Visual and Sensory Processing Disorders in Children with Cerebral Palsy and Cerebral Visual Impairment – Implications for Participation, Environmental Accessibility, and Quality of Life

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Dedication

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Visual and Sensory Processing Disorders

in Children with Cerebral Palsy and Cerebral Visual Impairment –

Implications for Participation, Environmental Accessibility, and Quality of Life

Nava Gelkop

Abstract

Background: Cerebral palsy (CP), a neurodevelopmental motor disorder is frequently accompanied by cerebral visual impairment (CVI), and sensory processing difficulties, which together limit daily functioning, participation and quality of life (QOL). Yet, the mechanisms linking sensory processing difficulties, higher-order visual and oculomotor dysfunctions to these functional outcomes remain poorly understood, particularly in children with CP and CVI who exhibit relatively preserved cognitive and basic capacities but show dorsal-stream and integrative perceptual deficits. Grounded in the International Classification of Functioning, Disability and Health (ICF; World Health Organization, 2001) and the person-environment-occupation-performance (PEOP) framework, this work examined how visual and sensory processing difficulties interact and jointly predict participation and QOL.

Objective: (1) To examine the prevalence of visual processing difficulties and sensory processing disorder in children with CP and CVI (CP-CVI) and neurotypical group, (2) To validate a novel, psychophysical visual processing screening tool for identifying CVI, (3) To compare participation, environmental accessibility and QOL between children with CP-CVI and neurotypical children; and examine the associations within the CP-CVI group, (4) To identify visual processing, sensory processing, functional and environmental predictors of participation and QOL.

Methods: The study combined standardized clinical questionnaires with a series of psychophysical and eye-tracking experiments designed to probe multiple levels of visual and oculomotor processing. Ninety-nine children aged 4 to 17 years (51 with CP-CVI and

48 neurotypical controls) completed the Insight Inventory Questionnaire (IIQ) assessing visual processing and CVI-related difficulties, the Sensory Profile (SP) assessing sensory modulation and registration, the Participation and Environment Measure for Children and Youth and the Pediatric Quality of Life Inventory. In addition, all children performed three experimental paradigms: (1) a smooth pursuit task, in which they tracked a moving target under both simple and occluded conditions to assess pursuit gain, catch-up latency, vergence variability, and fixation stability; (2) a visual oddball pointing task adapted from McKyton et al. (2015), which examined response accuracy and latency under increasing levels of figure-ground complexity; and (3) a free-viewing task in which participants watched short video clips while their eye movements were recorded to assess naturalistic gaze exploration.

Data analysis: Data were analyzed using IBM SPSS software (Version 27) and MATLAB® R2022a (MathWorks, Natick, MA) for the analysis of psychophysics computerized data. Analyses used nonparametric tests (Mann-Whitney U, Friedman), Spearman correlations, and stepwise linear regression.

Results: Across these modalities, children with CP-CVI exhibit convergent patterns of atypical visual and oculomotor functioning despite being near normal or corrected to normal acuity. Questionnaire data revealed marked difficulties in visual attention, search, and guidance of movement, accompanied by abnormal sensory registration and modulation.

Both visual and sensory measures correlated with reduced participation, greater environmental barriers, and lower physical, social, and emotional QOL. In the smooth pursuit task, children with CP-CVI showed increased fixation error, greater vergence variability, and stronger head movement at stimulus onset, despite similar average pursuit velocity. Under occlusion, their pursuit trajectories deviated significantly from the unoccluded baseline, indicating impaired prediction and reduced closed-loop control. These oculomotor measures correlated with clinical indices including the CVI Range, the Visual Function Classification

System (VFCS), and IIQ visual attention scores, collectively explaining a substantial proportion of variance in functional vision.

In the visual oddball task, children with CP-CVI demonstrated slower reaction times and reduced accuracy, especially under cluttered conditions, reflecting deficits in higher-level visual integration and attentional gating. During video watching, their gaze patterns diverged markedly from those of neurotypical controls (average correlation $R \approx 0.4$ vs. 0.8, $p < 0.0005$) presumably due to slower transitions to new locations, accompanied by increased saccadic vigor (more saccadic speed for the same distance) and increased temporal randomness in gaze transitions. Importantly, gaze similarity to the control means strongly predicted VFCS and IIQ attention scores ($R \approx 0.7$, $p < 0.001$), confirming the ecological validity of the eye-tracking measure as a screening tool for CVI.

Sensory processing difficulties were more common in the CP-CVI than in neurotypical peers, especially in visual, vestibular, and auditory domains, and modulation domains (tone, movement, behavior responses). Sensory registration quadrant was most affected (98%), followed by avoiding and seeking. SP domains correlated with functional classification, IIQ visual domains and psychophysical performance variables. Children with CP-CVI showed reduced participation (frequency and number), and greater environmental barriers across all settings. Participation and environment measures were associated with key visual processing and sensory variables. At home, participation number and frequency correlated with IIQ visual attention ($r = .28–.34$; $p < .05$) and reaction time ($r = .30–.39$, $p < .01$). School participation involvement, environmental barrier correlated with SP behavioral responsiveness ($r = .30–.35$, $p < .01$). In the community, support and barriers correlated with visual recognition and complexity ($r = –.42–.29$, $p < .05–.01$) and SP behavioral responsiveness ($r = .28$, $p < .05$), and desire for change with oddball pointing reaction time ($r = .30–.39$; $p < .01$). Regression analyses showed that home participation was predicted by IIQ visual attention ($R^2 = .14$) and school participation predicted by IIQ

movement perception, visual recognition/navigation, and VFCS levels (R^2 = .37). QOL scores were significantly lower across domains in the CP-CVI group. Social and psychosocial QOL correlated with SP domains (r =.27–.49, p < .05–.001). Physical QOL correlates with all functional classification (r = -.30 to -.61, p < .05– .001), and total score of QOL correlated with SP behavioral responsiveness and avoiding and seeking quadrants (r = .36–.39, p < .01). Stepwise regression models indicated that physical QOL was predicted by the gross motor function classification system, IIQ (guidance of movement, visual search), and participation and environmental factors (R^2 = .71). Social QOL was predicted by sensory modulation (SP), visual attention (IIQ), and community environmental support (R^2 = .59); emotional QOL by community support, visual guidance, and SP-behavioral responsiveness (R^2 = .27); and total QOL by IIQ visual attention, sensory-seeking and avoiding (SP), and community environmental support (R^2 = .36).

Conclusions: Taken together, these results reveal a distinctive visuomotor signature in children with CP-CVI, characterized by unstable and slower gaze transitions, poor binocular coordination, and diminished predictive control. These deficits were closely interrelated with sensory modulation difficulties and with limitations in participation and QOL, suggesting a dual-system vulnerability encompassing both visual and sensory domains.

Furthermore, sensory processing profile revealed distinct pattern in this group with heterogeneity suggesting detailed sensory and visual assessments-beyond functional visual classification are essential for capturing meaningful variability. Clinically, the findings support a multidimensional approach (ICF and PEOP) that integrates sensory, oculomotor, and perceptual assessments to capture functional variability, participation, and QOL more effectively. Eye-tracking during naturalistic viewing provides a promising, objective tool for detecting functional vision impairments. Interventions targeting both sensory integration and visuomotor prediction mechanisms may enhance engagement, learning, and everyday functioning, thereby improving participation and QOL in the CP-CVI population.

Interdisciplinary collaboration among health, vision, and educational professionals is essential to ensure ecological validity and consistency of care.

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List of Abbreviations

ADHD ..... attention-deficit/hyperactivity disorder
ASD ..... autism spectrum disorder
CFCS ..... communication function classification system
CP ..... cerebral palsy
CVI ..... cortical or cerebral visual impairment
CVIT-3-6 ..... Cerebral Visual Impairment Test
EDACS ..... eating and drinking classification system
ERP ..... event-related potentials
GMFCS ..... gross motor function classification system
HVFQ51 ..... Higher Visual Function Deficits in Children With CVI Questionnaire
ICDL ..... Interdisciplinary Council on Developmental and Learning Disorders
ICF ..... international classification of functioning, disability, and health
ICF-CY ..... ICF: children and youth version
IIQ ..... Insight Inventory Questionnaire
MACS ..... manual ability classification system
MRI ..... magnetic resonance imaging
PedsQL ..... Pediatric Quality of Life Questionnaire
PEM-CY ..... Participation and Environment Assessment
PEOP ..... person–environment–occupation–performance
PVL ..... periventricular leukomalacia
QOL ..... quality of life
RT ..... reaction time
SCSIT ..... Southern California Sensory Integration Tests
SIPT ..... Sensory Integration and Praxis Tests
SMD ..... sensory modulation disorder
SP ..... Sensory Profile
SP2 ..... Sensory Profile 2
SPD ..... sensory processing disorder
VEP ..... visual evoked potential
VFCS ..... visual function classification system
VP ..... visuoperceptual
WHO ..... World Health Organization

Chapter 1: Introduction and Literature Review; Theoretical Background

1.1 Introduction

Cerebral palsy (CP) is the leading cause of childhood motor disability, which is often accompanied by disturbances of other systems, such as sensation, perception, and cognition (Rosenbaum et al., 2007). These aspects of the sensory systems are essential. A person's ability to sense their environment is critical for the functional integrity of other bodily abilities and to function effectively in the environment (Dunn, 2001). Nevertheless, not all sensory and visual processing aspects are adequately detected in children with CP; they probably are underdiagnosed. Furthermore, the World Health Organization ([WHO], 2001) guides health providers by the international classification of functioning, disability, and health (ICF) and the children and youth (ICF-CY) framework to refer to interactions between body dysfunctions and participation in daily activities to elevate the quality of life (QOL).

However, implementing the ICF model in complex CP conditions has been scarce. It is essential to ensure an adequate, adapted, supportive environment for learning, especially with the positive changes increasing the inclusion of children with disabilities in Israel's mainstream schools. This study will use the ICF framework to elucidate relationships among body dysfunctions, focusing on two body capacities studied less in children with CP: visual processing and sensory modulation (via self-reports and objective measures). It will first highlight the relationship among visual processing and sensory modulation abilities, participation, and QOL in children with CP with cerebral visual impairment (CVI). This thorough assessment may allow constructing effective treatment plans that refer to as many components as possible affecting a person's functioning, ability to participate, and QOL. The research will also direct a novel visual assessment to detect underdiagnosed children of educational age with CVI. Last, according to the results, the research will suggest a model/subgrouping for children with CP focusing on their unique needs in their daily lives.

1.2 Cerebral Palsy

Cerebral palsy is the leading cause of childhood motor disability globally, with an incidence of 1 in 500 newborns (H. K. Graham et al., 2016; McGuire et al., 2019; Morgan et al., 2021), which starts to decline by 30% in high-income countries (Galea et al., 2019). *Cerebral palsy* is described as a group of permanent disorders of movement and posture development causing activity limitation and attributed to nonprogressive disturbances in the developing fetal or infant brain. Although the definition describes nonprogressive motor disability syndrome secondary to neurological impairment, it occurs at an early development stage (Rosenbaum et al., 2007); still, motor abilities may decline later in life, mainly at low functioning levels (Hanna et al., 2009).

Different brain parts can be affected in CP, contributing to a broad range of clinical findings (Vitrikas et al., 2020). The complete causal path to CP is the complex interplay between several risk factors but is unclear in approximately 80% of cases and considered idiopathic (Morgan et al., 2019; Nelson, 2008; Novak et al., 2017). Risk factors are often identifiable from history-taking about conception, pregnancy, birth, and the postneonatal period (Nelson, 2008). Risk factors may include preterm birth, perinatal infection, intrauterine growth restriction, use of preterm antibiotics before membrane rupture, acidosis or asphyxia, and multiple gestations (Shi et al., 2017). Approximately 92% of CP cases are from the perinatal period (O'Callaghan et al., 2011), 10% are attributable to intrapartum hypoxia, and 8% are at older ages due to head injury or infection (Vitrikas et al., 2020).

Guidelines for early accurate detection of CP recommend combining magnetic resonance imaging (MRI) with two clinical examinations: the General Movement Assessment and the Hammersmith Infant Neurological Examination (Morgan et al., 2019). Neuroimaging improves understanding of the neuroanatomical basis for function in CP (Himmelmann & Uvebrant, 2011), and injury analysis status can be determined according to the MRI classification system review (Himmelmann et al., 2016). However, the relationship

between structural brain lesions identified by MRI and motor outcomes and accompanying impairments in children with CP needs to be further elucidated (Franki et al., 2020; Himmelmann & Uvebrant, 2011).

The primary motor disorders of CP are often accompanied by disturbances of sensation, perception, cognition, communication, behavior, epilepsy, and secondary musculoskeletal problems (Rosenbaum et al., 2007). Those accompanied impairments, diseases, and functional limitations change over time, reducing function and QOL (Bottos et al., 2001; Delacy et al., 2016; Jacobsson & Hagberg, 2004; Livingstone et al., 2007). Reported incidences include pain (75%), intellectual disability (50%), inability to walk (33%), hip displacement (33%), inability to speak (25%), epilepsy (25%), incontinence (25%), and behavioral or sleep disorders (20% to 25%; Novak et al., 2012). The reported incidence of vision impairments is 11%, and hearing impairments is 4% (Morgan et al., 2021); however, vision disorder due to CVI is possibly higher due to underdiagnosis.

The type and severity of motor impairment and the occurrence of accompanying impairments are related to the timing of lesions in the developing brain (Himmelmann & Uvebrant, 2011). Thus, reporting the complex condition of a child with CP should first include initial motor impairment in terms of distribution (body area-quadriplegia, hemiplegia, diplegia); second, the nature of muscle tone (expression of muscle tension) as stiff muscles (spasticity), which is the most common movement disorder in 80% of children with CP, uncontrollable movements (dyskinesia), poor coordination (ataxia), and mixed spasticity (Vitrikas et al., 2020); thirdly, report the functional level concerning the accompanying disorders in various areas.

Functioning-level classification systems have been developed in different areas to define and categorize functions into levels via assessment or observation. Gross motor activities are categorized using the gross motor function classification system (GMFCS; Palisano et al., 1997) and the Functional Mobility Scale (H. K. Graham et al., 2004). The

upper-limb function is categorized by the manual ability classification system (MACS; Eliasson et al., 2006). Communication abilities are categorized by the communication function classification system (CFCS; Hidecker et al., 2011) and eating and drinking functions by the eating and drinking classification system (EDACS; Sellers, 2014).

Although the focus in CP is on motor impairments, brain lesions may also affect brain areas related to other functions, such as sensory and cognitive. Sensory impairment was reported in possibly 90% of children with CP (Cooper et al., 1995). The expression of sensory impairment is in the dysfunction of specific sensory modalities, such as reduced tactile discrimination, proprioceptive discrimination, stereognosis with higher pain sensitivity (Bleyenheuft & Gordon, 2013; Riquelme & Montoya, 2010; Sanger & Kukke, 2007; Van Heest et al., 1993; Wingert et al., 2009), and reduced sensory processing and modulation in all CP subtypes compared to typical children (Pavão & Rocha, 2017; Soomro et al., 2011). Furthermore, the visual system is a prevalent sensory modality that might affect CP. Visual processing impairment (CVI) is found in 60% to 70% of children with CP and affects all CP subtypes to varying degrees (S. S. Philip et al., 2020). However, the research in sensory modulation and CVI is still lacking, with very little research focusing on its impact on daily function, participation, or QOL.

1.3 Visual Impairment in Children With CP

The incidence of visual impairment, including peripheral and central (cortical), was noted in 42% to 60% of children with CP (Baxter & Goldstein, 2007; Stiers et al., 2002). It is more common in premature children with spastic diplegia and some form of periventricular leukomalacia, with the incidence as high as 70% (Hoyt, 2003). Guzzetta et al. (2001) found that more than 80% of 1-year-old children with hemiplegic CP showed abnormal results in at least one visual test, and MRI cannot always predict it.

This distribution of visual impairment was in proportion with the GMFCS levels in Australia (Shevell et al., 2009). However, due to gross motor disorder, children may be less

exposed to tasks requiring ophthalmic fixation and cannot sufficiently maintain activities requiring ophthalmic attention (McClelland et al., 2006). Therefore, the limited experience would likely hinder the development of ophthalmic and visual functions (Lew et al., 2015). This is further important because sensory restoration research provided the first evidence for the role of experience in the typical development of different neural systems (Ricciardi et al., 2020).

Cortical/ Cerebral visual impairment is the leading cause of severe visual impairment or blindness in children (Dutton & Jacobson, 2001). In 60% of children with CVI, it is due to CP (Boonstra et al., 2022). In the past, ocular diseases such as cataracts, glaucoma, retinoblastoma, and rubella were the predominant causes of reduced vision in children. As medical services improved, the percentage of ocular deficits in children decreased. However, the number of preterm and severely sick children who survive with visual impairment due to brain damage has increased (Dutton et al., 2006; Grönqvist et al., 2001).

A recent review reported that CVI is found in 60% to 70% of children with CP but assumed the percentage was higher than reported (S. S. Philip et al., 2020). Perinatal hypoxic-ischemic damage is the most frequent cause of CVI (Boonstra et al., 2022), but the problem is not restricted to CP of hypoxic-ischaemic origin (Stiers et al., 2002). Thus, all CP subtypes may have varying degrees of CVI (S. S. Philip et al., 2020). Conditions such as periventricular leukomalacia (PVL), meningitis, encephalitis, hypoxic-ischemic encephalopathy, hydrocephalus, brain injury, and metabolic diseases can be expressed with visual perception and attention dysfunction (Atkinson & Braddick, 2007; Fazzi et al., 2009; Ortibus et al., 2011; Tinelli et al., 2020). Furthermore, the proportion of children with learning difficulties and CVI attending special schools is possibly more than 50% (Black et al., 2019; Chokron et al., 2021; Williams et al., 2021). This statistic stresses the need for children's detailed assessment of visual function that might further influence learning difficulties in children with CP.

