; SD: 2 years, 6 months) and compared between the two groups. The CVI-Inventory (CVI-I) was used to evaluate functional vision-related problems and to cluster subjects.

Results: Visual attention, visual perception, global motor coordination, and visual constructive scores didn't differ between the two groups even if children with CVI showed lower scores in the intellectual, visual, visual cognitive, and motor abilities. The overlap index confirmed an overlap on most of the variables considered. Six discriminative questions from the CVI-I clustered subjects into two groups: the first, with more children with CVI (62.9 %) and a more compromised neuropsychological profile, and the second, with more children with DCD (86.7 %).

Conclusion: DCD and CVI share both similarities and differences. Low visual acuity, low IQ scores, severe visual-motor integration challenges, and difficulties with fine motor and balance skills should prompt clinicians to screen for CVI in children with DCD. Specific functional vision-related problems can assist in this differentiation.

* Correspondence to: ASST Spedali Civili of Brescia, Unit of Child Neurology and Psychiatry, Brescia Piazzale Spedali Civili 1, Brescia 25123, Italy.
E-mail addresses: serena.micheletti@unibs.it (S. Micheletti), marika.vezzoli@unibs.it (M. Vezzoli), jessica.galli@unibs.it (J. Galli), paola.mattei@asst-spedalicivili.it (P. Mattei), andrea.rossi@asst-spedalicivili.it (A. Rossi), giulia.paderni@hotmail.it (G. Paderni), lotfi_merabet@meei.harvard.edu (L.B. Merabet), elisa.fazzi@unibs.it (E. Fazzi).
[1] ORCID: 0000–0003-2313–5824
[2] ORCID:0000–0002-0424–4235
[3] ORCID: 0000–0002-3347–7548
[4] These authors share senior authorship
[5] ORCID: 0000–0002-8094–9536
[6] ORCID: 0000–0003-4805–7906

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WHAT THIS PAPER ADDS

For the first time, this study explores potential similarities and differences in the clinical profiles of children and adolescents with Developmental Coordination Disorder (DCD) and Cerebral Visual Impairment (CVI). In both conditions, a high prevalence of males and a high co-occurrence of neurodevelopmental disorders were observed. Additionally, both groups showed high rates of premature birth, which may suggest shared predisposing factors. Some degree of semiological and symptomatic overlap between the two disorders was noted, particularly in difficulties related to visual attention, visual construction, visual perception, and global motor coordination skills. However, children with DCD generally exhibited normal visual acuity, unlike those with CVI, and tended to show higher scores in intellectual functioning, visual-motor integration, fine motor, and balance skills. From a visual-behavioral perspective, a subset of questions from the CVI inventory may assist in identifying children diagnosed with DCD who could benefit from further assessment for suspected CVI, but the utility of these questions requires further validation. These findings may have clinical implications as they: (1) provide preliminary insights into clinical features that could be shared between the two diagnoses; (2) suggest the importance of evaluating visual aspects in individuals with DCD, which is currently underemphasized in existing diagnostic guidelines; (3) highlight that specific tests that, when particularly impaired in individuals with DCD, may warrant further screening for CVI; and (4) indicate that reported difficulties in seeing fast-moving objects, finding the beginning of a line when reading, reaching for objects properly, and crossing floor boundaries may serve as potential behavioural indicators for further investigation in children with DCD for suspected CVI.

1. Introduction

Developmental Coordination Disorder (DCD) is often regarded as a silent, unknown, and frequently under-diagnosed neurodevelopmental condition (Caçola, 2016; Novak et al., 2012). It is marked by significant difficulties in both fine and gross motor coordination (Vaivre-Douret, 2014) which cannot be attributed to intellectual disabilities or major neurological disorders (American Psychiatric Association, 2013). Present from early childhood, DCD affects up to 5–6 % of school-aged children (Blank et al., 2019). Its etiology is currently believed to be multifactorial, involving both pre/perinatal problems, genetic and environmental factors (Gomez & Sirigu, 2015). Children with DCD face several challenges, such as issues with anticipatory motor planning (Adams et al., 2017), impaired anticipatory postural adjustments during various motor tasks (Emanuele et al., 2022), simplified motor control strategies, balance problems (Lust et al., 2022), and reduced movement complexity due to difficulties in coordinating the various possible planes of motion during specific motor tasks (Derikx & Schoemaker, 2020).

Beyond motor impairments, children with DCD often face additional challenges, including visual (Van Dyck et al., 2022) cognitive (Subara-Zukic et al., 2022), and learning difficulties (Wilson et al., 2003). They also struggle with higher-order tasks, such as nonverbal measures of working memory, inhibition, planning, and fluency (Leonard et al., 2015). In the DCD population, comorbidity is thus more the rule than the exception (Kaplan et al., 1998), particularly with respect to other neurodevelopmental disorders. These include specific learning disorders, Autism Spectrum Disorder, ADHD, and language disorder (Blank et al., 2019; Tamplain et al., 2024). Additionally Pearsall-Jones and colleagues (Pearsall-Jones et al., 2010) proposed a continuum of movement disorders between DCD and cerebral palsy.

Approximately half of the children with DCD exhibit generalized difficulties across motor and visual cognitive skills (Pinero-Pinto et al., 2022). Numerous studies have demonstrated that children with DCD have difficulties in visual perceptual tests and visual-motor integration tasks, particularly when requiring speed to complete (Cantin et al., 2014; Tsai et al., 2008). Visual perception and visual motor integration skills involve both object identity and spatial localization; they are closely connected with action systems and have historically been linked to the functioning of the dorsal and ventral visual associative streams in the brain (Goodale & Milner, 1992; Goodale et al., 1994; Milner & Goodale, 2008). Specifically, the ventral stream is involved in perceiving information about objects (vision for perception), while the dorsal stream processes information to guide actions (vision for action).

The integrity of these pathways has previously been linked with visual perceptual abilities in Cerebral Visual Impairment (Dutton, 2009). CVI is defined as a spectrum of visual impairments caused by an underlying brain abnormality that affects the development of visual processing pathways and is characterized by deficits in visual function and functional vision (see Chang et al., 2024 for further details and criteria). CVI frequently co-occurs in children with other neurodevelopmental conditions (Pilling et al., 2022) and affects at least 3 % of children in mainstream schools (Williams et al., 2025). However, the lack of an international consensus regarding the definition and diagnostic criteria, as well as limited prevalence data currently available drive the need for more epidemiological studies to be carried out in the future. CVI is commonly associated with perinatal neurological injury and maldevelopment, such as hypoxic-ischemic injury, trauma, and infection, as well as genetic and metabolic disorders; premature birth is often associated with this diagnosis (Fazzi et al., 2021). Just as DCD comprises an umbrella term for several types of motor deficits, CVI comprises an umbrella term for a range of visually impaired functions (Chokron et al., 2020). The visual dysfunction in CVI may manifest as lower-order or higher order afferent visual deficits, or both, leading to characteristic behaviors in affected individuals (Chang et al., 2024). The profile of visual impairments in CVI is usually characterized by lower-order visual deficits such as reduced visual acuity, visual field limitations, and ocular motor abnormalities (Fazzi et al., 2007; Ortibus et al., 2019). Higher-order visual perceptual deficits associated with impaired visuospatial processing are also commonly described (Ortibus et al., 2019). In some cases, these higher-order deficits represent the most prominent clinical deficits, especially in those individuals with normal or near-normal visual acuity, presenting as higher-functioning CVI (Boot et al., 2010; Chandna et al., 2021). This broad and complex profile of visual function deficits is accompanied by a certain degree of functional vision impairment, which affects an individual's performance when interacting with the

visual environment.

Children with CVI present with functional vision-related problems in the everyday environment, such as impairments in spatial orientation, representation and navigation, object and face recognition, visual search, locating objects in cluttered environments, mental imagery and multiple task management (Ben Itzhak et al., 2023; Lueck & Dutton, 2015; Pehere & Dutton, 2021). Children with CVI (like those with DCD) are also at risk of developing delays or deficits in motor and postural control, motor execution, and oculomotor coordination, since visual guidance of movement embraces the mapping of visual information in the mind (Pehere & Dutton, 2021). These functional vision-related problems in daily life can be detailed using caregiver-rated questionnaires or structured inventories available in clinical practice, such as the Cerebral Visual Impairment Inventory (CVI-I) (Dutton et al. 2010, Dutton, 2011) and the Flemish CVI questionnaire (Ben Itzhak et al., 2020; Ortibus et al., 2011).

Children with DCD and CVI may thus exhibit overlapping signs and symptoms, as well as share common etiological factors and conditions, such as a history of preterm birth, which may be accompanied by cerebral anoxia or hypoxia (Chokron & Dutton, 2016). Children with DCD and CVI are also often assessed using similar neuropsychological tools, including tests of visual motor integration (Morelli et al., 2022; Valverde et al., 2020), of visual perception (Sakki et al., 2021; Tsai et al., 2008), of motor coordination skills (Gras et al., 2023) and tasks from the NEPSY battery (Ben Itzhak et al., 2021). Parents' reports have also been used to gain information on daily life symptoms and fatigue, both in children with DCD (Cancer et al., 2020; De Roubaix et al., 2023; Jasmin et al., 2018) and with CVI (Chandna et al., 2021; Dutton, 2011; Gorrie et al., 2019; Ortibus et al., 2011). Additionally, experimental paradigms that measure coherence sensitivity to global visual form and global visual motion have been used to assess the functioning of the ventral and dorsal cortical streams, respectively (Atkinson et al., 1997; Gunn et al., 2002) and have been applied to both children with DCD (Micheletti et al., 2021; Tallet and Wilson, 2020) and children with CVI (Merabet et al., 2023; Pamir et al., 2021). In a previous study (Micheletti et al., 2021) it was found that children with DCD exhibited behaviors consistent with dorsal and ventral stream dysfunction, as tested by coherence sensitivity to global visual form and global visual motion tasks. Motor skill performance was also related to both global form and global motion sensitivity, even after controlling for age and differences in IQ level.

Given the potential for their conceptual overlap between DCD and CVI, it is crucial to educate clinical practitioners about the complexities involved in differentiating these two conditions. To our knowledge, the overlap between DCD and the motor coordination difficulties stemming from visuo-perceptual and visual deficits associated with CVI has not been previously investigated. This is useful to ensure that children receive the most appropriate therapy tailored to the primary nature of their deficits (i.e., visual or motor; (Chokron & Dutton, 2016). Accordingly, in this study, we explored potential convergences and divergences between DCD and CVI with respect to their neuropsychological profile, with particular regard to their visual cognitive skills, visual acuity, and their functional

Table 1
Descriptive statistics on demographic and clinical characteristics of the sample stratified by the diagnosis.

	CVI (N = 35)	DCD (N = 65)	Total (N = 100)	p value
Gender				***0.015***[a]
Males n. (%)	20 (57.1 %)	52 (80 %)	72 (72 %)	
Females n. (%)	15 (42.9 %)	13 (20 %)	28 (28 %)	
GA				0.271[b]
Mean (SD)	36.94 (3.45)	37.68 (3.50)	37.42 (3.48)	
Median (Q1, Q3)	38 (35, 40)	39 (37.00, 40.00)	39 (36, 40)	
Range	28–41	24–42	24–42	
Preterm birth				
(<37 weeks)	10 (28.6 %)	12 (18.5 %)	22 (22 %)	0.181[a]
(<32 weeks)	4 (11.4 %)	6 (9.2 %)	10 (10 %)	0.488[a]
Age				0.474[b]
Mean (SD)	8.69 (2.51)	8.09 (1.71)	8.30 (2.03)	
Median (Q1, Q3)	8 (7, 10)	8.00 (7, 9)	8 (7, 9)	
Range	6–15	6–13	6–15	
Independent mobility				***0.011***[b]
Mean (SD)	15.86 (3.55)	14.37 (2.99)	14.89 (3.26)	
Median (Q1, Q3)	15 (14.00, 17.50)	14 (12, 15)	14 (13, 16)	
Range	10–30	9–27	9.00–30	
Visual Acuity				***< 0.001***[b]
Mean (SD)	8.14 (1.96)	9.66 (0.91)	9.13 (1.54)	
Median (Q1, Q3)	8 (6.50, 10.00)	10 (10, 10)	10 (9, 10)	
Range	4–10	5–10	4–10	
FIQ				***< 0.001***[b]
Mean (SD)	88.34 (18.01)	101.51 (14.97)	96.90 (17.21)	
Median (Q1, Q3)	81 (74.00, 96.50)	102 (91.00, 110.00)	96 (82.75, 109.00)	
Range	70–135	73–137	70–137	
VIQ				***0.025***[b]
Mean (SD)	101.54 (13.85)	108.57 (15.24)	106.11 (15.08)	
Median (Q1, Q3)	100 (88, 111)	108 (96, 120)	107.50 (92.00, 118.50)	
Range	85–134	85–149	85–149	

In bold and Italics: significative p-values (<0.05)

[a] Chi-square test

[b] Wilcoxon Rank Sum test

vision-related problems in daily life.

Specifically, the study aims to explore possible convergences and divergences between DCD and CVI diagnoses by addressing the following questions: First, can similarities and differences be identified in the neuropsychological and visual profiles of children with DCD compared to those with CVI? Second, can similarities and distinctions in functional vision-related problems, as revealed by parents-rated questionnaires, be identified between children with DCD and those with CVI?