More research is needed to understand the possible mechanisms of visual impairment and the impact of visual difficulties in everyday life, emphasizing CVI in children with CP. The next sections discuss the human brain's visual processing mechanism and introduce visual impairment and CVI in children with CP and its characteristics and assessment process.

1.4 Visual Processing

Visual processing is crucial for adaptive function in the complex daily environment. In the human brain, visual processing involves three main areas. Different streams convey diverse information from scene to percept movement, percept cognitive high-order stimuli aspects, and direct attention to the correct visual stimuli (Gilbert & Li, 2013). These streams produce the capability of some key elements, including environment perception, movement guidance, environment analysis (figure/background, figure contour), visual exploration, attention, recognition (of significant new stimuli in the environment), and visual memory (Ego et al., 2015; Leuck et al., 2019).

The visual system can be divided into input and processing systems (Leuck & Dutton, 2015). The *input system* includes the eye and the pathway from the eye to the striate cortex, where the information is organized and detected in *low-level vision*. The organized information transfers to the processing streams refer to *higher processing centers* to continue processing medium and higher-level vision. This *higher processing system* includes two main streams in the parietal and temporal lobes. Further *top–down* pathways involve the entire neocortex and are relayed through thalamic nuclei.

The visual system can also be discussed as *anterior* and *posterior pathways*. The *anterior visual pathways* include the eye and optic nerve to the chiasma. The *posterior visual pathways* refer to the system posterior to the chiasma, through the lateral geniculate bodies in the thalamus, optic radiation, primary visual cortices-the striate cortex in the occipital lobe-and two main streams in the parietal and temporal lobes. Those terms are

considered when defining CVI in children with CP and directing relevant assessment tools for CVI diagnosis and function level.

Neurophysiologically, the processing in the striate cortex is hierarchical, with cortical areas representing increasingly complex images, objects, and characteristic categories. The level depends less on coincidental spatial features, such as precise location, retinal size, viewpoint, lighting, or color (Hochstein & Ahissar, 2002). Over 30 years ago, Goodale and Milner (1992) suggested that visual information is segregated and processed in two distinct functional streams. Mishkin and Ungerleider (1982) further distinguished between *what* (object vision) and *where* (spatial vision) systems. Thus, the *ventral stream* runs to the inferior temporal cortex. It processes information about object identity, recognition, and route finding; the *dorsal stream* runs to the posterior parietal cortex and processes information about visuospatial abilities, object location and movement, extracting data from a crowded visual scene, and visually guided movement (Dutton, 2015b; Sheth & Young, 2016; Van Genderen et al., 2012).

Cortical neurons are a further subject of *top–down influences* on attention, expectation, and perceptual tasks. When perceiving a visual scene, the initial conscious percept vision matches a high-level, generalized, categorical scene interpretation—identifying "the forest before the trees." For later vision with an examination, *reverse hierarchy* routines focus on specific, active, low-level units, incorporating detailed information into conscious perception (Hochstein & Ahissar, 2002; McKyton et al., 2015). The process suggested by the *reverse hierarchy theory* could explain the difficulty of children with CP in perceiving complex scenes. These are further challenging to assess. The nature of the receptive field also includes contextual influences, experience, behavioral context, and expectations that influence feedforward connection and response (Gilbert & Li, 2013; Hochstein & Ahissar, 2002). The interconnection continuum of descending pathways

through the thalamic nuclei stresses the role of intersensory processing and modulation during functional vision in a stimulating environment.

Nevertheless, the underlying neural mechanisms in the higher processing pathways are still poorly understood in children with CP (Leuck & Dutton, 2015; McKillop & Dutton, 2008; VerMaas et al., 2021). It was recently proposed that the *weaker occipital oscillations* may reflect *poor bottom–up* processing of incoming visual information. Such poor processing subsequently affects the *higher order visual computations* essential for accurate visual perception, visuospatial and attention components, and decision-making integration (VerMaas et al., 2021). Detecting visual behavioral characteristics attributed to visuospatial and attentional components in children with CP may shed light on this proposed mechanism.

The current research will add an objective assessment of those visual components to subjective assessments describing functional visual behaviors. Correlating those components to sensory modulation disorder levels may further highlight the proposed mechanism.

1.5 Visual Impairment due to CVI

Cortical or cerebral visual impairment is defined as "a broad visual difficulty which cannot be attributed to disorders of the *anterior visual pathways* (before the chiasma) or ocular impairment" (Ortibus et al., 2019; Sakki et al., 2018). Cortical or cerebral visual impairment can result from lesions affecting any level of *posterior visual pathways*: optic chiasm, lateral geniculate bodies, optic radiations, primary visual cortices, middle temporal lobes, or visual association areas (Chokron et al., 2021). The lesions lead to problems with higher order visual functions, causing visual processing and integrating dysfunction (Boonstra et al., 2022; Fazzi et al., 2007; Good et al., 2001; S. S. Philip & Dutton, 2014). Some researchers referred to the abbreviation CVI as "cortical"; others used "cerebral." The term "cerebral" was substituted for "cortical" to encompass these higher order visual-processing deficits more globally (Merabet et al., 2017). However, the term "cortical" is

misleading. It fails to describe the children with visual impairment resulting from primarily deep, subcortical, white matter insults (PVL; Hoyt, 2003).

The neurophysiological basis of CVI's observed visual processing deficits in pediatrics is still not fully understood (Merabet et al., 2017). Historically, CVI was described in adult soldiers who exhibited vision loss-despite having regular eye function-after suffering traumatic gunshot wounds to the posterior of the head (Holmes, 1918; Merabet et al., 2017). This is why, a century ago, CVI in children was termed *cortical blindness*, referring to blindness by bilateral damage to the occipital cortex. However, the term does not appropriately describe the clinical conditions of children's visual loss (Hoyt, 2003). First, most children have residual sight, and multiple neurodevelopmental disabilities and blindness caused by a bilateral disturbance of the optic radiation and calcarine cortex are infrequent (Hoyt, 2003; Jan, 2001). Second, unlike in adults, visual recovery can be seen in children with neurological vision loss; thus, the term *cortical visual impairment* was introduced to emphasize the visual potential of recovery in these neurologically damaged children (Cioni et al., 2011; Fiori & Guzzetta, 2015). Last, the CVI condition is more heterogeneous and challenging to characterize in children than in adults with acquired brain injury (Merabet et al., 2017). For those reasons, CVI has become a significant issue in rehabilitation in pediatrics only in the last decade and still challenges researchers and clinicians (Ortibus et al., 2019).

Neuroimaging examination may help define predictive biomarkers of neurodevelopmental outcomes, including CVI, in the preterm brain but not in all cases (Dammann & Leviton, 2006; Ment et al., 2009; Tinelli et al., 2020; Woodward et al., 2006). Damage in the white matter surrounding the lateral ventricles in preterm infants and children with CP is the most common brain damage associated with the CVI diagnosis (Fazzi et al., 1994, 2004; Koeda & Takeshita, 1992; McKillop & Dutton, 2008; Skranes et al., 1997). These visual functions' structures can be affected to varying degrees in isolation or

combinations (Chokron et al., 2021). The lack of vision tends to be profound when the thalamus is involved (Ricci et al., 2006).

There is no consensus on the definition, assessment, or diagnostic methods to identify CVI and limited knowledge of whether it is a unitary condition or composed of discrete subtypes (Sakki et al., 2021). Further, lesions with no noticeable motor-behavior impairments and low-level visual functions in preterm children may remain unknown to parents or health care professionals. Even MRI examinations, outside standard medical practices for this population, only sometimes explain visual function. Widespread neuronal damage; other sensory, cognitive, and motor deficits; and neurologic conditions (e.g., seizures) may mask the CVI characteristic, and eye movement control disorders may exacerbate the resulting visual impairment (Boot et al., 2010; Dutton, 2015a; Fazzi et al., 2009; Ortibus et al., 2011).

1.6 Functional Classification of CVI

Increasing attention is now paid to subtyping CVI (Ortibus et al., 2019). Subtyping developed in response to the growing realization that CVI's heterogeneity requires more subclassifications to identify needs better, establish greater consensus in the field, and reach more informed knowledge through clinical assessment and research (Sakki et al., 2018). A few schemes to be subclassified have been suggested. The first suggestion was subclassification according to the visual function severity: selective/more severe and broader/profound visuoperceptual (VP) and visuomotor impairment (Chokron et al., 2021; Dutton, 2015a, 2015b; Sakki et al., 2021).

The second suggested classification follows the CVI Range assessment scoring and classifies the child in 1 of 10 visual behavioral levels divided into three phases. The child can only notice visual stimulation in the first phase and process visual information in an adaptive environment in the second phase. In the third phase, the involvement of the 10 visual behavioral characteristics is reduced, requiring less environmental adaptation

(Roman-Lantzy, 2018). The third suggestion classifies children with CVI according to vision function profile severity and "external variables", such as etiological risk factors, co-occurring neurodevelopmental impairments, parent-reported QOL, or everyday vision differentiation (Sakki et al., 2021). The last scheme suggested grading the visual disability according to the level of interference with everyday activity and cognitive disability (Leuck et al., 2019). No suggested classification scheme has been validated or used further in research. The new visual function classification system (VFCS) in CP classifies visual functions according to self-strategies and the need for environmental adaptations to visual functions. However, it is not specific to CVI (Baranello et al., 2020).

In summary, neurologic brain damage can occur in high prevalence in CP at different levels and affect the posterior visual pathway, resulting in visual processing dysfunction, termed CVI. Definition, assessment, and classification methods are still developing with suggestions to subtype the condition due to its complexity and heterogeneity. The next sections review the clinical and research literature on detected clinical CVI characteristics and known behaviors, then present the available assessment protocols and tools.

1.7 Characteristics of Visual Behavior in CVI

The CVI disorder can occur in different combinations depending on the nature and distribution of the underlying brain damage (Dutton, 2003; Fazzi et al., 2009). The damage can be discussed according to ICF dimensions as visual (body) functions and functional vision (activity) that may influence daily living (participation).

Decreased visual functions, such as visual acuity and visual field deficits, can be seen with damage to the *visual brain/striate cortex*; impairments in oculomotor, visuomotor, and cognitive visual processing can be seen while damaging *higher processing centers* (Fazzi et al., 2007; McKillop & Dutton, 2008). The visual functions' clinical symptoms may be slow eye movements (saccades), crowding (impaired ability to recognize objects in clutter), impaired accommodation, short visual-attention span, markedly fluctuating visual

performances, and the need for time, environmental stability, and item repetition to obtain the best response (Boonstra et al., 2022; Bosch et al., 2014; Fazzi et al., 2007).

As mentioned, not all symptoms typically co-occur. They can evolve due to recovery and plasticity mechanisms, acquire compensation strategies for visual deficits, or develop other nonvisual perceptual senses that may become superior (Fiori & Guzzetta, 2015; Guzzetta et al., 2010; Ortibus et al., 2019). In Guzzetta et al.'s (2001) study, acuity was the minor impaired function. Visual field and nystagmus were abnormal in more than 50% of the cohort, and visual field defects were not always related to contralateral damage in the optic radiation.

Traditionally, those clinical CVI symptoms are grouped according to the proposed underlying neuroanatomical distribution of the visual pathway functions first described in adults (Ortibus et al., 2019). Children with *ventral stream* dysfunction and good acuities might mistake a stranger for a parent and quickly become lost (Dutton, 2003). Motion analysis could address only one or two items in their visual scene. Although they have intact stereopsis in some cases, the children cannot use vision to guide movement. Children with *dorsal stream* pathways dysfunction are challenged in analyzing the complex visual scene, granting selective visual attention to specific elements while suppressing other elements, and handling other incoming sensory data such as hearing and touch (Dutton et al., 2006).

Examples of implications of CVI visual characteristics on children's function and participation in daily lives can also include difficulty visually processing crowding, such as finding a toy on a patterned carpet or reading long words. Depth-perception disorders can manifest as difficulty crossing a floor, climbing a step, or walking on uneven ground. Impaired accommodation and convergence influence visually guided movements and challenge the ability to track in the third dimension (depth). New environments will challenge children with reduced vision, affecting recognition and navigation.

In contrast, familiarity with the environment appears to enhance visual performance. A child with CVI often experiences an intermittent lack of visual attention. As a result, the child may look away from the material to prevent overload and rapidly tire with new material. Prolonged processing of visual tasks, which reduces the child's performance speed, is a common feature; sufficient time should be given, and educational strategies devised.

Dutton et al. (1996) suggested grouping those primary disorder characteristics into five types to make the VP function detection process more organized and understandable: recognition, orientation, depth perception, movement perception, and simultaneous perception (Leuck & Dutton, 2015). Recent Delphi studies suggested grouping by the seven VP dimensions found to be discriminative in children with CVI (Ben Itzhak et al., 2020; Ben Itzhak, Vancleef et al., 2021): visual discrimination and matching, object or picture recognition, visuospatial perception, figure–ground perception, motion perception, visual short-term memory, and scene perception.

Ben Itzhak, Vancleef et al. (2021) reported the most discriminating VP dimensions for CVI: object/picture recognition, visuospatial perception, visual discrimination and matching, and figure–ground perception. Roman-Lantzy (2018) defined and focused on 10 behavioral characteristics seen only in children with CVI. These unique behaviors can be expressed at different levels, including staring at a light, delayed response, attraction to movement, attraction to specific colors, noticing a familiar item, and needing to reduce a complex visual scene. These items are coded following interviews with parents and caregivers and further therapist observations. It is important to profile each child's intact VP skills to detect and prioritize intervention. The grouping characteristics highlight the main visual dysfunction seen in children with CVI and direct adequate assessment tools, especially important with children in mainstream schools. The assessment should express the expected visual functions and abilities according to educational and environmental requirements in kindergarten and school settings and must meet age-related cognition

activities. The following sections review the current CVI assessment process and available assessment tools discussed in the literature.

1.8 CVI Assessment Process

Those behaviors are the basis of items included in the CVI assessment process. They are of utmost importance, considering how visual impairment interferes with many development aspects, such as fine and gross motor functions, spatial concepts, cognitive abilities, attention and memory, communication and social skills, and learning processes (Leuck & Dutton, 2015). Although no single CVI assessment protocol is recommended, there are recommended guidelines for the detection and assessment process. These include medical history, interview, neuroimaging detection usage, ophthalmological examination, and visual function and functional visual processing assessments (Boonstra et al., 2022).

There are knowledge gaps and complexities in assessing and managing vision for children with CP, with little clarity on when or what should measure their vision-related constructs (Deramore Denver et al., 2017) and no agreed-upon clinical guidelines for investigating and diagnosing CVI (Boonstra et al., 2022; McConnell et al., 2021). Many clinics' CVI assessments are still based on ophthalmological examinations rather than functional evaluations of visual abilities (Baranello et al., 2020; Khetpal & Donahue, 2007; Van Genderen et al., 2012). The assessment should test how effectively a child's eyes function, how well the child understands and interprets what they see, and how well they use their vision in daily activities (Baxter & Goldstein, 2007; Deramore Denver et al., 2017; Dutton & Jacobson, 2001; Leuck & Dutton, 2015).

A broad, transdisciplinary assessment combining objective ocular, neurological, and observational behavior assessments supporting the diagnosis is recommended (Leuck & Dutton, 2015). The assessment should be based on interviews, questionnaires, and observation of parents, teachers, and caregivers to provide a clinical picture of each child's visual abilities in a complex environment (Dutton et al., 1999; Ego et al., 2015; Leuck &

Dutton, 2015; McCulloch et al., 2007). In addition, it should be sensitive and patient-friendly (Baxter & Goldstein, 2007; S. S. Philip et al., 2020). In a recent review, McConnell et al. (2021) grouped all CVI assessment tools reported in the literature into 10 assessment categories: medical history, vision/ophthalmologic, neuroimaging, visual behavior and direct observation, structured history-taking, visual perception, ocular movement and posture, intelligence/IQ, clinical electrophysiology, and neurodevelopmental.

The next section addresses the main categories of a CVI diagnosis assessment process relevant to this research, divided into objective and subjective assessment tools.

1.8.1 Medical History and Structured History-Taking

A structured interview for medical history is an essential basis for CVI assessment. Consideration of the child's medical history in the assessment process was found to identify risk factors for CVI (listed in the previous section) and direct adequate evaluation (Boonstra et al., 2022; McConnell et al., 2021; Ortibus et al., 2009; Van Genderen et al., 2012).

1.8.2 Optometric Check

Optometric tests are included for general screening and addressing the visual system. An optometric check is essential in children with CVI because supportive information diagnosing the coexistence of ocular (peripheral) involvement has been reported. However, CVI may occur despite normal or near-normal visual acuity (Fazzi et al., 2009). With coexistent optic nerve atrophy and CVI, a clinical decision should be made during the examination about the primary reason for the visual loss. The decision is based on the pupillary reactivity, disk appearance, and history of the structural central nervous system lesions (Khetpal & Donahue, 2007). Around 50% of children with CVI have a refractive error or impaired focusing, necessitating spectacle correction (Pehere et al., 2018). Therefore, all children must have their range of accommodation checked and refracted and their postrefraction vision checked with their salient spectacle correction for near and distance vision to plan their habilitation (Chokron et al., 2021).