2. Methods

2.1. Participants

In this prospective, cross-sectional study, a group of children and adolescents with DCD and a group of children and adolescents with CVI were recruited at the Unit of Child Neurology and Psychiatry of ASST Spedali Civili of Brescia, Italy, from May 2023 to May 2024. Children were recruited both from those who consecutively received a diagnosis of DCD or CVI at the Unit within the specified time range and from those who visited our Unit with a previous diagnosis of DCD or CVI for clinical monitoring. All the children with DCD meeting the following criteria were selected: (1) diagnosis of DCD, either previously determined or detected during the consultation, according to DSM-5 criteria and International Guidelines; (2) IQ within the normal range or borderline intellectual functioning (Verbal IQ – VIQ or Verbal Comprehension Index - VCI $>$ 85 and Full IQ - FIQ $\geq$ 70) as measured by the WISC IV (Wechsler et al., 2012); (3) proficiency in the Italian language (both the child and parents); and (4) age range of 6–16 years. All families of the selected participants provided informed consent to participate in the study, resulting in a group of 65 children with DCD (13 females: 20 %, 52 males: 80 %, mean age 8 years and 1 month; SD: 1 year and 6 months) (see Table 1 for further details). Complications during pregnancy were reported in 20 cases (30.7 %), including placenta previa, gestational diabetes, preeclampsia, infections, and HELLP syndrome. Perinatal problems such as cesarean and instrumental deliveries were reported in 15 cases (23.1 %). Twelve children were born before the 37th week of gestational age (GA) (18.5 %), six of them (9.2 %) before the 32nd weeks of gestation age, leading to NICU admission and a 3-year neurological follow-up, without major neurological signs out of DCD. Other neurodevelopmental co-occurring disorders were identified in 52 % of children (see Table A1 for details).

During the same period, a group of children and adolescents with CVI were recruited at the Centre for Diagnosis and Treatment of Children with Neurovisual Problems and Multi-disabilities, affiliated with the Unit of Child Neurology and Psychiatry of ASST Spedali Civili of Brescia, Italy. The diagnosis of CVI was made according to the protocol routinely used at the Centre (Fazzi et al., 2007; Galli et al., 2022; Micheletti et al., 2024) and to the available CVI definitions (Chang et al., 2024; Dutton et al., 2006; Sakki et al., 2018). For this study the children meeting the following inclusion criteria were selected: (1) normal or near normal visual acuity ($>$ 3 tenth); (2) IQ within the normal range or borderline intellectual functioning (Verbal IQ – VIQ/VCI $>$ 85 and Full IQ - FIQ $\geq$ 70) as measured by the WISC IV; (3) proficiency in the Italian language (both the child and the parents); and (4) age range 6–16 years, defining a group of children with higher functioning CVI (HF-CVI). All families of the invited participants provided informed consent to participate in the study, resulting in a group of 35 children (15 females - 42.9 %, 20 males - 57.1 %, mean age 8 years and 5 months; SD: 2 years and 6 months) participated in the study (Table 1). CVI etiologies included perinatal neurological injury (hypoxic/ischemic injury), structural malformations, genetic/syndromic, infection, and unknown conditions. Ten children were born before the 37th week of GA (28.6 %) and four of them (11.4 %) before the 32nd week of GA. Other neurodevelopmental co-occurring disorders were identified in 32 children (91.43 %) (See Table A1 for further details).

All participants in both groups had attended kindergarten in Italy and received education within the mainstream school system. A learning support teacher assisted 18 children (52 %) in the CVI group during school hours, even though they followed the regular class-learning program. No children with DCD received support from a learning support teacher during school hours.

2.2. Procedures

The study received approval from the Ethics Committee of the Hospital Institution (NP n. 5906). The research was conducted in compliance with the World Medical Association's Code of Ethics (Declaration of Helsinki) for human experimentation. Clinical and demographic characteristics (sex, age at evaluation, GA, independent walking expressed in months), along with data on neurological, intellectual, and neuromotor assessments and visual acuity, were extracted from the clinical records of both cohorts (Table 1). Scores from the WISC-IV (Wechsler, 2012), and the Movement Assessment Battery for Children, 2nd edition (Henderson et al., 2007), relevant to CVI and DCD diagnosis, were collected for indexes and total scores (Verbal Comprehension, Visual Reasoning, Working Memory, Processing Speed Indexes, Full Scale IQ for WISC-IV, Fine Motor, Ball, Balance Skills, and Total Score for MABC2). Visual acuity data for both groups were retrieved from clinical records and assessed under maximum refractive correction using letter optotypes, with results expressed in tenths. For children with CVI, comprehensive neurovisual profile data were obtained (Table A2). The neuropsychological evaluation, conducted within three weeks post-recruitment, included assessments of visual cognitive abilities for both groups. This included visual-motor integration tasks using the Beery-Buktenica Developmental Test of Visual-Motor Integration - VMI - (Beery & Buktenica, 2000) and the Block Design subtest from NEPSY II (Korkman et al., 2007). Visual perceptual skills were assessed via the Street Completion Test (Bova et al., 2007; Gugliotta et al., 2023), which measures the ability to integrate incomplete visual stimuli into a coherent perceptual whole. Visual attention skills, encompassing both selective and sustained attention, were evaluated using the Bell's Cancellation Task (Biancardi & Stoppa, 1997). Additionally, parents of participants in both groups completed the Cerebral Visual Impairment Inventory (CVI-I) (Dutton et al., 2010; Dutton, 2011), a structured tool to document parental observations and functional CVI-related problems. Parents rated their child's difficulties on a 5-point Likert scale ranging from 'never' to 'always'.

All participants completed the evaluations, and any missing data were handled using appropriate statistical methods (see Statistical section for further details).

2.3. Statistical analysis

Descriptive statistics were computed on variables of different nature. Specifically, for quantitative variables we computed the number of missing values (N-Miss); mean and standard deviation (SD); median; first quartile (Q1) and third quartile (Q3); range (minimum–maximum). In the case of categorical variables, frequencies (absolute and percentage values) were computed. Data were also stratified by the diagnosis (CVI/DCD) to identify any significant differences (p- value$<$ 0.05) between the two subpopulations obtained. For this purpose, the Wilcoxon Rank Sum test (for quantitative variables) and the Chi-square test (for qualitative variables) were applied.

To better assess the similarity between the subgroups of CVI and DCD patients with respect to psychometric scores, the Overlap Index (OVL) was introduced to quantify the degree of overlap between two probability distributions. Mathematically, the OVL is computed as:

$$OVL = \int (f_1(x), f_2(x))\, dx$$

where $f_1(x)$ and $f_2(x)$ represent the probability density functions of the two subgroups. This index ranges from 0 (no overlap) to 1 (complete overlap). When it falls within the interval [0.3, 0.7], it indicates a moderate degree of separation between the subgroups. The OVL is useful for assessing group differentiation without assuming the normality of the continuous variables. The extension of the density function beyond the limits (min-max) of the analyzed variable is an artifact of the smoothing techniques in Kernel Density Estimation, which assumes a continuous and unbounded density function.

Only for CVI patients in the sample, Spearman correlation coefficients p_s between pairs of CVI-I 51 items were visualized by means of a correlation plot to facilitate the examination of putative relationships between the data. This plot reports an upper triangular matrix where blue and red cells correspond to positive ($0 \leq p_S \leq 1$) and negative ($-1 \leq p_S \leq 0$) correlations, respectively. Moreover, the color intensity is proportional to the magnitude of Spearman indexes (with their values reported in each cell). White cells correspond to non-statistically significant correlations.

To control for the confounding effect of the Verbal Comprehension Index (VCI), linear regression models were applied to compare neuropsychological outcomes between diagnostic groups (CVI vs. DCD), adjusting for VCI scores. Estimated marginal means (and corresponding standard errors, se) were computed to facilitate the comparison of adjusted group means, allowing for a more accurate interpretation of the neuropsychological differences between groups.

Since CVI was the underrepresented class in the sample analyzed, the Synthetic Minority Over-sampling Technique (SMOTE) (Chawla et al., 2002) was employed to rebalance the dataset by artificially doubling the number of CVI subjects. It creates synthetic observations by interpolating between randomly selected points from the minority class and their nearest neighbors. This increases the number of minority class instances without simply duplicating existing data, helping to improve the performance of predictive models when dealing with this type of problems. On the rebalanced dataset, a machine learning method, such as Random Forest (RF) (Breiman, 2001; Carpita and Vezzoli, 2012; Doglietto et al., 2020; Garrafa et al., 2021), was estimated using the diagnosis as the outcome and the 51 CVI-I items as covariates. This analysis was conducted to extract the relative Variable Importance Measure (relVIM) to identify which items could best discriminate between CVI and DCD patients. The most predictive variables (those with relVIM $\geq$ 50) were visualized by means of a lollipop plot and, subsequently, used for further analysis.

Two cluster analyses were performed, both employing an Unsupervised Random Forest, to estimate the proximity matrices. These matrices capture complex, non-linear relationships in the data and reflect similarities between subjects without relying on predefined labels. The Unsupervised Random Forest algorithm leverages decision trees to compute distances between observations (patients) and group them into clusters.

The first cluster analysis was performed exclusively on the original CVI patients (without considering those created artificially) and was based on all 51 CVI-I items, with the goal of exploring internal homogeneity within the CVI group. The second cluster analysis was applied to the rebalanced dataset, focusing on the important items selected by relVIM extracted from the RF. The groups derived from both analyses were used as stratification variables to assess the descriptive statistics of the clinical variables in the dataset with respect to the subpopulations identified through clustering. For comparisons, the Wilcoxon Rank Sum test (for quantitative variables) and the Chi-square test (for qualitative variables) were employed.

All the statistical analyses was performed using R (version 4.4.1).

3. Results

The analyzed dataset comprised 100 children diagnosed with Developmental Coordination Disorder (DCD) (65 %) and Cerebral Visual Impairment (CVI) (35 %).

The clinical features of the two groups are described in Table 1. No significant differences were found in age ($p = 0.474$), GA ($p = 0.271$), and preterm birth ($<$37 weeks $p = 0.181$; $<$32 weeks $p = 0.488$). However, children with DCD were more frequently males ($p = 0.015$), demonstrated a significantly younger age for achieving independent walking ($p = 0.011$), better visual acuity ($p < 0.001$), and higher scores in full IQ ($p < 0.001$) and the Verbal Comprehension Index ($p = 0.025$) compared to those with CVI.

3.1. Neuropsychological profile

The neuropsychological profile of the two groups is detailed in Fig. 1 and Table A3.

Children with DCD showed better performance with respect to all the variables considered, namely motor coordination skills, intellectual functioning, visual attention, visual motor integration and construction, and visual perceptual skills (Fig. 1). After adjusting the results for verbal IQ (Verbal Comprehension Index – VCI from WISC IV), differences between the two groups on most tasks, namely Visual Selective Attention, Visual Sustained Attention, Block Building Test, Street Completion Test, Ball skills index and total index of the MABC2, were no longer statistically significant. Even after adjusting for VCI, all the indices of the WISC IV, the VMI test, and the Fine-motor and Balance Indexes at MABC2 remained higher in children with DCD compared to CVI (Table 2).

Fig. 2 presents a density plot and the OVL index, stratified by diagnosis (CVI and DCD), for intellectual functions, visual acuity, visual cognitive abilities, and motor coordination skills: WISC IV: Full IQ, Visual Reasoning Index (VRI), Visual Acuity; Visual Selective Attention; Visual Sustained Attention; VMI; Block Building Test; Street Completion Test; MABC2 Total Score and Fine Motor, Ball and Balance Indexes. Gestational age was added as an indirect measure of possible etiopathogenetic components. Most of the scores included in the analysis showed a high degree of overlap. The only three variables that showed a moderate distinction between the two clinical groups were the Total score, Fine Motor skills at MABC2, and the Visual Acuity level, which were more compromised in children with CVI.

3.1.1. Functional vision-related problems at CVI-I

Before comparing the two groups based on their functional vision-related problems, an internal verification of the CVI-I was conducted (see Appendix B, Table A4, Fig. 1S).

A RF was generated where the outcome variable was the diagnosis (CVI or DCD) and the covariates were the 51 CVI-I items. Since the dataset was imbalanced (35 CVI vs. 65 DCD) the SMOTE algorithm was applied to increase the number of CVI patients and thus rebalance the two diagnostic categories (DCD and CVI groups). The final sample consisted of 70 subjects with CVI and 65 subjects with DCD. The RF model was primary used to identify which items were most informative in distinguishing between the two diagnoses. Consequently, the relative variable importance measure (relVIM) was extracted. The results were visualized using a lollipop graph (Fig. 3), and only six items emerged as particularly informative in distinguishing between CVI and DCD (Fig. 3), as their relVIM was greater than 50 (Vezzoli, 2011). These items related to difficulties in: seeing objects that are moving quickly, seeing passing vehicles while in a car, finding the beginning of a line when reading, reaching objects accurately, crossing interior floor boundaries, and the need to look down while crossing them.

To further assess the discriminative capacity of the six selected items in dividing subjects into homogeneous groups, a cluster analysis was conducted using an Unsupervised Random Forest applied to the rebalanced dataset. This analysis identified two sub-populations (Table 3). The first (Cluster 1–105 subjects) exhibited a prevalence of 62.9 % of individuals with CVI, while the second (Cluster 2–30 subjects) had a prevalence of 86.7 % of individuals with DCD (chi-square test $p < 0.001$). These clusters were