1.8.3 Visual Evoked Potential

Visual evoked potential (VEP) assesses the function of the visual pathways. Its use in CVI has been studied carefully, and the results varied. Studies failed to demonstrate significant differences in the VEP responses of children with CVI compared to children with CP without visual problems (Good et al., 1994). In patients with CVI, the VEP response often did not correlate with the vision loss severity. However, recent research found that VEP in young children with CVI might have prognostic value for future acuity (Howes et al., 2022). Thus, it was recommended to consider VEP in cases where visual acuity was not measured, and optical coherence tomography of the retina did not provide enough information on the optic nerve (Boonstra et al., 2022).

1.8.4 Magnetic Resonance Imaging

Magnetic resonance imaging is recommended because CVI in most children is due to CP. However, in 10% of children with CVI, it is due to genetic syndromes. Thus, the MRI results may be typical. In many clinics, a CVI diagnosis will not be given without an MRI finding and a neurologic history in the anamnesis process (personal knowledge). It is vital to be aware of possible exceptions. For example, Fazzi et al. (2009) emphasized that conventional MRI does not exclude the possibility of higher visual-processing systems malfunctioning in children with PVL. On the other hand, Chokron et al. (2021) acknowledged that an MRI could be “normal” in a child with a neurovisual impairment, 30% of adults with stroke, and 12% of CP cases. This study follows the recommendation to include MRI findings in the research.

1.8.5 Visual Processing Function Tests

A wide range of tests is available to examine aspects of visual perception. However, each test assesses different visual perception aspects (McConnell et al., 2021). Some aim at various facets of visual perception, such as the L94 visual perception battery (Ortibus et al., 2009), the Test of Visual Perceptual Skills-revised (T. Brown & Rodger, 2009), and

Developmental Test of Visual Perception (T. Brown, 2016). Further, tests such as the LEA Rectangle and LEA Mailbox for spatial perception ability detect specific visual perception aspects (Buultjens et al., 2010). A recently developed assessment, the Cerebral Visual Impairment Test (CVIT-3-6), was designed for the broad range of visual perception impairments commonly reported in children with CVI. This assessment is computerized and valid for 3- to 6-year-olds.

1.8.6 Computerized Visual Assessment and Intervention

In the last few years, a new way of assessing visual tasks on the computer screen has been developed and used in research for children with CVI to detect objectively visual functions. These functions include tracking, recognizing, movement detection, and contrast detection. Technology had come a long way since the 1980s, when the most advanced technologic equipment for children with visual impairment was the LightBox. The iPad, developed in 2010, provided a new technological option for assessing and teaching in significantly more appealing and motivating ways (Campaña & Ouimet, 2015; De Bortoli & Gaggi, 2011). A decade ago, computer games and iPad applications started to be used to rehabilitate children affected by CVI (Tallent et al., 2012). Since then, advanced vision rehabilitation games to improve VP skills in children with CVI have been developed (Ciman et al., 2013, 2018; Linehan et al., 2014). Project characterization of existing computer game content according to VP skills commonly impaired in children with CVI followed the game development (Ben Itzhak, Franki et al., 2021).

Computer games' potential in visual rehabilitation also was shown during the COVID-19 pandemic (Battistin et al., 2021). Today, computerized psychophysics evaluations assess visual abilities and behaviors in children with CVI (C. R. Bennett et al., 2020; Ciman et al., 2013; Gaggi et al., 2017; Vancleef et al., 2020). Computerized systems offer advantages—combining basic visual search tasks with complex ones requiring

attention and cognitive processes, such as decision-making. They can identify all strength and difficulty areas (ocular, oculomotor, perceptual, and visual-cognitive preserved skills).

Another unique, promising computerized vision-screening option appeared recently. *Eye-tracking* technologies promise excellent support because they can measure the left and right eye movements separately. Thus, they are well suited for objective measurements (Ali et al., 2020) and show promise for visual assessment of children with CVI in clinical and research settings (Chang & Borchet, 2021). Eye-tracking technologies can reveal visual detection abilities with no need for motor function in children with CP where movement disorder is the main difficulty.

Computerized patient-friendly technologies show evidence of effectiveness in the pediatric population (Ali et al., 2020; Ciman et al., 2018). They are more enjoyable and motivational and increase cooperation. These results also can be seen in pediatric virtual-reality interventions that successfully reduce pain and anxiety (Eijlers et al., 2019), increase psychological well-being (Tennant et al., 2020), and improve selective attention (Amprasi et al., 2022) and motor abilities (Levac & Sveistrup, 2014; Rathinam et al., 2019). Recently, virtual reality has been used for visual processing detection in children with CVI with promising results (Manley et al., 2022).

1.8.7 Questionnaires: Subjective Measures of CVI

Primary caregivers should gather information about the child's ability to function in different situations, environments, and task demands based on CVI's significant impacts on a child's daily life. Therefore, questionnaires were developed for parents to reflect on daily life and visual abilities. They consist of questions about everyday activities and the ability to participate in situations with visual demands and refer to possible known behavior characteristics of CVI in various challenging situations. Although criticized as yielding too many false positives (Van Genderen et al., 2012), standardized questionnaires developed in the last decade are highly discriminative (Tsirka et al., 2020). Some summarize visual

abilities and disabilities in everyday life and guide practical recommendations and adaptations (Bowman, 2016; Lantzy & Lantzy, 2010; Leuck & Dutton, 2015). The information on the child's everyday function can be an essential link between the assessment and intervention processes. There are no guidelines for using questionnaires with children with CP, but Boonstra et al. (2022) recently advised using one-to-screen visual functions.

Example questionnaires for kindergarten- and school-age children are the 50-question Scottish Insight Inventory or Macintyre-Beon questionnaire (Macintyre-Beon et al., 2012), Structured Clinical Question Inventory (S. S. Philip et al., 2016), and Flemish questionnaire, with 46 questions in six domains (Ortibus et al., 2011). The five-question Higher Visual Function Deficits in Children with CVI questionnaire (HVFQ51) was derived from the Macintyre-Beon Questionnaire's 50 items (Chandna et al., 2021).

In sum, the literature highlighted the lack of a single CVI assessment protocol and the need to develop sensitive, easy-to-use, patient-friendly, and economically viable tools to assess children with CVI accurately (Baxter & Goldstein, 2007; S. S. Philip et al., 2020). This study aims to build a CVI assessment protocol based on the literature, including the broadly accepted criteria highlighting various visual functions and functional vision aspects. The protocol will include an assessment battery with medical recordings, detection and observation of visual functions and functional visual abilities with optometric examinations, a novel computerized assessment, a direct observational tool, and a visual questionnaire to detect the reduced visual perception functions reported in CVI.

The Insight Inventory questionnaire and CVI Range direct evaluation were chosen for this study due to their ability to summarize visual abilities and disabilities in everyday life and guide practical recommendations and adaptations (Bowman, 2016; Lantzy & Lantzy, 2010; Leuck & Dutton, 2015). Five questions were derived from the 52-item Insight Inventory and found to be highly reliable ($\alpha = 0.968$) and sensitive ($\alpha = 0.817$) in

distinguishing children with CVI with good visual acuity from typically developing children (Chandna et al., 2024).

Additionally, the sensory processing and modulation assessment will be added to highlight the differential diagnoses and explain the underlying mechanisms in subgroups of children with CP with CVI and sensory modulation disorder (SMD). Finally, the study will use parents' questionnaire data to correlate ICF dimension aspects—body function, structure, and activity—and predict the children's everyday activity, participation, and QOL in different environments.

As discussed, there is no one CVI assessment, but a comprehensive assessment tool based mainly on the child's expected behaviors. Some differential diagnoses and associated comorbidities can make assessing and diagnosing CVI more demanding (Sakki et al., 2021). Clinicians should be trained to distinguish CVI diagnoses from other ophthalmological visual disorders and specific learning and communication disorders (Chokron et al., 2021). Additionally, CP in the presence of cognitive impairment has been reported in conjunction with CVI. These associated comorbidities make diagnosing and characterizing the underlying visual impairment even more challenging (Merabet et al., 2017).

Similarly, children with unknown CVI could be misinterpreted as cognitively challenged or having communication difficulties (Kozeis et al., 2007; Leuck & Dutton, 2015). Moreover, children with CP with sensory processing disorder (SPD) and those with attention-deficit/hyperactivity disorder (ADHD) can show similar behaviors in visually stimulating environments. Thus, assessing visual abilities, sensory processing, and modulation function might highlight both diagnoses and explain the underlying mechanism in subgroups of children with CP with CVI and SMD. The next section discusses the visual perception function as part of multisensory processing functions.

1.9 Visual Processing as Part of the General Sensory and Modulation Processes

Sensory processing is how sensory information (e.g., visual, auditory, vestibular, and proprioceptive stimuli) is managed in the cerebral cortex and brainstem. Ayres (1979, 1985) termed *sensory processing* as *sensory integration* or Ayres *sensory integration* and described two essential principles of the central nervous system: "intersensory integration" and "self-organizing system" (Lane et al., 2019). Those principles enable an adaptive response to the environment and engagement in meaningful daily activities (Dunn, 1997; Humphry, 2002; Johnson-Ecker & Parham, 2000; Miller & Lane, 2000). Adaptive response is the central nervous system's ability to regulate and constantly adapt to changing sensory stimuli (the input's intensity, frequency, duration, and novelty; Miller & Lane, 2000).

All sensory systems, including vision, develop interdependently and are necessary for the full development of multisensory processing functions (Putzar et al., 2007). The vision process involves more than 50% of the brain. Thus, neurologic brain damage can impair the visual system and associated pathways, disturbing the sensory input, processing system, and ability to act accordingly (Leuck et al., 2019). Further, vision development induces the default use of an external coordinate frame for multisensory action control (Röder et al., 2007). Thus, in individuals with blindness, their age at the onset of blindness critically determines their visually defined reference frames for tactile control perception and auditory action (Gori et al., 2021; Röder et al., 2004). In addition, paired auditory and visual stimuli, known as the *temporal binding window,* integrate within a limited time window. The *temporal binding window* is enlarged in neurodevelopmental disorders such as autism spectrum disorder (ASD) and ADHD (Zhou et al., 2020).

These findings stress the essential consideration of sensory processing in its broad definition when referring to visual disability in children with neurodevelopmental conditions such as CP. However, most current research on visual disorders in CP concentrates on aspects of the visual-processing disorder. The literature on children with ASD discusses

visual-processing disorder as an aspect of a broad sensory modulation disorder. It suggests that their perceptual symptoms are due to distinct, low-level changes in the neural circuitry dedicated to perceptual processing, including primary sensory areas (Robertson & Baron-Cohen, 2017). Brincker and Torres (2013) proposed that many behavioral-level findings can be redefined as downstream effects of developing nervous systems. They suggested looking at the systems' attempts to cope and adapt to the challenges of various noisy, unpredictable, and unreliable peripheral inputs in children with autism rather than high cognitive functions. Sensory modulation disorder was researched further in children with autism and characterized by possible subgroups according to the sensory modulation profile to understand daily life implications and plan adequate intervention (Ben Sasson et al., 2009).

In a complex condition like CP, some behaviors can be interpreted as a visual or broader SPD. A better understanding of those processes' dysfunctions can highlight similarities and differences and direct adequate personal interventions. Further, a broader sensory processing investigation might identify different mechanisms and subgroups in the CP and CVI groups. Thus, visual-processing dysfunction might be explained as an aspect of SPD and SMD in one or more subgroups of children with CP and CVI.

The following sections discuss and highlight sensory processing theoretical models and assessment processes as aspects of SPD and SMD. In addition, current knowledge of those topics related to children with CP is reviewed, stressing this study's novelty, rationale, and protocol.

1.10 Sensory Processing and Modulation Disorders

Sensory processing, as highlighted earlier, enables adaptive responses to the environment and engagement in meaningful daily activities (Dunn, 1997; Humphry, 2002; Johnson-Ecker & Parham, 2000; Miller & Lane, 2000). When sensory processing is impaired, participation and enjoyment is restricted (Chien et al., 2016). Human experiences are usually characterized by a sensory viewpoint of everyday life and provide a common

ground for understanding (Dunn, 2001). Individuals differ in processing sensory information, often described in terms of their "interest in," "tolerance for," or "pleasure with" sensation (Huebner & Dunn, 2001). However, given the different personal experiences with sensation, it is sometimes difficult or even inconceivable to imagine another person's experience with an object, event, or context. It is especially challenging, albeit meaningful, with SPD conditions.

Sensory processing disorder is an umbrella term for a group of disorders involving challenges in modulation, integration, organization, and discrimination of sensory input in a graded manner. As a result, the person does not respond appropriately to the input and experiences disruptions in daily activities and emotional and behavioral patterns (Interdisciplinary Council on Developmental and Learning Disorders [ICDL], 2005; Miller et al., 2007). Alterations in sensory processing are also called sensory regulation dysfunction or sensory dysfunction disorder (Galiana-Simal et al., 2020).

Sensory modulation is one aspect of sensory processing representing the brain's capability to regulate information by balancing excitation and inhibition of sensory input (Dunn, 1999). Sensory modulation difficulties include hyper- or hyposensitivity to "regular" stimuli and relate to elevated sympathetic responses and difficulties habituating to sensory stimuli (Schaaf et al., 2015). These difficulties are prevalent in children with neurologic conditions and have far-reaching implications for their daily function and QOL (Cascio, 2010; Engel-Yeger, 2019; Galiana-Simal et al., 2020; Genizi et al., 2019).

Three diagnostic classification references acknowledge SPD and SMD: the Diagnostic Classification of Mental Health and Developmental Disorders of Infancy and Early Childhood (Emde et al., 2005), the Diagnostic Manual for Infancy and Early Childhood of the Interdisciplinary Council on Developmental and Learning Disorders (ICDL, 2005), and the Psychodynamic Diagnostic Manual (Etnyre, 2008).

Among children in a Western lifestyle population, 5% to 15% were diagnosed with SPD and SMD; however, many health professionals still do not know about this condition, giving rise to unattended children and frustrated families (Galiana-Simal et al., 2020).

1.11 Sensory Processing and Modulation: Theoretical Models

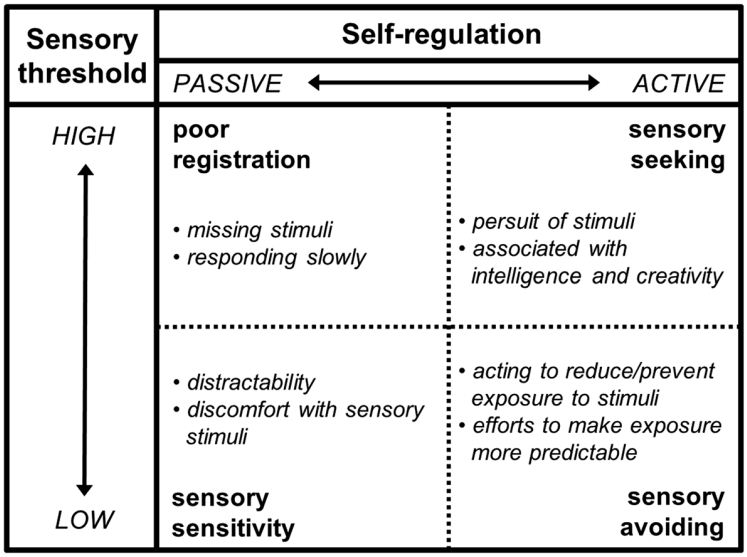
Sensory processing disorder is difficult to understand and diagnose because more than one sensory system can be involved with various symptoms (Galiana-Simal et al., 2020). Furthermore, no one person demonstrates only a single pattern of sensory processing. For example, a person might have sensitivity to touch but low registration for sounds (Dunn, 2007a). Therefore, theoretical models refer to sensory processing and modulation abilities and try to simplify by emphasizing specific aspects, subgroupings, and classifications to detect sensory dysfunction and direct intervention.

Dunn's (1997) model (Figure 1) is an early model referring to the relationship between neurological thresholds and self-regulation strategies for adaptive behavior. The neurological thresholds range from high (requiring high-intensity stimuli for a response) to low (low-intensity stimuli provoke a response) thresholds. The continuity of self-regulation ranges from passive (individuals do not counteract unpleasant stimuli) to active (individuals act to control the amount and type of sensory input) strategies.

Based on this interaction, Dunn's (2007a) model classified sensory processing patterns into four subtypes, as presented in Figure 1. Sensation seeking represents high thresholds and an active self-regulation strategy. These individuals energetically engage in actions that add more intense bodily sensations. Because of these urges, sensory-seeking individuals tend to be inattentive and unfocused during learning tasks and social interactions. Sensation avoiding includes low thresholds and an active self-regulation strategy. These individuals' behavior is characterized by rigid, uncompromising rituality and difficulty accommodating and transitioning. They often feel threatened by sensation and adopt avoidance behavior. Sensation sensitivity includes low thresholds and a passive self-

regulation strategy. These children respond to sensation faster, more intensely, or longer than those with typical sensory responsiveness. Their behavior may range from active, negative, impulsive, or aggressive responses to passive withdrawal or sensation avoidance. Low registration represents a high threshold and passive self-regulation strategy. These individuals tend to disregard or not respond to sensory stimuli in their environment. They appear not to detect incoming sensory information and lack responsiveness. Thus, they appear introverted, apathetic, or lethargic, lacking the inner drive to initiate exploration. Dunn's model is wide-ranging. Those four fundamental sensory processing patterns are found in each age group from infancy to older adulthood in typical development and children with disabilities.

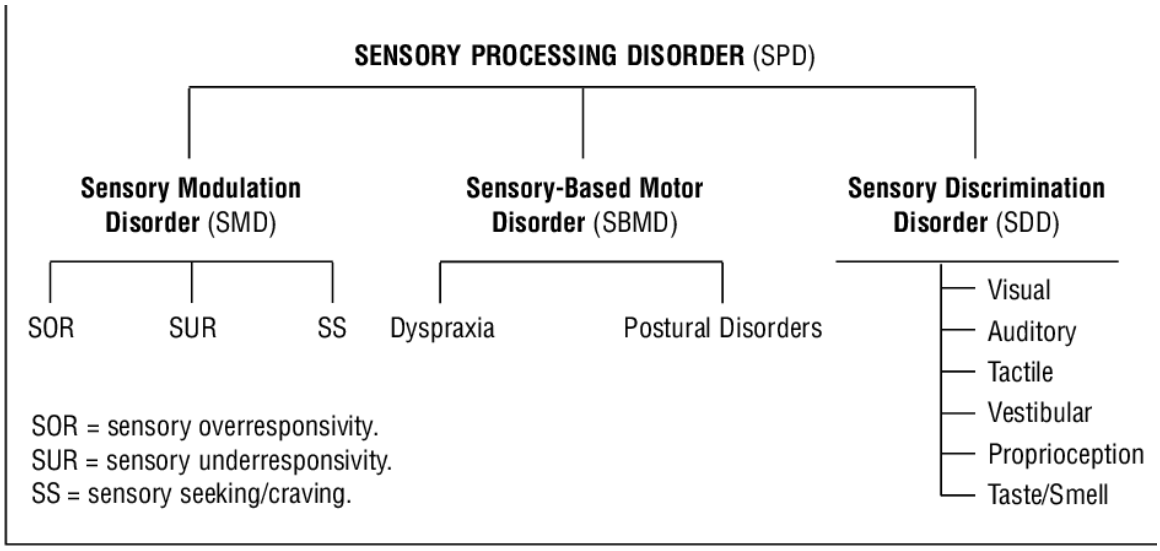
Figure 1
Van Campen et al.'s (2015) Adaption of Dunn's (1997) Model of Classified Patterns of Sensory Processing



Miller et al.'s (2007) nosology subclassified SPD first according to the sensory-processing phases (modulation, discrimination, and sensorimotor) and then into three

possible types of disorders that can coexist (Figure 2): SMD, sensory-based motor disorder, and sensory-discrimination disorder. Miller et al. further highlighted three subtypes in the SMD group, two dyspraxia and postural disorder subgroups in the sensory-based motor disorder group, and six sensation subgroups in the sensory-discrimination disorder group. In SMD, the subtypes differed by the response to sensory input. Each response type is inconsistent with the sensory situation's demands, and adapting to sensory challenges encountered in daily life was observed.

Figure 2
Miller et al.'s (2007) Nosology for Sensory Processing Disorder

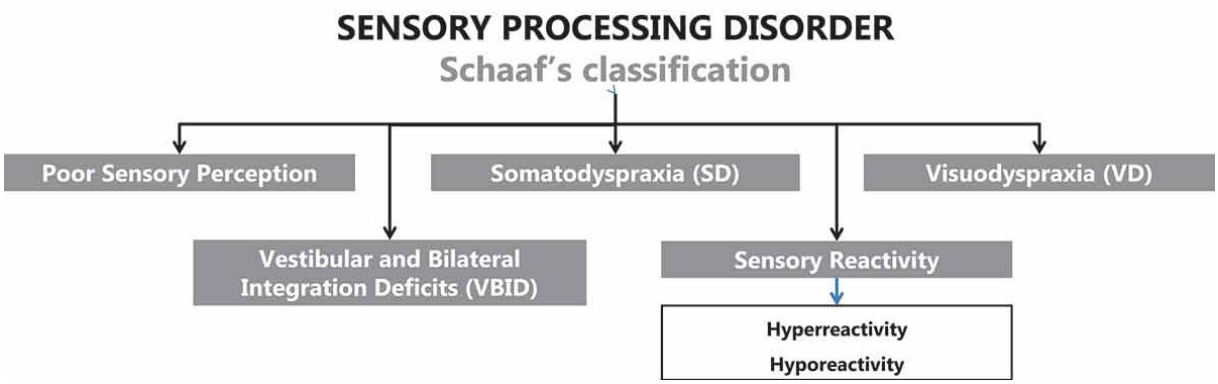


Schaaf's model includes different characteristics and definitions highlighting the motor aspects and dyspraxias, mainly in children with ASD. Schaaf's research compared SPD in children with different developmental disorders (including ASD) to typical development and suggested classifying five SPD subtypes (Schaaf & Mailloux, 2015). Her model is based on the Southern California Sensory Integration Tests (SCSIT; Ayres, 1972) and Sensory Integration and Praxis Tests (SIPT; Ayres, 1989). As depicted in Figure 3, the

model focuses on sensory processing and divides motor praxis aspects into somatodyspraxia and visuodyspraxia, highlighting further vestibular and coordination aspects.

The subtypes are poor sensory-perception overview, somatodyspraxia, vestibular and bilateral integration deficits, visuodyspraxia (i.e., VP), and sensory reactivity. The *poor sensory-perception overview* pattern is characterized by difficulty identifying, discriminating, and interpreting sensory information in more than one sensory system. The *somatodyspraxia* pattern is associated with poor sensory perception (including tactile) and signs of poor motor planning involving imitating, planning, and sequencing actions. *Vestibular and bilateral integration deficits* refer to poor vestibular processing and difficulties in related motor functions such as muscle tone, postural and oculomotor control, balance, midline integration, and bilateral coordination. Visuodyspraxia means poor visual perception with poor visuomotor skills and planning. Finally, *sensory reactivity* refers to excessive reactions to typical sensation levels, interfering with participation in daily activities. For example, it might manifest as a fight-flight-freeze response and produce anxiety, high activity levels, or inattention. Finally, sensory reactivity can manifest as sensory hyper- or hyporeactivity.

Figure 3
Classification of Sensory Processing Disorder and Subtypes Proposed by Schaaf (From Schaaf & Mailloux, 2015)



These models emphasize different aspects of SPD and behaviors. The sensorimotor aspect is essential in children with CP; however, this study focuses mainly on SMD aspects expressed in behaviors also described in children with CVI. This study aims to characterize the different SPD subgroups, primarily SMD in children with CVI, to highlight a possible mechanism explaining those behavioral characteristics. Thus, Dunn's (2007a) model emphasizes the study rationale and direction for an adequate sensory assessment tool.

1.12 SPD and SMD Etiology

The etiology of SPD and SMD is unknown. However, factors such as prenatal or birth complications, low birth weight (< 2.2 kg), genetic factors, and part of a general syndrome or disease could lead to SPD and SMD (Ben-Sasson et al., 2009; Galiana-Simal et al., 2020; Keuler et al., 2011; May-Benson et al., 2009; Schneider, 2008). Sensory processing and modulation disorders are estimated to be between 5% and 16% in the general population (Ahn et al., 2004; Ben-Sasson et al., 2009) and should be followed with preterm children until school age, given its high (30%–70%) prevalence (Niutanen et al., 2020). These disorders are frequent as high as 90% in children with ASD (A. E. Z. Baker et al., 2008) and ADHD (Shimizu et al., 2014) and are included in the *Diagnostic and Statistical Manual of Mental Disorders* (5th ed.) diagnostic criteria (Schaaf & Lane, 2015).

1.13 Sensory Processing and Modulation Assessment Tools

Sensory assessment may direct assessment of specific modalities with specific functional tests. For example, functional sensory assessments direct tactile discrimination with the 2-point discrimination (Shooter, 2005), hand-function touch-pressure, and kinaesthesis measurements (Klingels et al., 2010) all correlated to hand-function levels in children with CP. Another way is detecting sensory function neurophysiologically with tools such as event-related potentials (ERP). Thus, it could be shown that an abnormal reaction in ERP strongly relates to sensory impairment in children with ADHD and SMD (Parush et al., 2007) and children with CP (Teflioudi et al., 2011).

However, based on the complex interaction between the sensory systems and other body functions (as motor, cognitive, and emotional) and adaptive behavior/participation in daily life, studies highlighted the need to refer in specific cases, such as clinical populations, to all sensory modalities and better understand the interaction between the systems. Thus, it further detects which sensory system is more affected by the clinical diagnosis and the implications on the child's daily function.

Ayres (1972) developed an observation evaluation method for *sensory integration*, including sensory assessment of somatosensory, kinesthetic, visual, and visuomotor functions. The SIPT (Ayres, 1989) followed the SCSIT (Ayres, 1972), updating the previous tests while retaining subtests evaluating tactile, kinesthetic, visual, and visuomotor processing abilities. These assessments have limitations: the person administering the tests must have special training, the assessment takes several hours to complete, and the scores do not always reveal how the child performs in natural settings (Dunn, 1994).

Thus, new subjective measures developed based on caregivers' reports and parents' questionnaires reflect the solid relationship between the neurological system's abilities to process/modulate sensory information and the person's behavioral response in daily life. The Sensory Profile (SP; Dunn, 1999; Jorquera-Cabrera et al., 2017) and its new version, the SP2, are the most used tools to examine how sensory processing and modulation are expressed in the child's daily scenarios (while dressing, eating, etc.; Chien et al., 2016; Dunn & Westman, 1997). Since then, other questionnaires have been developed to address functions and abilities relevant to age and expected challenging behaviors in different populations or environments: the Sensory Experiences Questionnaire for young children with autism (Baranek et al., 2006), Adolescent and Adult Sensory Profile (C. Brown et al., 2001), and Diagnostic Interview for Social and Communication Disorders (DuBois et al., 2017) for adolescents and adults with ASD. In addition, the Sensory Processing Measure

examines parents' and teachers' perceptions of the child's sensory processing functions in various environments (Fernández-Andrés et al., 2015).

The SP (Dunn, 1999) will be used in this study because it can detect the person's behavioral responses in daily life, which are relevant in children with CP and CVI. It is valid for the CP population and age range and feasible in this comprehensive assessment correlative study.

1.14 Sensory Processing and Modulation Disorders in Children With Cerebral Palsy

Children with CP have multiple sensorimotor deficits that affect development and all aspects of daily function (Gaebler-Spira, 2011). The primary motor problem in CP cannot be separated from the sensory system's role of providing additional information about the movement and environment. Ayres (1979, 1985) described the human brain as a "sensory processing machine," considering that over 80% of the nervous system is involved in processing or organizing sensory input. In children with CP, conditions of lesions to periventricular white matter and somatosensory cortex may lead to abnormal movement and loss of postural control. This condition further hinders building a proper proprioceptive sense and movement feedback (Louwrens, 2018; Mishra et al., 2020). The MRI findings suggested that sensorimotor deficit in CP cannot simply be attributed to changes in the integrity of descending corticospinal projections (Scheck et al., 2012). Rather, lesions to periventricular white matter also affect the development of the cortical and thalamic regions (lower number of fibers and based fractional anisotropy values) of both corticospinal tracts and posterior thalamic radiation in children with CP, with correlation to GMFCS levels (Tsao et al., 2014; Yoshida et al., 2010). Loss of thalamocortical projections is expected to reduce sensory function (Hoon et al., 2002). Conditions of periventricular white matter lesions were reported in 45% to 56% of children with CP and occurred more in preterm (90%) than in term-born children (20%; Krägeloh-Mann & Horber, 2007; Reid et al., 2015).

Sensory impairment was reported in possibly 90% of the children with CP (Cooper et al., 1995). However, many studies on sensory abilities in CP in the last two decades focused on specific sensory modalities, such as tactile or proprioceptive discrimination affecting fine motor skills. Therefore, a standardized clinical sensory battery was recommended mainly in the upper limb. Studies found reduced stereognosis, tactile discrimination, and proprioception with higher pain sensitivity in children with CP than in typical children (Bleyenheuft & Gordon, 2013; Riquelme & Montoya, 2010; Sanger & Kukke, 2007; Van Heest et al., 1993; Wingert et al., 2009). Further, children with diplegic and hemiplegic CP exhibited tactile sensory deficits in both hands (Wingert et al., 2009), emphasizing the importance of a broader sensory processing assessment. The assumption of a correspondence between finger-sensory skills and finger dexterity in children with CP has been challenged by independent stress involvement of motor and sensory deficits (Bleyenheuft & Gordon, 2013; Guedin et al., 2018). Lower-limb sensory deficits also contribute to pronounced balance and motor impairments in CP (Zarkou et al., 2018).

Sensory perception is discussed because it could lead to severe developmental disability (Ahn et al., 2004; Barela et al., 2011; Beckung & Hagberg, 2002). However, few studies addressed sensory processing disturbances in children with CP. Children with CP present more sensory processing deficits than typical children (Pavão & Rocha, 2017). Sensory processing involves perceiving and registering sensory stimuli and modulating sensory information, balancing between excitation and inhibition and affecting the child's behaviors and ability to attend, learn, and organize (Dunn & Daniels, 2002; Humphry, 2002). Thus, the systematic evaluation of sensory processing will consist of different approaches and tools, such as caregiver questionnaires, interviews, and observations (Pavão & Rocha, 2017; Schaaf & Miller, 2005). Sensory processing in children with CP at GMFCS Levels I to II is associated with their ability to perform daily activities and social interaction with the environment (Pavão et al., 2021). Further, severe sensory processing difficulties

presented more in the CP diplegic and quadriplegic subtypes than in the hemiplegic group (Soomro et al., 2011) and more in preschool children than school-age children (Kim et al., 2015).

Concerning sensory modulation, specific patterns were further emphasized to be prevalent in different CP types (Louwrens, 2018). They are less responsive to sensory information and, thus, less able to adjust during sensory perturbation affects postural control ability (Pavão et al., 2015). Moreover, their sensory processing abilities relate to GMFCS and MACS levels and functional mobility (Mishra et al., 2020; Park, 2017). Although different CP subtypes may present with different SPD, different sensory systems may be involved. Each child may have unique internal or external factors; thus, the assessment should be holistic and consider all contextual and functional aspects and environmental factors contributing to the child's observed patterns (Louwrens, 2018). Research using principles or elements of sensory integration with children with CP supports positive outcomes in attention, motor performance, and daily living activities (Bumin & Kayihan, 2001; Kashoo & Ahmad, 2019; Shamsoddini & Hollisaz, 2009; Tahir et al., 2019).

A correlation between visual functions and sensorimotor impairments has been shown recently in children with hemiplegic CP (Hawe et al., 2020). The relationship was further highlighted in recent intervention research with infants with CP with CVI. The researchers compared sensory integration intervention combined with the physiotherapy program to the physiotherapy program alone. The combined program was more effective in increasing sensory-processing skills (Cemali et al., 2022).

A possible neurophysiological mechanism for this correlation may be due to changes to the thalamocortical projections in children with CP, discussed in conditions of sensory modulation (Papadelis et al., 2014) and visual function abnormalities (Ricci et al., 2006). However, research on children with CP did not highlight those two conditions of SMD and CVI jointly in children with CP. Moreover, their relationships to participation in daily life

are minimal (Pavão & Rocha, 2017). Such research is especially essential because research on sensory-integration interventions (Kantor, 2022) and visual-directed interventions (Morgan et al., 2021; Tsirka et al., 2020) in children with CP showed promising functional effectiveness. That is, sensory-integration interventions for children with CP were shown to effectively improve gross motor skills (Shamsoddini & Hollizas, 2009), sensory-perceptual motor functions (Bumin & Kayihan, 2001), gait (Seyam et al., 2021), and fine motor skills (Olfatian et al., 2021).

To summarize, the literature discusses CVI in children with CP as a unique dysfunction of the visual streams, mostly separate from broad sensory processing and modulation disorders. Based on brain networks and the obligatory relations between sensory brain areas for human function, it is necessary to elaborate on the relations between CVI and sensory processing/modulation. Therefore, this research will apply for the first time a broad assessment detecting visual ability, sensory processing, and modulation in daily life scenarios with children with CP and CVI. The results may highlight characteristics leading to different subgroups of children with CP and CVI and direct adequate interventions. Further, SPD and visual processing disorder influence the child's ability to participate in daily life but are purely researched (Hochhauser & Engel-Yeger, 2010; Leuck & Dutton, 2015; Lueck et al., 2019).

Because this research is based on the ICF and PEOP models, it will further address the correlation between body functions as SPD and visual disorder to activity in daily life and participation levels in specific settings, followed by detecting each aspect's contribution to QOL. Lastly, those models acknowledge environment as influence on function and participation, especially with children with CP included in mainstream schools. Thus, the research will address environmental barriers and direct environmental intervention recommendations.

Both ICF and PEOP models and the components of body function, activity, and environmental are presented in the following sections. First, I review the impact of these components on participation in the CP group, especially with the children included in mainstream schools. Then, I discuss the practical application of environment and accessibility in general and in children with CP with CVI and SPD. Last, I introduce the possible influence of those aspects on QOL levels in children with CP.

1.15 ICF-CY Model and the PEOP Model and Their Relevance to Children With CP

Two decades ago, the *medical model* assumed that disability was an endogenic medical condition due to a person's state. It focused on the disability's impact and attempted to correct the disability through medical interventions, such as medications, surgeries, or aids. Changes in the therapeutic model emphasized that an intervention's overarching goal is to improve participation in various activities and thus improve QOL. This *social model* assumes that disability is also a product of environmental conditions and social context. Therefore, a change in environmental adaptation or social demands could alleviate or even eliminate the disability (Horowitz & Haritos, 1998; Simeonsonn et al., 2002).

These changes reflect a shift in the WHO's ICF models from focusing on the "consequences of the disease" (WHO, 1980) to its "health components" (WHO, 2001). The shift greatly influenced changes in rehabilitative perceptions. Thus, the intervention process's overarching goal is to improve participation and QOL. As a result, new research fields were developed for different populations, including children with CP, focusing on participation, QOL, and environmental factor impact (Rosenbaum & Stewart, 2004).