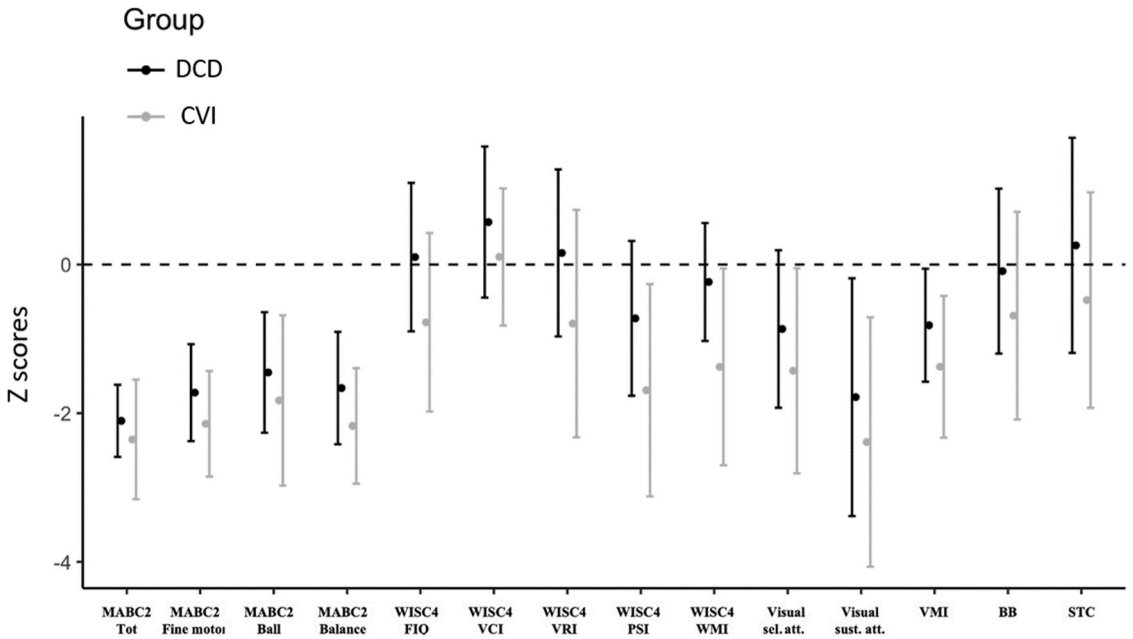

Fig. 1. Neuropsychological profile stratified by DCD versus CVI groups: MABC2: Movement ABC test - 2nd version; FIQ: Full Intelligent Quotient; VCI: Verbal Comprehension Index; VRI: Visual reasoning Index; PSI: Processing Speed Index; WMI: Working Memory Index; VMI: Berry-Buktenica Visual Motor Integration Test; BB: Block Building Test; STC: Street Completion Test.

Table 2
Marginal means adjusted for the effect of VCI for neuropsychological variables.

Variables	CVI mean (se)	DCD mean (se)	p.value
MABC2 Total Score	−2.34 (0.11)	−2.11 (0.08)	0.082
MABC2 Fine Motor Skills	−2.14 (0.12)	−1.72 (0.09)	***0.005***
MABC2 Ball Skills	−1.83 (0.16)	−1.45 (0.12)	0.065
MABC2 Balance Skills	−2.15 (0.13)	−1.67 (0.10)	***0.004***
Full IQ	−0.55 (0.13)	−0.02 (0.10)	***0.002***
Visual Reasoning Index (VRI)	−0.62 (0.20)	0.06 (0.14)	***0.007***
Processing Speed Index (PSI)	−1.62 (0.23)	−0.76 (0.16)	***0.003***
Working Memory Index (WMI)	−1.20 (0.19)	−0.33 (0.14)	***0.001***
Visual Selective Attention	−1.37 (0.20)	−0.90 (0.15)	0.066
Visual Sustained Attention	−2.36 (0.28)	−1.80 (0.20)	0.117
Visual Motor Integration Test (VMI)	−1.30 (0.14)	−0.86 (0.10)	***0.011***
Block Building Test	−0.55 (0.21)	−0.16 (0.14)	0.121
Street Completion Test	−0.36 (0.28)	0.20 (0.20)	0.115

In bold and Italics: significative p-values (<0.05)

subsequently used to stratify the rebalanced dataset, and the descriptive statistics of the clinical and neuropsychological variables (not used in the clustering) were computed and compared between the two clusters. Results highlighted that six out of ten clinical variables were significantly different between the subgroups. Specifically, one variable concerned motor coordination skills (MABC2 Balance skills), while the others were related to visual cognitive skills (Visual Selective Attention, Visual Sustained Attention, Block Building test, VMI test) and Visual Acuity, all of which were consistently more impaired in children belonging to Cluster 1 (where CVI was more prevalent).

4. Discussion

Based on the definition of DCD provided by the DSM 5 (American Psychiatric Association, 2013) and international guidelines (Blank et al., 2019), it is established that a DCD diagnosis can only be made in the absence of "movement disorders with known etiologies" or sensory problems, such as "substantial visual impairments". This excludes the possibility of diagnosing DCD in individuals exhibiting major neurological signs related, for example, to cerebral palsy or muscular dystrophy. Furthermore, it excludes individuals with significant alterations in basic visual functions, such as impaired visual acuity, contrast sensitivity, and limited visual field, as in cases like CVI in relation to early neurological injury and maldevelopment. However, recent scientific evidence highlights the presence of CVI in individuals with normal or near normal visual acuity and only mildly compromised basic visual functions, defining the picture of high-functioning CVI (HF-CVI) (Chandna et al., 2021; Chang and Merabet, 2024). This has blurred the boundaries between HF-CVI and DCD, making the distinction between these conditions less clear and raising the need for further analytical approaches to differentiate between them.

This study aimed to explore potential similarities and distinctions between children and adolescents with DCD and those with CVI by examining specific clinical aspects, visual and neuropsychological characteristics, and functional vision-related problems in daily life. To ensure comparability, the CVI group included individuals with normal or near-normal visual acuity and average verbal intellectual abilities, representing higher-functioning cases of CVI.

The results suggest that these diagnoses may share certain commonalities in clinical history, neuropsychological profiles, and functional challenges reported in both home and external environments while also exhibiting some differences. Both groups showed a high rate of preterm birth, approximately twice as high as that reported in developed countries (Ohuma et al., 2023), and a high prevalence of co-occurring neurodevelopmental conditions (see Table A1). These observations raise the possibility of shared pre-, peri-, and post-natal predisposing factors (Chokron & Dutton, 2016), though further research is needed to clarify the nature of this relationship. A greater proportion of males was observed in both the samples, with this trend being significantly more pronounced in children with DCD. Additionally, children with DCD tended to begin walking earlier, had better visual acuity and higher Full IQ and VCI scores on the WISC IV. These findings may suggest a relatively milder clinical profile in children with DCD, at least regarding the specific clinical features assessed in this study.