The ICF (WHO, 2001) provides a standard language and framework for describing health and health-related states. A classification of health and health-related domains that describe changes in body function and structure, it refers to what a person with a health condition could do in a standard environment (their capacity level) and what they actually do in their usual environment (their performance level).

These domains are classified from body, individual, and societal perspectives using lists of body functions/structure and activity/participation domains. In the ICF, functioning refers to all body functions, activities, and participation, whereas disability is an umbrella term for impairments, activity limitations, and participation restrictions. The ICF also lists environmental factors that interact with these components (WHO, 2001). Studies showed that diagnosis alone does not predict service needs, functional outcomes, or the likelihood of social integration. Thus, diagnoses such as CP, CVI, or SPD will not have the full information needed for health planning and management. The ICF makes it possible to collect more vital data in a consistent and internationally comparable manner for all domains (e.g., function and participation) found to be more influential on the person's QOL.

The person–environment–occupation–performance (PEOP) model (Baum et al., 2015) is an occupational therapy framework emphasizing the dynamic interaction among the person, their environment, the occupations they engage in, and the resulting performance outcomes. It proposes that successful participation in meaningful activities arises from an optimal fit between personal capacities (e.g., physical, cognitive, sensory, and psychological abilities), environmental contexts (physical, social, cultural, policy-related), and occupational demands.

In the context of children with CP and CVI, the PEOP model highlights how visual and sensory processing functions (as personal factors) interact with environmental facilitators and barriers to influence daily participation and QOL. For example, visual complexity, classroom design, and social support can act as critical environmental determinants of performance.

Integrating the PEOP model with the WHO's (2001) ICF enhances the ecological and person-centered interpretation of functioning. While the ICF provides a standardized taxonomy of body functions, activities, participation, and environmental factors, the PEOP model expands on the mechanisms linking these domains, emphasizing occupational

meaning and engagement as central mediators of health and well-being. The combined use of ICF and PEOP allows assessment and intervention to be grounded in both classification and lived experience-bridging impairment-level data (e.g., sensory or visual deficits) with participation-level goals (e.g., school or play activities).

This integrated framework supports individualized, context-sensitive goal setting, ensuring that visual and sensory assessments translate directly to intervention planning that optimizes participation. It also aligns with contemporary rehabilitation paradigms emphasizing function, participation, and QOL rather than deficit correction alone.

1.16 Participation in Children With CP

Participation defines the individual's involvement in structured and unstructured activities (Law, 2002; WHO, 2001). It is one of the most critical indicators of intervention success because it relates to the individual's daily life and significant integration into various life areas. The word participation originates from Latin—derived from *particeps,* meaning part-taking, and *pars (+) capere*, meaning to take or to share in; thus, its central concept is involvement or sharing (Law, 2002). Participation is structured and objectively reported in several dimensions' measurements: the person's preferences and interests, such as activity types, frequency, involvement level, environment, reference group, and degree of enjoyment and satisfaction from experiences (Engel-Yeger et al., 2009; Law, 2002). Participation and QoL are the primary essential intervention outcomes but are related differently to the level of impairment; thus, they must be assessed separately (Colver et al., 2011).

For children, participation is necessary for healthy development, learning, and shaping identity and sense of belonging (Imms et al., 2017; Limond et al., 2009). However, participation in daily activities is reduced in children with disabilities (Engel-Yeger et al., 2009; Lim et al., 2016). They participate in fewer active recreation activities, home tasks, informal social engagements (Law, 2002; Law et al., 1999), and leisure activities and less intensely (Longo et al., 2013; Majnemer et al., 2015) than children without disabilities.

Many factors may influence children's participation patterns including age, gender, socioeconomic status, and environmental accessibility.

The research looked at the structural and functional components and their relative impact on participation with children with disabilities. Their participation levels were proportional to the degree of injury, functional level, and number of disabilities (Anaby et al., 2013; Schenker et al., 2005). Similarly, reduced participation in active-physical and skill-based activities was seen in children with intellectual disabilities, perhaps due to reduced physical, cognitive, and social skills. Nevertheless, children with physical and neurological disabilities reported enjoyment from the same activities did children without disabilities. They also reported the need to feel connected with their friends and a sense of accomplishment from doing things independently (King et al., 2013).

When referring to children with CP, some research focused on a body-function component's influence on participation. Lower motor abilities predicted 69% of the participation levels in children with CP integrated into a mainstream educational setting in Israel (Shenker et al., 2005). Motor and intellectual limitations predicted functioning and participation in children with CP at home and in the community (Beckung & Hagberg, 2002; Østensjø et al., 2003). More difficulty was found in participating in activities in the community than at home, which was already seen in toddlers (Di Marino et al., 2018). The frequency of participation in leisure activities for children and youth with CP was also associated with various variables. The essential variables were gross motor function, manual ability, cognitive ability, communication skills, age, and gender (Bult et al., 2011).

Decreased participation levels and patterns (diversity, intensity, and enjoyment) were shown in children with typical development upon transition to adolescence (Jarus et al., 2010). However, typically developing youth engaged in a broader range of activities more frequently than youth with CP. Adolescents with CP participated less in nonstructured activities with similar enjoyment levels compared with typical development groups (Engel-

Yeger et al., 2009) and engaged in more activities with others outside of their family if their parents had higher education levels. Increased social participation with friends was associated with body functions, such as higher sports and physical functioning (Kang et al., 2010). In adolescents with CP, pain, childhood psychological components, and parental stress also influenced participation (Dang et al., 2015).

1.17 Significance of Sensory Processing to Participation of Children With CP

The ability to process and modulate sensory input is a body-function component that significantly affects a child's function and participation in daily activities (Dunn, 2007b; Hochhauser & Engel-Yeger, 2010; Leuck & Dutton, 2015; Lueck et al., 2019). Although relevant for children with typical development (Piwinski et al., 2021; Sleeman & Brown, 2022), there is a greater emphasis on children with developmental disabilities (Bar-Shalita et al., 2008; Spira, 2014; Yochman et al., 2013). In children with typical development, sensory processing was found to predict occupation outcomes, including sleep, motor development, play, behavior, and resiliency (Appleyard et al., 2020; Dean et al., 2018; Pfeiffer et al., 2018). Sensory processing accounted for 69.8% ($p = 0.001$) of the variance in participation diversity and 45.9% ($p = 0.024$) of the variance in participation intensity in children with typical development (Sleeman & Brown, 2022).

Children with SPD (without comorbidities) showed reduced participation in daily occupations and lower enjoyment of that participation than typical children (Bar-Shalita et al., 2008; Chien et al., 2016; Cosbey et al., 2010; Dunn et al., 2016; Yochman et al., 2013). Social activities were the most-reduced participation domain for school-aged children with SPD (Cosbey et al., 2010). Interestingly, children with SPD demonstrated more frequent conflicts than their typical peers and did not consistently respond appropriately to their peers' behavioral cues. Compared to children with typical development of kindergarten age, children with SPD showed higher participation levels in outdoor free play (Cosbey et al., 2012) but reduced participation in structured physical activity at school age (Cosbey

et al., 2010; Hertzog et al., 2019). They participated more in active physical activities, such as water sports, team sports, racing, or track and field, than typically developed children (Engel-Yeger, 2008). Moreover, in children with SPD, participation in structured physical activity was positively associated with the frequency and level of enjoyment in all occupation areas, including enjoyment of play and leisure participation (Dean et al., 2018).

Although SPD in children with typical development may relate to their participation patterns, most studies referred to the interactions between SPD and participation in clinical populations. For example, SPD patterns in children with ASD and comorbid emotional and behavioral difficulties (A. E. Z. Baker et al., 2008; Ben Sasson et al., 2009) affected the children's participation frequency. This was relevant to activities inside and outside the home (Little et al., 2015; Schaaf et al., 2011). For instance, in high-functioning children and adolescents with ASD, sensory hyper- and hyposensitivity decreased participation in community social activities (Pfeiffer et al., 2005). Sensory sensitivity and avoiding patterns in children with ASD correlated with lower participation in social, physical, and informal activities in the home and school environments (Hochhauser & Engel-Yeger, 2010; Reynolds et al., 2011). Further, difficulties processing visual and auditory input are related to reduced participation of children with ASD in school (Ashburner et al., 2008).

Another clinical population in which the relation between SPD and participation was largely studied is children with ADHD (Ghanizadeh, 2010). In these children, SPD was associated with limited participation in daily activities (Bar-Shalita et al., 2008) and a reduced preference for leisure activities (Engel-Yeger & Ziv-on, 2011). Children with more sensation-seeking showed higher preferences to participate in physical activities. Nevertheless, as with typical children, the most common activity type related to SPD was social activities (Little et al., 2018).

In children with other central nervous system deficiencies, SPD was also related to reduced participation. For example, in children with Down syndrome and fragile X

syndrome, SPD correlated with lower participation in daily life and school activities (Baranek et al., 2002; Wuang & Su, 2011).

Although CP is a known CNS impairment in childhood that also may involve the sensory systems, the research about SPD is limited, as is research about participation and the interaction between SPD and participation. As mentioned, only a few studies focused on specific sensory systems. Jovellar-Isiegas et al. (2020) found that auditory-, visual-, and tactile-processing impairments correlated with reduced participation in the school environment in children with hemiplegic CP. Further, visual perception components, especially visual sequential memory, were associated with activities of daily living processing ability in school-age (8–17 years) children with hemiplegic CP (James et al., 2015).

Regardless, the impact of sensory and visual processing disorders on participation has not been researched extensively. The sensory processing challenges and participation impact of visual processing difficulties, as studied in children with typical development, SPD (without comorbidities), and other disabilities, highlighted the importance of researching SPD in children with CP and CVI. Based on these results, SPD in school-age children can reduce their participation in various activities that further influence learning and development achievements. At school age, there is a demand for increased participation in various activities inside and outside school hours. Such participation at school age is vital for positive self-esteem, higher social participation, a sense of competence, QOL, higher academic achievements, and romantic relationships in adulthood (Longo et al., 2013; Michelsen et al., 2014; Shikako-Thomas et al., 2012; Wiegerink et al., 2010).

Interestingly, regardless of condition, children with SPD gain coping and executive functioning skills to counteract unpleasant or overwhelming sensory experiences as they age. It may be that parents, teachers, and service providers provide environmental or task modifications that decrease particular sensory and behavioral features (Little et al., 2018).

Adults can manage and provide care with specific suggestions for adapting everyday life situations to meet the needs of children with different sensory-processing patterns (Dunn, 2007b). Thus, adequate assessment addressing sensory challenges within the specific age and environmental contexts of children with CP with CVI is essential. The next sections discuss environmental considerations and inclusion at school age to increase participation.

1.18 Environment Component Impact on Participation

Recent research influenced by the ICF highlighted the complexity and interaction of various effects on human and family functioning (Rosenbaum & Stewart, 2004). Therefore, a new model emphasizes the environment's role as a mediated space between the disability level and the participation of children with disabilities (Anaby et al., 2013, 2014). This information is of utmost importance because the environment can be a facilitator or a barrier and a strong predictor of participation (Anaby et al., 2014; Di Marino et al., 2018; Law et al., 2007).

The ICF combines individual health components and environmental context elements. The environmental elements are divided into five main groups: products and technology, natural and manufactured environment, support and relations, access, and government services and media (WHO, 2001). These elements include social and geographic support in traffic collection, team relations and services, bureaucracy, laws, aids, or delayed participation. They, therefore, might affect the QOL of children with CP (Anaby et al., 2013, 2014; Badia et al., 2016; Bedell et al., 2013).

In a sociopolitical model, disabilities are viewed as a problem in the individual's relationship with the environment, not as a problem within the child or youth (Colver & SPARCLE Group, 2006). Contextual factors such as personal lifestyle preferences, demographic characteristics, family function, and environmental attributes influence the level of participation in leisure activities (Shikako-Thomas et al., 2008).

Components of the environment's impact on participation are being explored and considered in clinical intervention planning. Children with CP who participated in diverse activities reported social attitudes and physical environments as barriers to participation (Imms, 2008). Children with CP in Spain reported reduced leisure activity participation. They described physical, social, and attitudinal environmental barriers (Longo et al., 2020) and cultural differences also affecting children's performance in Israel (Josman et al., 2006).

The research highlighted the reduced demand for physical activity and social interaction in the home environment with significant difficulty participating in community activities (Engel-Yeger et al., 2009; Lim et al., 2016; Majnemer et al., 2008). Engel-Yeger et al. (2007) reported that culture might significantly affect children's participation in the community. A recent study examined the relationship between participation, environmental accessibility, and QOL in children with CP and motor disabilities integrated into mainstream schools in Israel (Gelkop & Engel-Yeger, 2025). The findings highlighted the "lack of resources" in the community environment as the primary (37%) predictor of the children's QOL. The results spotlighted the significance of optimizing participation and accessibility of community daily environments to improve children's QOL and their inclusion in society.

The importance of the environment is its potential for value and impact in the intervention. Environmental approaches are defined as the environmental provision of various aspects in interactions between service providers and recipients: physical environment, service, social provision, and cultural contexts (Israeli Ministry of Justice, n.d.). Studies found a connection between participation models and environmental factors in children with CP (Anaby et al., 2015; Di Marino et al., 2018). Changes in the environment would significantly affect function and participation (Anaby et al., 2015; Law, 2002; Law et al., 1999; Waisman-Nitzan et al., 2022). Those researchers showed that programs that map and change environmental components support the children's goals, achievement participation level improvement, and even changes in body function structure components

(Anaby et al., 2018, 2020). A recent study summarized the most common environmental factors associated with participation. Participation, attendance, and involvement were associated with family ecology, type of school, and parental stress. In contrast, participation-related constructs, such as activity competence, sense of self, and preferences, were associated with parental stress and the physical environment (Van der Kemp et al., 2022).

Nevertheless, studies emphasizing the interaction between vision, sensory modulation, participation, and environmental accessibility, remain scarce. Furthermore, no child with CP has similar challenges to another child with CP; thus, it is not "one size fits all." Therefore, further research is needed to highlight aspects such as vision and sensory modulation, to allow adequate adaptation and optimize participation and inclusion possibilities for children with CP.

1.18.1 Environment and Inclusion of Children With Disabilities and With CP

The growing understanding of environmental influences on function and participation highlights another aspect to consider with the increasing inclusion of children with special needs in mainstream schools. Israel's Special Education Law of 1988 was amended with the Inclusion Act in 2002 (Israeli Ministry of Education and Culture, 2002). As a result, 2009 to 2017 saw an increasing trend in the percentage of students with special needs studying in regular classes in primary and secondary education. By 2017, almost 65% of special needs students studied in regular classes (Central Bureau of Statistics, Israel, 2017). Thus, 91% of students with blindness/visual impairment, 82% of students with developmental delay, 80% of students with deafness/hard of hearing, and 50% of students with CP/severe physical disabilities are included in mainstream schools in Israel.

The inclusion philosophy connects to the concepts of human rights and equal participation opportunities for individuals. It calls for listening to an individual's goals and needs to engage in activities that the disability impedes, regardless of the disability type (Gal et al., 2010). School is essential for all children's and adolescents' cognitive and social-

emotional development. In the United States, the inclusion discussion started during the 1970s emphasized school as preparation for life beyond school, irrespective of abilities or disabilities (Department for Education and Science, 1978). Attending school could be understood as behavior and developmental outcomes. It marks the youth's developmental capacity to separate from their caregiver and engage at school (Melvin et al., 2019).

School placement (special or mainstream systems) affects students' participation at school. Children with disabilities report more interaction with their peers in mainstream classrooms than in special classrooms (K. Baker &ottom , 2001). Segregation practices effectively prevent children with physical disabilities from engaging in wider social settings. However, the influence of educational placement has not been widely studied for students with CP (Finnvold, 2018). For adolescents, school placement explained a significant amount of variance for mobility, responsibility, and community participation, whereas motor-function level and receptive language significantly predicted pre-adolescents' participation (Paz Pérez-Salas et al., 2020). It was concluded that attending special schools negatively influences some participation domains (Finnvold, 2018). A better understanding of the association between mobility, communication, and school placement and CP students' participation is crucial to promoting interventions that consider participation a critical aspect of rehabilitation and inclusion (Paz Pérez-Salas et al., 2020).

The terms inclusive and mainstream often are used interchangeably despite being mutually incompatible (L. Graham, 2020). Segregation has been defined as "when education of students with disabilities is provided in separate environments designed or used to respond to a particular or various impairments, in isolation from students without disabilities" (United Nations [UN], 2016, para 11). Integration is defined as "a process of placing persons with disabilities in existing mainstream educational institutions, as long as the former can adjust to the standardized requirements of such institutions [emphasis added]" (para 11). In comparison, inclusive education often is described as a journey to

protect inclusion's inherent flexibility and ongoing nature and prevent it from being reduced to a checklist (L. Graham, 2020). Thus, inclusion is defined as a process of systemic reform embodying changes and modifications in content, teaching methods, approaches, structures and strategies in education to overcome barriers with a vision serving to provide all students of the relevant age range with an equitable and participatory learning experience and environment that best corresponds to their requirements and preferences [emphasis added]. (UN, 2016, para 11)

It can be expected that the performance in an adapted environment, as in segregation education, will be higher than in an integration environment. However, the mechanism that ensures greater effectiveness of inclusive schools is complex. Parents of children with disabilities report that mainstream schools are more demanding than special schools, with more substantial pressure to achieve reflected learning time at home (Asif et al., 2021; Connor & Ferri, 2007). Higher socioeconomic status and parental engagement were positively associated with child placement and school achievement in integrative and regular schools rather than special ones (Szumski & Karwowski, 2012).