Regarding their neuropsychological profiles, both similarities and differences emerged after controlling for the Verbal Comprehension Index from the WISC-IV. Global motor coordination, visual attention, visual construction and visual perception skills in children with DCD did not differ significantly from those with CVI, suggesting the possibility of a comparable visual cognitive profile between the two groups when performances are adjusted for verbal intellectual abilities. However, this finding should be interpreted with caution, as other factors may contribute to the observed similarities. Persistent differences were observed in the indexes derived from the WISC-IV, VMI test, and the Fine Motor and Balance Indexes from the MABC-2, with children with CVI exhibiting significantly greater impairments. The similar performances on neuropsychological tests across the two groups may indicate some degree of overlap between their clinical profiles, though further research is needed. The greater impairment in intellectual, fine motor, and balance skills observed in individuals with CVI could be partially explained by the underlying etiology of CVI. Unlike DCD, which is often less clearly defined, CVI is more frequently associated with brain lesions, which may contribute to more severe intellectual and neuromotor difficulties (Fazzi et al., 2004; Fazzi et al., 2009). However, the extent to which these differences are attributable to distinct underlying mechanisms or other co-occurring factors remains to be further explored. This observation is further supported by the calculation of

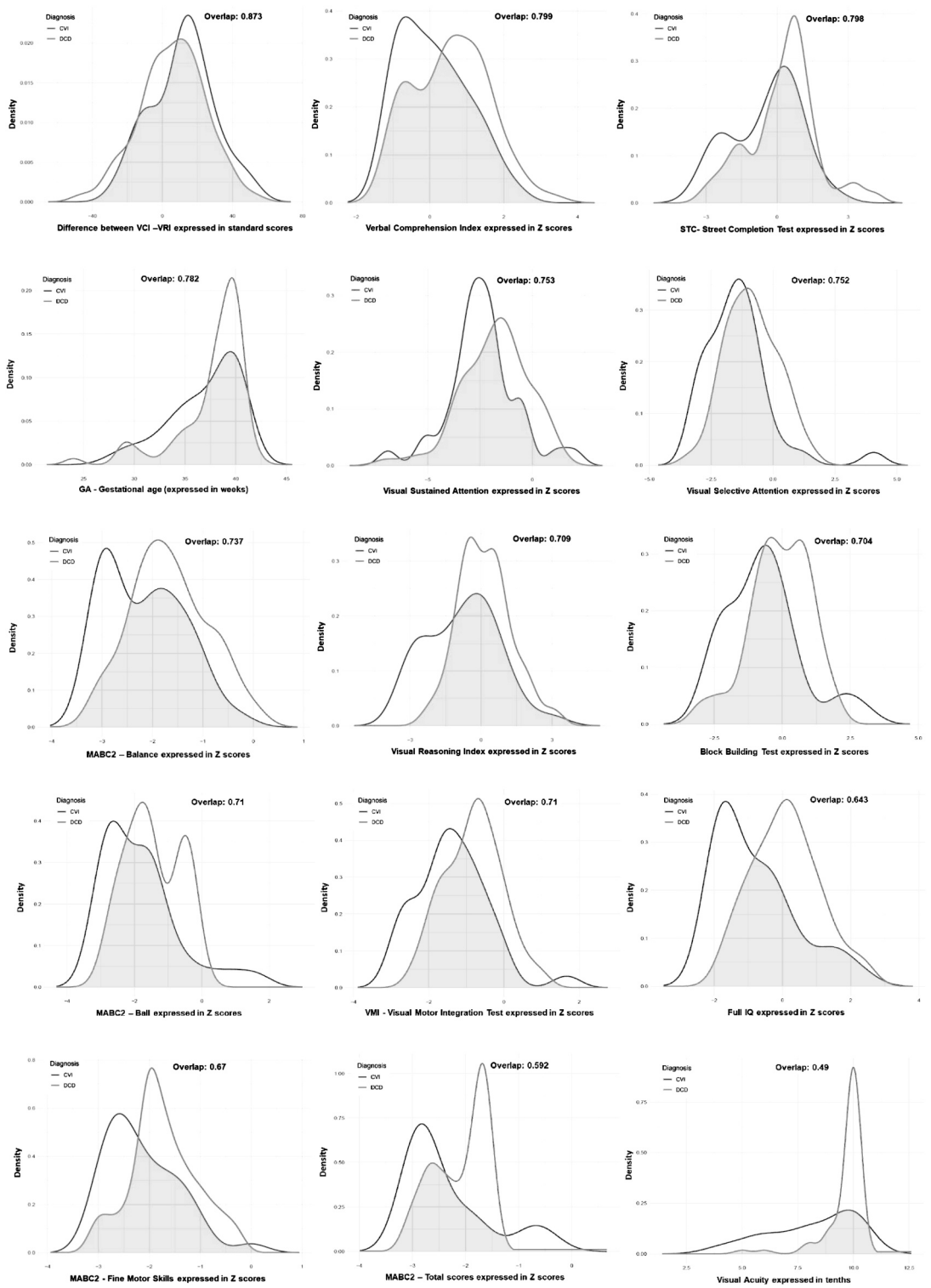

Fig. 2. Density plots and OVL indexes for each psychometric score included in the analysis, along with gestational age (GA), stratified by diagnosis (CVI and DCD). The overlapping regions are shaded in gray. The figures are arranged from highest to lowest OVL. Some figures show an extension of the density function beyond the variable's minimum and maximum limits; this is an artifact of the smoothing techniques used in the analysis (Kernel Density Estimation), which assumes a continuous and unbounded density function.

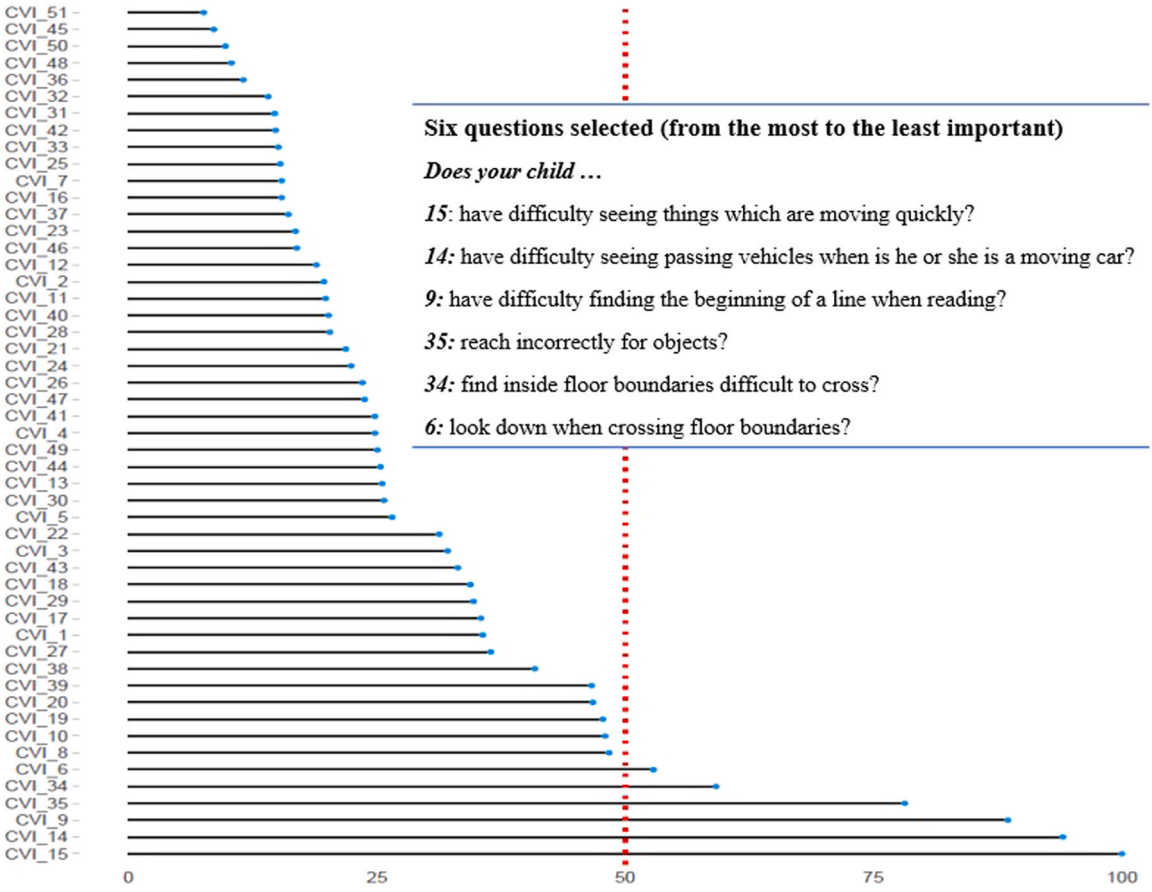

Fig. 3. Lollipop graph representing the six variables extracted from the VIM analysis on the rebalanced dataset.