The WHO (2001) emphasized the role of environmental factors in facilitating a person's functioning. The WHO claimed that an accessible human and physical environment is necessary to furnish equal opportunities for the participation of people with disabilities. Thus, teachers are obliged to create suitable physical environments (e.g., less, more, or different stimuli), didactic strategies (e.g., consistency, routines, repetitions), and accommodations for assessments and tasks (combining visual and auditory information, breaking-down tasks; Dumas et al., 2003). Still, inclusion barriers include the educational staff's lack of knowledge and ability to provide appropriate support for every individual's needs (File & Kontos, 1992; Jennings & McDougald, 2007; Voorman et al., 2006). Therefore, policies regarding full integration in regular classrooms should be treated with caution, especially for children with visual disabilities. For example, a child with a too-rich

visual environment, where the pace of presentation is too fast, might be unable to use their residual vision optimally (Good et al., 1994).

Despite acknowledging the importance of inclusion for children's abilities and participation, the Israeli educational system still faces challenges. Awareness and appropriate guidance for environmental adaptations can contribute to children's ability to participate fully in the daily school schedule. Children with visual disabilities receive unique guidance from vision teachers. However, appropriate guidance is missing for children with CP and CVI due to diagnosis challenges and difficulty differentiating behaviors. Further research is needed to sharpen the connections among visual function, SPD, participation, and environmental adaptations in children with CP-CVI. Most items on the available CVI questionnaires focus on body function and activity; very few address participation or environment (Deramore Denver et al., 2016, 2017). The clinical implication of the current research is to use the ICF model to focus on visual perception and sensory modulation as specific body-function aspects and look at their connection to participation levels and environmental adaptations for a precise assessment of an adequate intervention. In the next section, I explain the practical aspect of environmental accessibility and its impact on children with CP and children with CP and sensory and visual impairments.

1.18.2 Environment Accessibility, CP, and the Relevance to Sensory/Visual Processing

The UN Convention on the Rights of Persons with Disabilities ("the Convention") recognizes that disabilities result from interactions between persons with impairments and attitudinal and environmental barriers that hinder their full and effective participation in society equally with others (UN, 2006). The State of Israel enacted an amendment to the Law on Equality of Rights for Persons with Disabilities (the "Equality Law") in March 2003 and signed the Convention in March 2007. The Convention declares that action must be taken to make society more inclusive. Barriers should be removed to create equal opportunities for people, including children, with disabilities to develop through the years.

By that, the state ensures *accessibility* to public places and services (Israeli Ministry of Justice, n.d.; UN, 2006). The State of Israel further enacted individual accessibility under the Student and Parent Law in 2018, funding and supplying adaptive equipment at home and school for children with disabilities (Israeli Ministry of Justice, n.d.). *Accessibility* is an umbrella term for all parameters that enhance human environmental functioning, but it becomes more complex in the disability context. In applying the ICF definition of disability as an umbrella term, accessibility reflects negative aspects of interactions between an individual and contextual factors (Iwarsson & Stahl, 2003).

Ideally, an *accessible* environment should be designed for people of all ages (including children) and abilities, referred to as *universal design*. Human abilities are grouped into categories aimed at directing optimal universal design: cognition, vision, hearing and speech, body function, arm function, hand function, and mobility. For example, in the vision category, universal design means attention to the diverse perceptions of visual stimulation. This includes focusing on near and far objects, separating objects from the background, adapting to high- and low-lighting levels, tracking moving objects, exercising distance judgment, and clearly perceiving visual details, objects in the center and edges of the field of vision, and contrasts in color and shade (Israeli Ministry of Justice, n.d.).

A successful individual-accessibility process begins by mapping users' abilities and needs, identifying barriers, consulting experts and other users about options for removing barriers, and recommending environmental changes such as physiognomy, procedures, human assistance, and adjusting accessories and devices (Iwarsson & Stahl, 2003).

Purportedly, children's access to environments in a society obligated to the Convention should show no relationship with the children's impairment type or severity. However, only a decade ago, the physical, social, and attitudinal environmental access needed in the home, school, and community environments was found to vary significantly between regions and European states (Colver et al., 2011). This variety may still be seen

today. A recent review highlighted the lack of studies on school and community environmental factors, such as physical environment, supports and services, and attitudes relative to involving children with CP in participation (van der Kemp et al., 2022).

Several environmental factors were associated with the participation of children and adolescents with CP. Physical environmental factors, such as mobility, transport, support by and to parents, and individuals' and services' environmental attitudes, correlated with participation aspects (Lawlor et al., 2006; Mihaylov et al., 2004; Palisano et al., 2003, 2009; Schenker et al., 2006). Lack of information, available and accessible programs, and nearby facilities, coupled with high cost and time demands, were frequently cited barriers to the community and social participation of adolescents with CP (Kang et al., 2010). Further, adolescents with CP considered that additional environmental factors, such as crowds, terrain, weather, space, and time, might influence their social participation in school and the community (Palisano et al., 2009; Wintels et al., 2018). For instance, reduced ability to focus due to environmental sensory factors (such as noisy classrooms) made it more difficult to be socially included (Mihaylov et al., 2004; Wintels et al., 2018). Thus, low-stimulus physical environments at school, as well as adaptive devices and cognitive and behavioral adaptations, are essential to increase their participation (Huang et al., 2009; Schenker et al., 2006; Wintels et al., 2018).

Sensory environment factors, accessibility, and participation are discussed in conditions of sensory loss and SPD. For example, children with hearing or visual impairments showed limited participation in out-of-school activities (Engel-Yeger & Hamed-Daher, 2013). Environmental accessibility was found to be a critical factor for enhancing the participation of children with SPD (Bodison & Parham, 2018), caregivers speculated that well-designed multisensory environments could support their participation (Fletcher et al., 2019), and parents reported an enhanced participation experience following modifications to a museum's sensory environment (Silverman & Tyszka, 2017).

Interactions with the environment through the visual experience early in life influence the visual system and brain development of children with sensory impairments, such as blindness, deafness, and somatosensory impairments (Ricciardi et al., 2020; Röder et al., 2021). However, studies about the relationships between sensory/visual processing challenges and environmental accessibility for children with CP are relatively limited. Nevertheless, recent research on interventions for children with CVI showed promising results, with improved visual function in children with CVI following a focus on environmental-change interventions (Tsirka et al., 2020). Further, studies showed improved visual function and QOL following visual-support strategies in children with CVI and CP in low-income countries (Duke et al., 2019).

Dutton (2015b) stressed the challenges for children with CVI in modulating sensory information from the environment. Simultaneous incoming stimuli from various senses (visual, auditory, olfactory, gustatory, tactile, or proprioceptive kinesthetic input) and a sense of imbalance or discomfiture can interfere with the ability of children with CVI to accomplish visual tasks and daily functions. An accessible, controlled, clutter-free environment; good lighting; and optimal contrast are crucial for the children's good appraisal of visual stimuli. Factors such as environment adaptation and familiarity also should be considered in the visual-ability evaluation process for CVI (Ortibus et al., 2019) and in determining the visual classification level in CP (Baranello et al., 2020).

To summarize, ensuring accessibility by reducing environmental barriers and increasing facilitators could allow fuller participation, satisfaction, and enjoyment for children with CP and CVI or SPD. Thus, a better understanding of the associations between children's abilities, environmental aspects and accessibility, and school placement is critical to promoting interventions that consider CP students' participation a critical aspect of rehabilitation and inclusion (Paz Pérez-Salas et al., 2020). Such understanding would acknowledge the importance of the children's perceptions of life and well-being. This study

investigates further correlations between sensory/visual abilities, environmental factors, and participation in children with CP and CVI. It will look at correlations among ICF aspects like environmental factors and available accessibility and link them to the children's QOL perceptions. In the next section, I review QOL for children with CP.

1.19 Quality of Life for Children With CP

The QOL concept focuses on a person's perception of life and well-being. The WHO's proposed prevailing QOL definition addresses a person's perception of their status in life in the context of their culture, values, goals, expectations, concerns, and state where they live (Patrick & Chiang, 2000). According to the WHO QOL Group (1994), QOL is a broader concept than "health status." It contains social and physical environmental aspects that are not required to be affected by any health condition or treatment.

Consideration of QOL is essential in evaluating intervention effectiveness for children and adolescents with CP. Early QOL conceptualizations were based on functioning, and QOL assessment focused on physical health and functional limitations rather than an individual's broader well-being or experience (Davis et al., 2006). However, several studies brought these assumptions into question, demonstrating that, although functioning is correlated with QOL's physical domains, there is only a weak or nonsignificant relationship between functioning and children's psychosocial QOL domains (Davis et al., 2009). Issues concerning QOL in children with CP include physical health, pain and discomfort, social well-being and acceptance, participation, emotional well-being and self-esteem, supportive physical environment, communication, access to services, parent health and attitude, and adequate financial resources. During adolescence, QOL issues also include independence and transition, relationships and sexuality, acceptance of disability, and getting on well at school (Davis et al., 2009).

Some studies found that the QOL of children with CP is lower than their peers with typical development and decreases more in adulthood (Bottos et al., 2001; Pirpiris et al.,

2006; Varni et al., 2005). Another study in a few European countries found similar levels of QOL in children with CP and their typical friends, except in pain situations (Colver & SPARCLE Group, 2006; Dickinson et al., 2007). The difference may be due to challenges in assessing QOL in children with CP, especially those who cannot communicate or express themselves. The injury's severity would affect some but not aspects of these children's QOL (Piazza et al., 2016). Majnemer et al. (2007) found that QOL is highly variable in children with CP: about half experienced a life quality similar to typically developing children. The researchers found that motor and other activity limitations indicated physical but not psychosocial well-being.

Participation by children with CP leads to self-esteem and satisfaction (Engel-Yeger et al., 2009). Children with CP who participated in leisure activities reported higher enjoyment and QOL levels (Badia et al., 2013; Bult et al., 2011). Auditory, visual, and tactile processing were associated with participation in the school environment, and behavioral and social-emotional responses related to sensory processing were associated with psychological well-being in children with hemiplegic CP (Jovellar-Isiegas et al., 2020).

Understanding the relationship between participation in everyday life and QOL indicators is essential. Accordingly, it should guide practitioners and families to activity and environmental adaptations (Jovellar-Isiegas et al., 2020). Thus, the extent to which SMD and visual disabilities influence participation levels and QOL is essential and warrants further research. Acknowledging these disabilities and addressing environmental adaptations could immediately influence the children's function, learning abilities, and self-esteem.

Colver (2012) stressed the need in childhood to ensure high subjective well-being and participation in life, particularly in social domains, and foster self-determination and decision-making rather than allowing or requiring children to be passive recipients of therapy, care, and, sometimes, pity. Independence should be encouraged rather than a protective attitude determined by the views of parents and clinicians. Adults with CP have

poorer outcomes than the general population in all these domains, perhaps partly due to misplaced childhood interventions.

In sum, although diagnosis alone does not predict functional outcomes, research showed the relative impact of body-structure function on participation and QOL (Anaby et al., 2013; Beckung & Hagberg, 2002; Østensjø et al., 2003; Schenker et al., 2005). Thus, addressing visual dysfunction due to CVI and sensory processing and SMD in CP may be vital due to its relative impact on participation and QOL. Further, activity types, frequency, involvement levels, environments, reference groups, and degree of enjoyment contribute to participation and QOL. By adequately detecting CVI and SMD, interventions aimed at reducing specific barriers and increasing facilitators and environmental accessibility could be applied, ensuring full participation, satisfaction, enjoyment, and higher perceived QOL.

1.20 Study Rationale and Objectives

This review emphasizes challenges related to the complex condition of CP and CVI and *its* impact on participation and QOL aspects. It also highlights the influence of environmental components and environmental intervention on participation and QOL in children with CP. However, it reveals that visual and sensory impairments, especially CVI and SPD, still need to be sufficiently addressed and studied in the CP-CVI group. An understanding of the impacts of these conditions, separately and jointly, on participation and QOL are still scarce.

This study will refer to CVI and SPD body dysfunctions, CP functional severity, child participation, and QOL. The study's rationale is to elaborate insights about the unique sensory-processing abilities of children with CP and CVI, their participation in daily activities, and environmental accessibility. This knowledge may focus interventions on each child's specific developmental needs and enhance their daily function, inclusion in society, and QOL. In addition, this study uses objective and subjective measures of visual processing / CVI and SPD to help identify the underlying mechanisms of these body dysfunctions and

their implications on a child's daily life. This study will add information about the evaluation tools' feasibility and relevance to interventions for children with CP and CVI. Lastly, because visual processing and sensory modulation abilities are crucial for a child's successful inclusion and participation in academic and social activities, the study will focus on children with CP and CVI at educational ages (4-17 years).

1.20.1 Study Objectives

This study aims to (a) profile body dysfunctions of children with CP and CVI, with a focus on visual processing/CVI and SPD by referring to objective expressions (via objective measures of visual components) and implications on daily life (via parents' reports in questionnaires) and comparing school-aged children with CP-CVI to age- and gender-matched children with typical development; (b) compare both groups' participation patterns, environmental accessibility, and QOL domains (physical, social, emotional, and school-related QOL); (c) examine relationships among visual processing/CVI, SPD, and participation, environmental accessibility, and QOL in the group of children with CP-CVI; (d) examine the relative contributions of visual processing / CVI and SPD to predicting participation and QOL; and (e) create an ICF, PEOP-aligned model to describe the unique interrelations among body dysfunction, participation, environmental factors, and QOL in school-aged children with CP based on the results. The model will serve as a platform to improve detection and intervention, including environmental adaptations, according to the ICF.

1.20.2 Hypotheses

Four hypotheses were proposed: (1) Visual processing difficulties and sensory processing difficulties (SPD) would be more prevalent in children with CP-CVI than in neurotypical controls. (2) Subjective (clinical and parent-reported) and objective (clinical and computerized psychophysics task-based) measures of visual processing/CVI would significantly correlate, supporting the validity of objective assessments. (3) Participation

levels, environmental accessibility, and QOL would be lower in the CP-CVI group compared to the neurotypical control group and would significantly correlate with visual and sensory processing difficulties, within the CP-CVI group. (4) Visual and sensory processing difficulties, and environmental accessibility would predict participation and QOL outcomes.

1.20.3 Research Importance and Innovation

This research includes aspects of clinical importance and innovation. It is one of the first to refer to visual processing/CVI in children with CP and CVI using an elaborative perspective based on the ICF and PEOP models. It is one of the first to refer to a broad interaction between body dysfunctions, including CVI and SPD, CP severity, child participation, and QOL, illuminating the interrelations with environmental accessibility. It combines parents' self-reports with advanced objective assessments to bridge mechanisms and daily functions.

The resulting model detected, differentiated, and profiled specific sensory aspects that correlated with participation levels and environment adaptation (emphasizing visual and sensory processing and modulation items). It will increase family members', therapists', and teachers' awareness and can guide appropriate evaluation and intervention programs and environmental adaptation possibilities to enhance the children's function, development, and QOL. It is a pioneer study, applying objective and subjective measures of visual processing and CVI. The study findings validated evaluation tools for visual processing in children with CP and CVI at school age and add information on their feasibility and relevance to interventions for children with CP-CVI.

Further, this study looked at vision in broad sensory-processing contexts. It highlighted aspects of CVI and SPD challenges that are underdiagnosed but have simple interventions when detected. The correlative protocol suggests further study to define subgroups and illuminate an underlying mechanism. Lastly, this study focused on educational-aged children with CP-CVI. It may develop a practical recommendation

regarding relevant evaluation processes and possible environmental intervention protocols to advance children's inclusion and participation in academic and social activities in schools throughout Israel in both groups of children with CP-CVI and children with CP in general.

Chapter 2: Method

This study employed a quantitative, comparative, and correlational research design. The sampling method used was convenience sampling.

2.1 Participants

This cross-sectional and correlative study included 99 children ages 4 to 17 years. The group size was determined by G* Power analysis based on a one-tail *t*-test with effect size $d = .5$, $\alpha = .05$, and power = .80. The study group consists of 51 children with CP and CVI (CP-CVI) at an age range of 4-17.5 years, 28 (54.9%) boys and 23 (45.1%) girls. The children are at different physical functional levels, ranging from mild intellectual disabilities to average cognitive levels (based on clinical reports). Nine of the children are included in a mainstream school and 41 studied in special needs schools in high functional classes.

All 51 children in the CP-CVI group were diagnosed with CP and CVI. Forty children were diagnosed with CVI in their early childhood and ten were suspected of having CVI and were diagnosed following the study evaluation. For some participants, the current study evaluation process contributed to confirming the final diagnosis of CVI. The control group comprised 48 children with neurotypical development ages 4-16 2/3 years: 20 (41.7%) boys and 28 (58.3%) girls. The two groups are matched by age, gender, and socioeconomic level (Table 1).

Children with additional chronic conditions, severe diseases, profound intellectual disabilities, uncontrolled epilepsy, sensory deficiency or surgery interventions within 3 months of the study (based on information gathered from their parents and personal records) were not included in the study (Appendix A).