the Overlap Index among the visual, intellectual, visual-cognitive, and motor skills considered. The results indicated that total scores on the MABC2 and visual acuity were the most distinctive variables, with the CVI group exhibiting greater difficulties. Additionally, a moderate degree of overlap in the gestational ages of the two groups suggests a potential shared etiopathogenetic substrate in our samples, but the extent to which these differences are attributable to distinct underlying mechanisms or other co-occurring factors remains to be further explored.

To our knowledge, no previous study has compared this clinical population with a neuropsychological assessment battery, leaving this area of investigation largely unexplored. A convergence of neuropsychological signs between children with DCD and those with CVI has been previously mentioned by Chokron and colleagues (2020), who underlined the risk of a large number of children with CVI likely being inappropriately diagnosed as having DCD. Along these lines, these results may provide a useful contribute to the clinical practice, as according to the most recent clinical guidelines (Blank et al., 2019), a comprehensive visual evaluation (the potential correlation with CVI was not mentioned) is not clearly recommended for all the subjects with DCD. Additionally, the results suggest that VMI and MABC2 tests may serve as valuable assessment tools for identifying potential signs of CVI in children with DCD, and this consideration is particularly pertinent for children who experience significant difficulties in performing these tasks. Further analysis with a more comprehensive neuropsychological assessment battery, including all functions involved in the definition of CVI, is recommended.

The second aim of this study was to explore potential commonalities and differences in functional vision-related problems, as assessed through questionnaires, in children with DCD and those with CVI. Six items emerged as the most informative in differentiating between the two groups. According to the author of the CVI-I (Dutton et al., 2010; Dutton, 2011), the majority of the identified questions that were related to impaired perception of movement, visual field and visual attention deficits, and difficulties in visually guided movements, most of which were associated with skills independent of movement involvement. These findings may suggests some degrees of similaritiy between the two disorders, in terms of motor output and its impact on daily life. Given the nature of questionnaire-based assessments and the complexity of functional vision-related problems in daily life, these results should be interpreted with caution.

Gorrie et al. (2019) and Chandna et al. (2021) proposed a similar investigation of the most reliable questions in the CVI-I that could potentially serve as a brief screener or as a measure of CVI-related impairment in children at risk for CVI. The questions identified by the authors showed only a marginal overlap to those identified in our study. They appeared to be more characterized by issues in

Table 3
Descriptive statistics of the neuropsychological profile and visual acuity stratified by the two subgroups identified through cluster analysis on the rebalanced dataset based on the six questions selected by Random Forest

	Cluster 1 (N = 105)	Cluster 2 (N = 30)	Total (N = 135)	p value
Diagnosis				***< 0.001***[a]
CVI	66 (62.9 %)	4 (13.3 %)	70 (51.9 %)	
DCD	39 (37.1 %)	26 (86.7 %)	65 (48.1 %)	
MABC2 Tot score				0.104[b]
Mean (SD)	−2.24 (0.70)	−2.04 (0.57)	−2.20 (0.67)	
Median (Q1, Q3)	−2.44 (−2.67, −1.67)	−1.83 (−2.33, −1.67)	−2.33 (−2.67, −1.67)	
Range	−3.00 - −0.33	−3.00 - −0.67	−3.00 - −0.33	
MABC2 Fine Motor Skills				0.155[b]
Mean (SD)	−2.00 (0.68)	−1.79 (0.68)	−1.95 (0.68)	
Median (Q1, Q3)	−2.00 (−2.63, −1.61)	−1.83 (−2.00, −1.42)	−2.00 (−2.51, −1.58)	
Range	−3.00 - −0.33	−3.00–0.00	−3.00–0.00	
MABC2 Ball Skills				0.415[b]
Mean (SD)	−1.63 (1.05)	−1.54 (0.82)	−1.61 (1.00)	
Median (Q1, Q3)	−1.67 (−2.50, −1.22)	−1.67 (−2.00, −0.75)	−1.67 (−2.33, −1.03)	
Range	−3.00–1.67	−3.00 - −0.33	−3.00–1.67	
MABC2 Balance Skills				***0.014***[b]
Mean (SD)	−2.03 (0.72)	−1.56 (0.90)	−1.92 (0.78)	
Median (Q1, Q3)	−2.00 (−2.67, −1.43)	−1.67 (−2.25, −0.75)	−2.00 (−2.58, −1.33)	
Range	−3.00 - −0.67	−3.00–0.00	−3.00–0.00	
Visual Selective Attention				***0.038***[b]
Mean (SD)	−1.28 (1.22)	−0.84 (1.04)	−1.18 (1.19)	
Median (Q1, Q3)	−1.30 (−2.00, −0.80)	−0.90 (−1.50, −0.03)	−1.25 (−1.96, −0.70)	
Range	−3.40–4.06	−3.10–1.27	−3.40–4.06	
Visual Sustained Attention				***0.015***[b]
Mean (SD)	−2.29 (1.64)	−1.66 (1.47)	−2.15 (1.62)	
Median (Q1, Q3)	−2.26 (−3.28, −1.37)	−1.58 (−2.10, −0.88)	−2.16 (−3.12, −1.10)	
Range	−6.98–2.01	−5.69–1.12	−6.98–2.01	
Visual Motor Integration Test (VMI)				***0.012***[b]
Mean (SD)	−1.23 (0.87)	−0.81 (0.83)	−1.14 (0.87)	
Median (Q1, Q3)	−1.27 (−1.80, −0.73)	−0.77 (−1.30, −0.23)	−1.13 (−1.74, −0.60)	
Range	−2.80–1.67	−2.47–0.93	−2.80–1.67	
Block Building test				***0.007***[b]
Mean (SD)	−0.63 (1.18)	0.08 (1.21)	−0.48 (1.22)	
Median (Q1, Q3)	−0.55 (−1.33, 0.00)	0.00 (−0.67, 0.92)	−0.33 (−1.05, 0.33)	
Range	−3.00–2.33	−2.33–3.00	−3.00–3.00	
Street Completion Test				0.452[b]
Mean (SD)	−0.03 (1.29)	−0.14 (1.32)	−0.05 (1.29)	
Median (Q1, Q3)	0.17 (−0.50, 0.47)	0.43 (−1.12, 0.83)	0.20 (−0.52, 0.71)	
Range	−3.21–4.12	−3.07–1.37	−3.21–4.12	
Visual Acuity				***0.038***[b]
Mean (SD)	8.88 (1.60)	9.40 (1.30)	9.00 (1.55)	
Median (Q1, Q3)	10.00 (8.00, 10.00)	10.00 (10.00, 10.00)	10.00 (8.00, 10.00)	
Range	4.00–10.00	5.00–10.00	4.00–10.00	