Table 1

Descriptive and Demographic Statistics of the CP-CVI and Neurotypical Groups

Demographic variable	CP-CVI (n =51)		Neurotypical (n = 48)		t value	p
	M	(SD)	M	(SD)		
Child age	10.46	(3.79)	9.71	(3.18)	1.06	.293
Father age	42.64	(7.32)	42.90	(7.77)	-.17	.865
Mother age	40.80	(6.29)	40.70	(8.22)	.07	.944
No. of children	3.80	(2.10)	4.80	(1.50)	-2.71	.008
	%	(n)	%	(n)	χ^2	p
Child gender (boys)	54.9	(28)	41.70	(20)	1.73	.188
Complication at birth	74.50	(38)	8.30	(5)	41.34	< .010
Child school type					66.59	< .010
Mainstream religious	11.80	(6)	74.00	(37)		
Mainstream nonreligious	7.80	(4)	22.90	(11)		
Special needs school	80.40	(41)	0	(0)		
Living place					.86	.353
Town	90.20	(46)	83.30	(42)		
Village	9.80	(5)	16.60	(8)		
Parent marital status (married)	88.20	(45)	98.00	(47)	3.53	.060
Father education					36.96	< .010
Primary	4.00	(2)	0	(0)		
High school	36.00	(18)	0	(0)		
Postsecondary	18.00	(9)	2.00	(1)		
Academic	42.00	(21)	98.00	(48)		
Mother education					8.47	.140
High school	15.70	(8)	0	(0)		
Postsecondary	9.80	(5)	8.30	(4)		
Academic	74.50	(38)	91.60	(44)		
Family income					2.78	.249
Low (< 7,000)	37.30	(19)	22.90	(11)		
Average (7,000-14,000)	47.10	(24)	62.50	(30)		
High (> 14,000)	15.70	(8)	14.50	(7)		

Table 1 compares demographic characteristics of the CP-CVI and control groups. Child age, father age, and mother age did not differ between groups (all *ps* ≥ .29) Families in the control group reported higher number children living at home ($M = 4.8$, $SD = 1.5$) than families in the CP-CVI group ($M = 3.8$, $SD = 2.1$), $t(97) = -2.71$, $p = .008$. The groups did not differ in child gender distribution, $\chi^2 = 1.73$, $p = .188$, or place of residence (town vs. village), $\chi^2 = .86$, $p = .353$. Clear group differences emerged for several categorical variables. Birth complications were far more frequent in the CP-CVI group (74.5%) than in controls (8.3%), $\chi^2 = 41.34$, $p < .01$. School placement also differed sharply, $\chi^2 = 66.59$, $p < .01$: Most children with CP-CVI attended special-needs schools (80.4%), whereas all controls were in mainstream education (religious 74.0%; nonreligious 22.9%). Parental marital status showed a nonsignificant trend toward more married parents among controls (98%) than CP-CVI (88.2%), $\chi^2 = 3.53$, $p = .060$. Regarding socioeconomic indicators, father's education differed substantially, $\chi^2 = 36.96$, $p < .01$: academic education was more prevalent among control fathers (98%) than CP-CVI fathers (42%); lower education categories were concentrated in the CP-CVI group. Mother's education showed a similar, but nonsignificant pattern, $\chi^2 = 8.47$, $p = .14$. Family income did not differ significantly, $\chi^2 = 2.78$, $p = .249$.

In summary, apart from the expected differences in birth complications and school placement, the key demographic distinction was higher paternal academic education in the control group; other sociodemographic factors were broadly comparable.

2.1.1 Functional Classification in the CP-CVI Group

The functional classification levels for the five systems—GMFCS, MACS, CFCS, EDACS, and VFCS (Appendices C1–C5)—were determined within the CP-CVI group by the researcher, based on medical and therapy reports, to describe the children's abilities (Table 2).

Table 2

*Child Classification at the CP-CVI Group (*n *= 51), Based on Therapy and Medical Data*

	Level 1	Level 2	Level 3	Level 4	Level 5
			N (%)		
GMFCS	8 (17.8)	3 (6. 7)	8 (17. 8)	17 (37. 8)	9 (20.0)
MACS	6 (13.3)	11 (24.4)	14 (31.1)	14 (31.1)	0 (0.0)
CFCS	13 (28.9)	18 (40.0)	10 (22.2)	4 (8. 9)	0 (0.0)
VFCS	3 (6. 7)	17 (37. 8)	22 (48. 9)	3 (6. 7)	0 (0.0)
EDACS	19 (42. 2)	19 (42. 2)	6 (13. 3)	1 (2. 2)	0 (0.0)

Table 2 summarizes the distribution of functional classifications within the CP-CVI group (n = 51). The GMFCS showed the largest proportion at Level IV (37.8%), followed by Levels I and III (17.8% each) and Level V (20.0%). Only 6.7% of children were classified at Level II. For manual ability (MACS), the distribution centered on moderate to severe impairment: Levels III and IV each included 31.1% of the sample, while 24.4% were at Level II. Only 13.3% of children were classified at Level I, and none at Level V. In contrast, communication (CFCS) indicated stronger functioning, with most children in Levels I (28.9%) and II (40.0%). Fewer were at Levels III (22.2%) and IV (8.9%), and none at Level V. Visual function (VFCS) was most frequently rated at Levels II (37.8%) and III (48.9%), together representing 86.7% of the sample. Small proportions were classified at Levels I (6.7%) and IV (6.7%); no children were at Level V. Finally, the EDACS revealed relatively preserved function, with the majority at Levels I and II (42.2% each). A smaller proportion was at Level III (13.3%) and Level IV (2.2%); none were at Level V.

The CP-CVI cohort demonstrated heterogeneous profiles across classifications, with more pronounced limitations in gross motor and manual abilities, contrasted by relatively

preserved communication and feeding abilities. Visual function (VFCS) clustered mainly in the moderate range. The results are illustrated here in Figure 4.

Figure 4

Distribution of the CP-CVI Group Across Functional Classification Levels

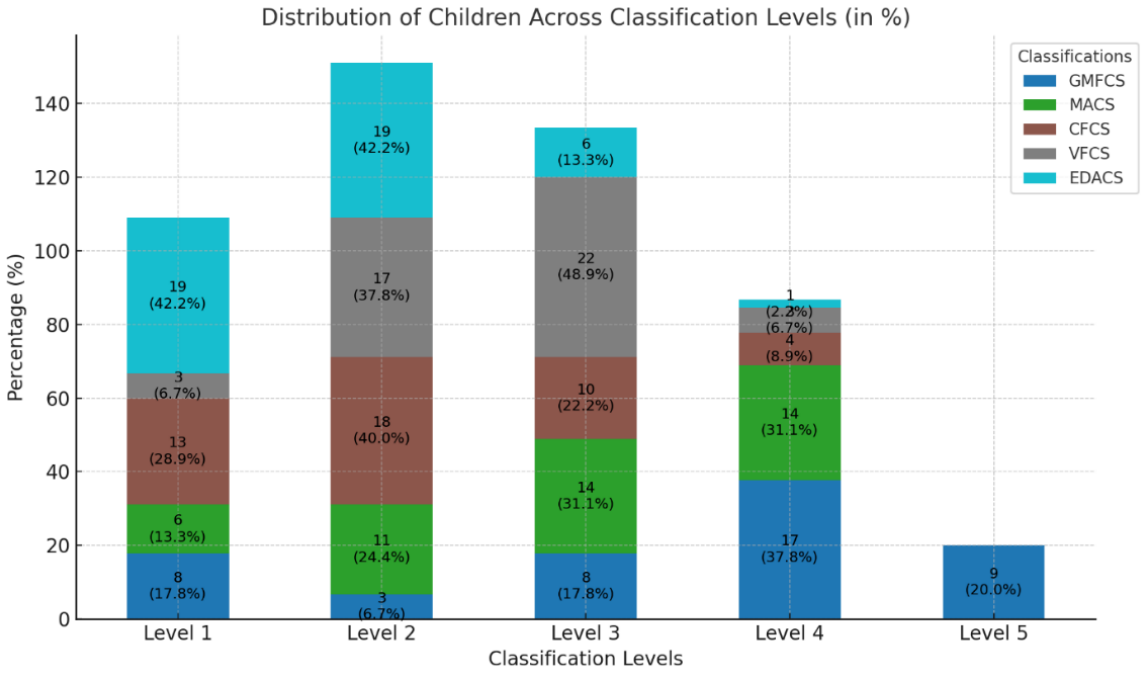


Figure 4 presents the distribution of the CP-CVI group across functional classification levels (GMFCS, MACS, CFCS, VFCS, EDACS). The figure illustrates variability within and across domains, highlighting group heterogeneity in motor, manual, communication, visual, and feeding abilities.

Figure 5

*Distribution of CVI Range 1 & 2 Scores in CP-CVI Group (*n = *51)*

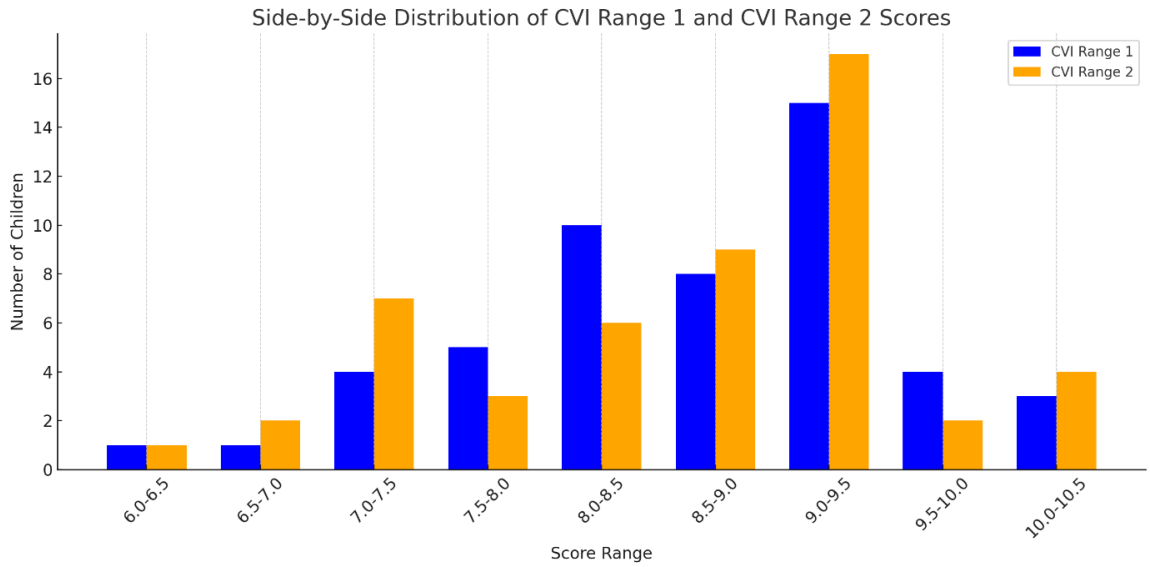


Figure 5 presents the distribution of CVI Range 1 and 2 scores in the CP-CVI group. The two parts of the assessment showed highly similar distributions, with most children scoring between 8.0 and 9.5 (Phase III), confirming the stability of functional vision ratings and the internal consistency of the CVI Range assessment. This stage is characterized by emerging visual consistency, improved recognition of familiar objects, and increasing-but still limited ability to process complex scenes. Although functional vision is more reliable, individualized support remains essential. Three children were classified in Phase II (scores 6–7), reflecting the Building Visual Function phase.

Table 3

*Neurological and Optometric Characteristics in the CP-CVI Group (*n = *51)*

Variable	***n* (%)** or ***M* (*SD*)**
CP type	Hemiplegia 19 (37.3%) Diplegia 12 (23.5%) Tetraplegia 20 (39.2%)
Gestational age (weeks)	*M* = 31.4 (*SD* 3.2)
Neurological diagnosis	PVL 24 (47.1%) IVH 9 (17.6%) HIE 12 (23.5%) Other 6 (11.8%)
VFCS distribution	I 3 (6.7%) II 17 (37.8%) III 22 (48.9%) IV 3 (6.7%) V 0
CVI range (1)	*M* = 8.6 (*SD* 1.2)
CVI range (2)	M = 8.8 (*SD* 1.1)
Refractive errors present	38 (74.5%)
Visual field deficits	26 (51.0%)
Smooth pursuit deficits	33 (64.7%)
Oculomotor abnormalities	29 (56.9%)

Note. For each child's neurologic and optometric information, see Appendix D.

Table 3 summarizes the neurological and optometric characteristics of the CP-CVI group (*n* = 51). The most frequent neurological findings being PVL (47.1%) or hypoxic–ischemic encephalopathy (23.5%). CP subtypes were distributed across hemiplegia (37.3%), diplegia (23.5%), and tetraplegia/quadriplegia (39.2%), reflecting heterogeneity motor presentations. The mean gestational age was 31.4 weeks, indicating a high prevalence of prematurity.

Visual function classifications showed the greatest concentration at VFCS Levels II and III (86.7%), with smaller proportions at Levels I (6.7%) and IV (6.7%); no children were classified at Level V. CVI Range scores averaged 8.6 and 8.8, across two assessments, placing most children in Phase III ("Integration of Vision with Function"), while three children remained in Phase II.

Optometric findings revealed high rates of visual difficulties: refractive errors (74.5%), visual field deficits (51.0%), smooth pursuit difficulties (64.7%), and oculomotor abnormalities (56.9%) were all common. Together, these data underscore the multifactorial complexity of CP-CVI, in which neurological injury, prematurity, and visual pathway dysfunction overlap to shape functional vision outcomes.

2.2 Measures

2.2.1 General Information

In the general sample, sociodemographic-health questionnaire - completed by the parents. Information also confirmed inclusion criteria. The questionnaire also collected information on the child's cognitive level (based on placement committees or neurologist reports), and history of visual and optometric evaluation (Appendix B).

2.2.2 Functional Classification (ICF: Body Function & Activity)

Among the study group, five classification systems were applied to characterize children's functioning across multiple domains: the GMFCS (Palisano et al., 2007) categorizes gross motor ability across five levels (I = least severe, V = most severe); the MACS (Eliasson et al., 2006) classifies hand and manual function across five levels; the CFCS (Hidecker et al., 2011) describes everyday communication ability (I = effective communication, V = seldom effective); the VFCS (Baranello et al., 2020) rates functional vision from Level I (best) to Level V (most impaired); and the EDACS (Sellers et al., 2014) categorizes oral motor and swallowing ability across five levels. These systems were

determined for each child based on medical and therapy reports, with verification by the researcher.

2.2.3 Visual and Sensory Measures (ICF: Body Functions & Activity)

2.2.3.1. Visual Processing/CVI Measures

To profile visual processing abilities, all participants completed the visual assessment battery, with the exception of the CVI Range, which was administered only with the CP-CVI group**.**

2.2.3.2 Ophthalmological Examination

In the general sample, each child's ophthalmologist conducted a routine examination to identify peripheral visual difficulties (e.g., refractive error, need for glasses). Examinations included visual acuity, refraction, accommodation, visual fields, and oculomotor function (pursuit, saccades, eye movements).

2.2.3.3 CVI Range (Newcomb, 2010; Roman-Lantzy, 2007)

The CVI Range is a structured parent interview and observation assessment that evaluates the functional impact of CVI on daily activities. It assessed ten visual and behavioral characteristics, each scored from 0 to 1, yielding a total score ranging from 0 to 10. Scores classify children into three phases: Phase I (0–3, minimal visual function), Phase II (4–7, emerging visual function), and Phase III (8–10, integrated visual function). The CVI-Range consists of two parts, each producing a separate score, therefore, the final result is expressed as a range between these two scores. The tool demonstrates strong psychometric properties, with reported internal consistency of α =.96 and interrater reliability r = .98 (Newcomb, 2010; Roman-Lantzy, 2018). The researcher completed official CVI Range training and used the English version of the tool in this study. The CVI Range is valid for evaluating the level functioning across the ten characteristic features of CVI. However, it is not appropriate for use with typically developing children.

2.2.3.4 Insight Inventory Questionnaire (IIQ)

The Insight Inventory Questionnaire (IIQ; MacIntyre-Beon et al., 2012) is a structured parent-report tool assessing functional vision in everyday settings. It covers domains including visual attention, recognition, navigation, and complex visual processing. Parents rate children's behaviors on a 5-point Likert scale with higher scores reflecting better functional vision. The IIQ has demonstrated good validity in children with CVI (Cronbach's alpha across domains .71–.82; full inventory $\alpha = .93$; S. S. Philip et al., 2016) and can also be applied to children with mild intellectual disabilities (Bowman, 2016).

For this study, the IIQ was translate to Hebrew with permission from the original authors. Translation followed standard guidelines: forward translation into Hebrew, back-translation into English, and expert review by therapists and vision teachers. A pilot administration with a small group of parents informed minor wording adjustments. The final Hebrew version was then administered to the full sample. The IIQ is a valid tool for CVI detection and screening, and it is suitable for use with both children with CVI and those with typical development.

2.2.4 Psychophysical Computerized Visual Assessments

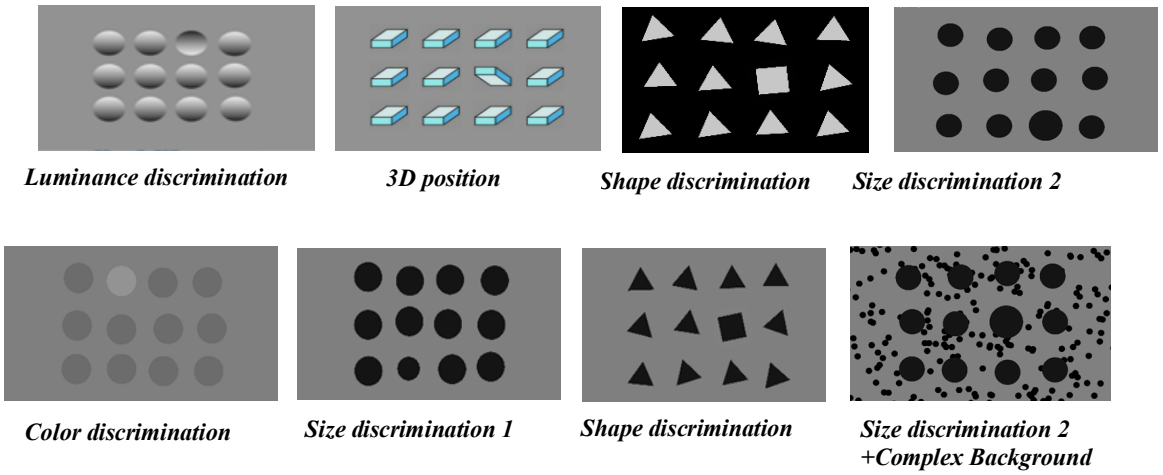
The study employed four computerized experiments designed to evaluate low- and mid-level visual functions required for higher-order visual processing. The system consisted of a PC with response switches and an eye tracker.