In bold and Italics: significative p-values (<0.05)
[a] Chi-square test
[b] Wilcoxon Rank Sum test

handling complex visual scenes and motor organization in space. Specifically, Gorrie et al. (2019) tested the validity and sensitivity of the "CVI-I Five Questions," which were extracted directly from the CVI-I by the author of the inventory (Dutton et al., 2010). These 5 questions described the range of visual difficulties most frequently reported in children with visual perceptual and cognitive deficits and demonstrated good convergent validity and internal consistency in screening for CVI in typically developing children. No clinical data on the group of children with CVI were reported by the authors. Moreover, none of these five questions corresponded to those identified in the current study. For their part, Chandna and colleagues (2021) identified a subset of 11 screening questions to distinguish between typical behaviors and those seen in children with CVI. They compared responses to the CVI-I from parents of children with CVI, most of whom had major neurological disorders (with no available IQ data), to those from a larger group of typically developing children. The 11 questions, identified through a series of dichotomy analyses, spanned various issues related to different visual cognitive domains, such as difficulties in handling complex visual scenes, visually guided movements, and visual attention skills, and only partially overlapped with those identified in the current study (items 6, 14, 34). This disparity likely reflects the differing clinical characteristics of the subjects recruited in these studies, which can be better defined only through specific questions derived from the entire inventory. In the current study, to explore the possible discriminative capacity of the 6 selected items in classifying subjects based on their diagnosis, an unsupervised Random Forest approach was applied, which resulted in two clusters. Children in Cluster 1 showed more frequent challenges with visual functioning at home, alongside greater difficulties in motor balance, visual attention, and visual-motor integration, as well as impaired visual acuity. This seems to suggest a link between visual cognitive signs

and functional vision-related problems in both home and external settings. Cluster 1 constituted approximately 80 % of the population and included almost all subjects with CVI, while the second cluster comprised only a small portion of the sample, consisting almost entirely of subjects with DCD. Therefore, while children with CVI were homogeneously organized based on functional vision-related problems in daily life, children with DCD were more dispersed between the two clusters, suggesting that the identified questions could serve as a screening tool to determine which subjects with a DCD diagnosis warrant further diagnostic evaluation for symptoms compatible with CVI.

This study does have several limitations to consider. Regarding the study participants, the limited number of recruited participants, especially in the CVI group, reduced the ability to generalize the results. For this reason, a SMOTE procedure was applied to ensure an equal number of patients in both groups. Additionally, the inclusion of children with other neurodevelopmental disorders could introduce confounding factors that are difficult to control during the analysis. However, since the presence of other neurodevelopmental disabilities is common in both CVI and DCD conditions, the selected sample can be considered as more representative of these clinical populations. As for the procedure, the criteria used for assessing CVI, despite being as objective as possible, did not follow "standard criteria" since no international guidelines for the diagnosis of CVI have been established so far. Nevertheless, a well-known and widely applied assessment protocol was used for the purposes of diagnosis. Furthermore, a limited number of tests were selected to assess the presence of visual perceptual and visual motor integration skills, which could underestimate the nature and extension of neuropsychological convergences and divergences between the two diagnoses. Further studies with more comprehensive assessment batteries that cover additional visual dysfunctions such as visual orientation and navigation, a more complete assessment of figure-ground perception, and an analysis of visual search strategies are recommended. Finally, part of the assessment protocol proposed to the participants consisted of parent-reported information, increasing the risk of over- or under-reporting symptoms and compromising objectivity. This choice was made because many CVI dysfunctions are related to daily activities and cannot be easily detected during structured evaluation procedures.

In conclusion, the findings from this study suggest that children with DCD and CVI may exhibit both similarities and differences. Both groups appeared to share a higher prevalence of males, higher rates of premature birth, a higher incidence of co-occurring neurodevelopmental conditions, and potentially similar visual cognitive profiles, including comparable skills in visual attention, perception, construction, and overall motor coordination skills. Moreover, the functional vision-related problems observed by caregivers in daily life environments provide only partial insight into the diagnostic picture.

Key differences between the groups were also noted, with the CVI group demostrating more severe impairments in basic visual functions, such as visual acuity, along with lower IQ levels and greater difficulties in fine motor and balance skills. Additionally, parental reports of difficulties related to movement perception, visual fields, visual attention, and visually guided movements may offer supplementary insights, but these should be interpreted in conjunction with comprehensive clinical evaluations when considering screening for CVI in children with DCD.

Overlapping semiological and symptomatic elements appear thus to be present between the two disorders, potentially indicating some degree of shared etiopathogenetic mechanisms. The similarity in GA distribution and the prevalence of preterm births in both groups could support this hypothesis, though further investigation is needed to confirm any underlying commonalities. At the same time, certain diagnosis-related characteristics—such as the greater severity of visual impairment (as measured by visual acuity), as well as greater intellectual and motor deficits in subjects with CVI—indicate possible points of divergence that may be linked to differences in neural involvement. The complex clinical profiles observed could suggest a spectrum of impairment, where some individuals exhibit higher-order visual and motor problems, as seen in DCD, while others present with more pronounced lower-level visual deficits and a generally more compromised visual cognitive and visual functional profile, as seen in CVI. Caution is warranted in interpreting these findings, as our study did not examine neuroimaging correlations, which could provide further insights into the neural basis of these conditions. Given these limitations, future research should aim to clarify the extent to which these disorders share common developmental pathways or represent distinct conditions with overlapping features. Longitudinal studies integrating neuroimaging, cognitive, and visual functional assessments will be particularly valuable in refining our understanding of their etiopathogenetic and clinical relationships.

CRediT authorship contribution statement

Micheletti Serena: Writing – original draft, Resources, Methodology, Investigation, Data curation, Conceptualization. **Vezzoli Marika:** Writing – original draft, Methodology, Formal analysis. **Galli Jessica:** Resources, Investigation, Conceptualization. **Mattei Paola:** Writing – original draft, Investigation, Conceptualization. **Rossi Andrea:** Supervision, Investigation. **Paderni Giulia:** Resources, Data curation, Conceptualization. **Merabet Lotfi B.:** Writing – original draft, Supervision, Methodology, Data curation, Conceptualization. **Fazzi Elisa:** Writing – original draft, Supervision, Methodology, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Chat GPT in order to improve language and readability. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Declaration of Competing Interest

The authors declare no competing interests.

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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.ridd.2025.105019.

Data Availability

Data will be made available on request.

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