2.2.4.1 Computerized Oddball Tasks (Pointing)

The first computerized experiment assessed core visual processing abilities in both groups through eight distinct visual discrimination tasks, adapted from McKyton et al. (2015). In each task, participants were required to identify a single deviant figure among 12 stimuli displayed on a touchscreen. These tasks were designed to evaluate low- and mid-level visual functions, which form the basis for higher-order visual processing. The assessed domains included visual acuity, contrast sensitivity, color and luminance detection,

geometric and size-based contour detection, and visual crowding. Tasks were presented in a structured sequence, progressing from lower- to mid-level visual functions (Figure 6)**,** while reaction time (RT) and accuracy were recorded.

Figure 6
The Oddball Experiment Domains

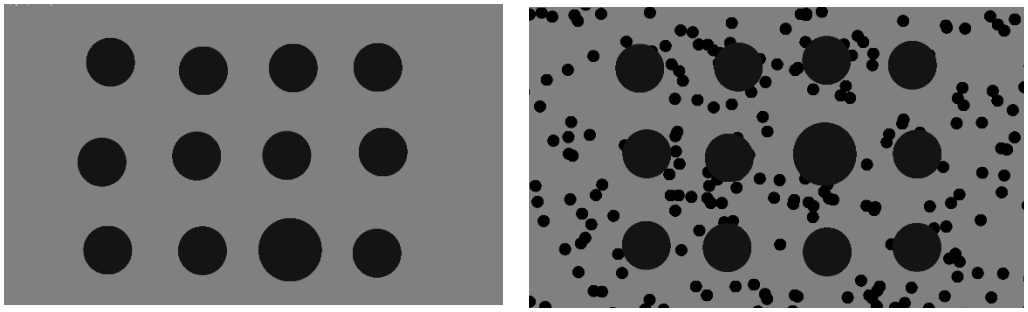


2.2.4.2 Computerized Oddball Task (Gaze)

In this experiment, we assessed visual discrimination using eye-tracking rather than pointing responses. It is a motor-free version performed rather than pointing, indicates target detection. This enables participation of children with severe motor impairments (GMFCS IV–V). Two previously administered oddball tasks (Figure 7) were presented while participants were instructed simply to look at the different figure. The display advanced automatically every 3 s while the eye-tracking system recorded gaze patterns and fixations. The experiment highlights the effects of Background Complexity (Clutter).

Figure 7

Two Discrimination Tasks Through Eye Gaze



2.2.4.3 Computerized Tracking and Pursuit Tasks

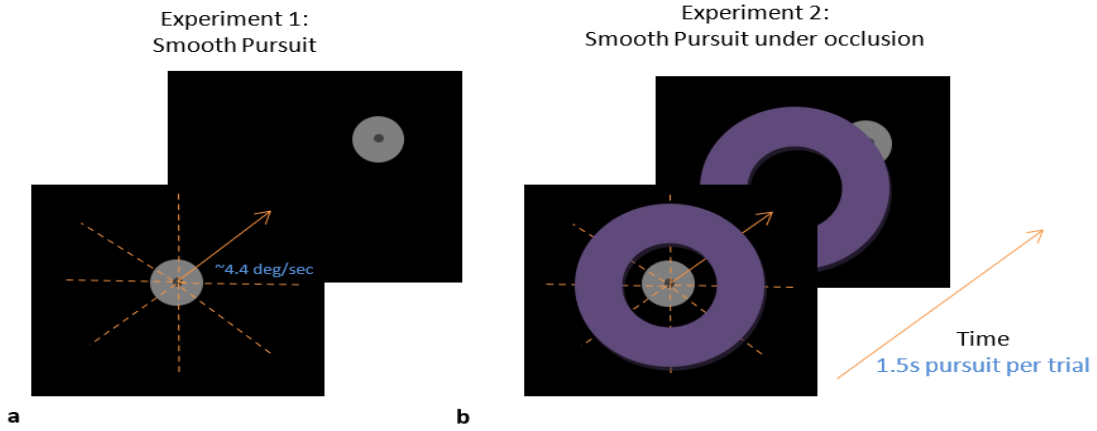
These tasks assess the ability to follow moving stimuli across the screen in two situations with and without a clutter. Measures include tracking error and smooth pursuit accuracy. Performance reflects oculomotor control and visual-motor integration.

Figure 8 (a & b)

Smooth Pursuit With and Without Occlusion

Figure 8a: **Smooth pursuit without occlusion**

Figure 8b: **Smooth pursuit with occlusion**



The smooth pursuit experiment was presented to the child in two different conditions (see Figures 8a and 8b). The first condition, referred to as **Simple Pursuit**, is illustrated in Figure 8(a). In this experiment, A central fixation cross was shown for 500 ms, then a bright disk appeared and started moving smoothly in one of eight directions in random order at ~4.4 deg/sec speed (horizontal and vertical components viewed from 60 cm), for 1.5s per trial repeated 16 times per run. The second condition, referred to as **Occluded Pursuit**, is shown in Figure 8(b). This condition followed the same sequence as the Simple Pursuit task, with the addition of an **occluding ring**. The ring varied in width, and in the current experiment (Figure 8b), the medium-width ring was presented. Eye movements were recorded throughout the trials using an eye-gaze tracking system.

2.2.4.4 Computerized Video Clip Paradigm

A short, engaging animated clip (≈90 s) from the popular animated children's film "The Incredibles" (see movie photos Figure 9), was presented to both groups to measure naturalistic visual attention. Gaze allocation, fixation stability, and attentional shifts were recorded using Tobii eye-tracking technology. The clip contained varied visual demands (fast/slow motion, simple/complex scenes, near/far imagery, high-contrast detail) to approximate real-life viewing conditions

Figure 9
The Free Viewing Video Paradigm: Sample Stimuli



This clip was selected because prior studies show that typically developing children perform consistently across ages, making it a reliable visual stimulus. The scene features the babysitter, Kari, observing Jack-Jack's unpredictable transformations—disappearing, floating, bursting into flames, and changing shape—while she grows increasingly overwhelmed. The clip condenses diverse visual challenges into a short timeframe, including near and distant imagery, fast and slow motion, simple and complex scenes, high-contrast details, flashing lights, and synchronized visual–auditory cues (Figure 10). Its humorous and engaging narrative sustains attention and motivation across age groups.

Figure 10

Illustration of Visual and Auditory Challenges During the Clip-Watching Task

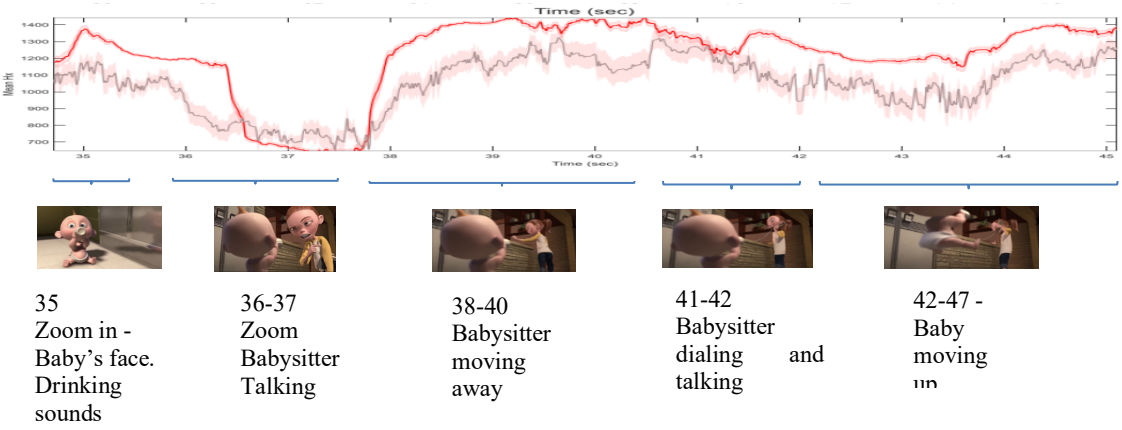


Figure 10 illustrates visual and auditory challenges during the clip-watching task. The red line represents neurotypical children, and the grey line represents children with CP-CVI. The pink shading indicates the range, reflecting the variability of children's performance around the mean.

2.2.4.5 Sensory Modulation Measure: Sensory Profile: (SP; Dunn, 1997)

The Sensory Profile (SP) is a parent-report questionnaire comprising 125 items that assess children's behavioral responses to sensory input in daily life. Items are rated on a 5-point Likert scale from 1 (almost always) to 5 (rarely), with 0 used for not applicable items. Raw scores (range from 51–255) are compared against normative data to classify performance as Less than others, Similar to others, or More than others. The SP evaluates responses across sensory modalities (tactile, auditory, visual, vestibular, proprioceptive), behaviors linked to sensory processing, and four response patterns: seeking, avoiding, sensitivity, and low registration. The Sensory Profile Caregiver Questionnaire demonstrates good test–retest reliability and internal consistency (test–retest reliability .80–.90; internal consistency .89–.95; Ohl et al., 2012). A Hebrew version was used in this study.

2.2.5 Participation and QOL Measures (ICF: Participation)

2.2.5.1. Participation and Environmental Accessibility Assessment (PEM-CY; Coster et al., 2012)

The PEM-CY is a parent-report questionnaire that evaluates children's participation in three contexts: home, school, and community. It assesses (a) frequency of participation, (b) number of activities, (c) level of involvement, and (d) parents' desire for change. In addition, the PEM-CY captures environmental support and barriers within each setting. Items are scored on Likert-type scales, and summary scores are generated for each domain. PEM-CY has strong psychometric properties and provides an ecologically valid measure of real-world participation. A reliable measure (internal consistency .59–.91; test–retest reliability .58-.95), the PEM-CY could distinguish between children with and without disabilities across all scales (effect size .51–1.44), supporting its validity (Coster et al., 2011, 2012).

2.2.5.2. The Pediatric Quality of Life Questionnaire (Varni et al., 2003)

The Pediatric Quality of Life (PedsQL) Questionnaire includes 23 items related to four QOL dimensions: physical, emotional, social, and school functioning. There is a parent-report and a child-report version. Each item is answered on a 5-point scale from 0 (never difficult) to 4 (almost always difficult). The scale is converted to a percentage (0%–100%). Average percentages are computed for each part and all parts together. A higher score represents higher QOL. The parent-report tool is highly reliable (.84–.90), allowing a distinction between the population of healthy children and those with diseases and with CP (Varni et al., 2003, 2005, 2006).

2.3 Procedure

The study commenced following ethical approval from three committees: the Faculty of Social Welfare and Health Sciences Ethics Committee at the University of Haifa; the Helsinki Committee at Alyn Rehabilitation Hospital; and the Israeli Ministry of Education. Recruitment targeted children with CP-CVI and typically developing peers through multiple channels, including Alyn Rehabilitation Hospital, "Mattia" regional centers for special education, and social media platforms, particularly WhatsApp parent groups specific to both CP-CVI and neurotypical populations. Parents expressing interest were first contacted by telephone or in person. During this stage, inclusion criteria were verified, and the parental assessment battery was administered, including the demographic questionnaire, Insight Inventory Questionnaire (IIQ), Sensory Profile (SP), Participation and Environment Measure for Children and Youth (PEM-CY), and the Pediatric Quality of Life Inventory (PedsQL). These sessions lasted approximately 1 hour. Direct child assessments were then conducted at the child's home, educational setting, or Alyn Rehabilitation Hospital, according to parental preference. The computerized visual tasks were administered in a fixed sequence of increasing difficulty, with rest periods tailored to each child's needs and attention span. Each session lasted between 60 to 90 min, allowing for a thorough

assessment while maintaining optimal engagement and performance. While most of the children completed the full assessment, a few discontinued due to fatigue or preference; these cases contributed to missing data. Missing values were excluded from the final analysis (available-case analysis), given their small proportion. Functional classification levels (GMFCS, MACS, CFCS, VFCS, EDACS) were assigned by the researcher based on direct observation and medical/therapy reports. Ophthalmological findings were integrated from each child's treating ophthalmologists. Computerized task data were analyzed at Bar-Ilan University's Vision Lab by a second researcher blinded to questionnaires and observational results. As an ethical consideration, parents received a written summary of their child's results with individual recommendations for follow-up or intervention.

2.4 Data Analysis

Data were analyzed using the IBM SPSS software (Version 27). Descriptive statistics were used to characterize participants' sociodemographic variables and outcome measure scores. Because the scores were not normally distributed, the Mann-Whitney U test was used to examine differences in total scores. Friedman nonparametric repeated-measures test was conducted for comparison among visual characteristics. Spearman correlations assessed associations among parameters, and stepwise regression analyses were conducted to test predictors of participation levels and QOL. A significant level of $p \leq .05$ was adopted. In cases of multiple comparisons, significance levels were Bonferroni adjusted. Computerized visual assessments data were processed and analyzed using MATLAB® R2022a (MathWorks, Natick, MA).

Chapter 3: Results

This chapter presents the study findings from the assessment of children with CP-CVI, compared to their neurotypical peers. The chapter begins with the psychometric validation of the core measurement instruments-Insight Inventory Questionnaire (IIQ), Sensory Profile, Participation and Environment Measure for Children and Youth (PEM-CY), and Pediatric Quality of Life Inventory (PedsQL)-through internal consistency (reliability) analyses.

Next, results addressing **Hypothesis 1** are presented, focusing on group differences between children with CP-CVI and the neurotypical control group. These analyses integrate data from objective psychophysical computerized visual assessments and subjective questionnaire-based evaluations, providing a multidimensional perspective on visual processing and sensory modulation.

The chapter then addresses **Hypothesis 2**, presenting correlational analyses between objective and subjective visual measures. These are examined in relation to the functional classification systems and Sensory Profile, offering insights into how visual functioning and sensory processing relate to daily performance and functional status.

Findings related to **Hypothesis 3** are then reported, focusing on the associations of visual and sensory variables with participation and quality of life (QOL) outcomes.

Finally, **Hypothesis 4** is examined, testing whether visual and sensory measures predict participation and QOL outcomes in the CP-CVI group through regression analyses.

Together, these results provide an integrative view of visual and sensory functioning, daily participation, and QOL in children with CP-CVI.

3.1 Internal Reliability of the Questionnaires

Cronbach's alpha values indicated good to excellent reliability across most questionnaires. **For the Insight Inventory questionnaire (IIQ)**, Cronbach's alpha values ranged from .72 to .95 (Table 4).

Table 4

Cronbach's Alpha Coefficients for the Insight Inventory Domains

IIQ domain	Cronbach's α
Visual fields	.92
Perception of movement	.87
Search	.95
Guidance of movement	.95
Attention	.72
Crowded scenes	.79
Recognition and navigation	.81

For the **Sensory Profile (SP),** alpha values ranged from .68- .96 (Table 5) with one exception: the Behavioral Outcomes subscale (α = .39), which demonstrated poor reliability.

Table 5

Cronbach's Alpha Coefficients for the Sensory Profile

SP section	**Cronbach's α**
Sensory processing domain	
Auditory processing	.83
Visual processing	.87
Vestibular processing	.78
Touch processing	.85
Multisensory processing	.78
Oral sensory processing	.90
Modulation domain	
Sensory processing related to endurance/tone	.96
Modulation related to body position and movement	.86
Modulation of movement affecting activity level	.79
Modulation of sensory input affecting emotional responses	.71
Modulation of visual input affecting emotional responses	.68
Behavioral and emotional responses	.90
Emotional/social responses	.90
Behavioral outcomes of sensory processing	.39
Items indicating thresholds for response – quadrants	
Registration	.90
Seeking	.90
Sensitivity	.90
Avoiding	.90

For the Participation and Environment Measure for Children and Youth (**PEM-CY),** internal consistency was generally satisfactory, with values ranging from .52 to .80 across home, school, and community sections (Table 6).

Table 6
Cronbach's Alpha Coefficients for the PEM-CY

PEM-CY domain	Cronbach's α
Home frequency	.66
Home involvement	.77
Home desire for change	.76
School frequency	.52
School involvement	.57
School desire for change	.77
Community frequency	.76
Community involvement	.77
Community desire for change	.80

For the Pediatric Quality of Life Inventory **(PedsQL)**, Cronbach's alpha values ranged from .77- .96 across physical, emotional, social, and school functioning domains (see Table 7).

Table 7
Cronbach's Alpha Coefficients for PedsQL

PedsQL domain	Cronbach's α
Physical	.96
Emotional	.77
Psychosocial	.85
School function	.77

3.2 Examination of the Research Hypotheses

3.2.1 Hypothesis 1: Group Differences (CP vs. TD)

Hypothesis 1 proposed that children with CP-CVI demonstrate significantly greater visual processing deficits and sensory modulation difficulties than neurotypical peers. The findings strongly support this hypothesis. Children with CP-CVI exhibited marked impairments across all visual processing domains and scored predominantly in the category of "More than others", on the sensory profile, reflecting significant challenges in sensory processing and sensory modulation. By contrast, neurotypical children showed typical visual processing abilities and scores mainly in the "Similar to others" and "Less than others" categories on the Sensory Profile.

In the subsequent sections of this chapter, I first present the visual assessment findings within the framework of the ICF. This is followed by a detailed analysis of sensory processing and modulation domains in both groups, and finally by correlation analyses linking visual outcomes with sensory profiles.

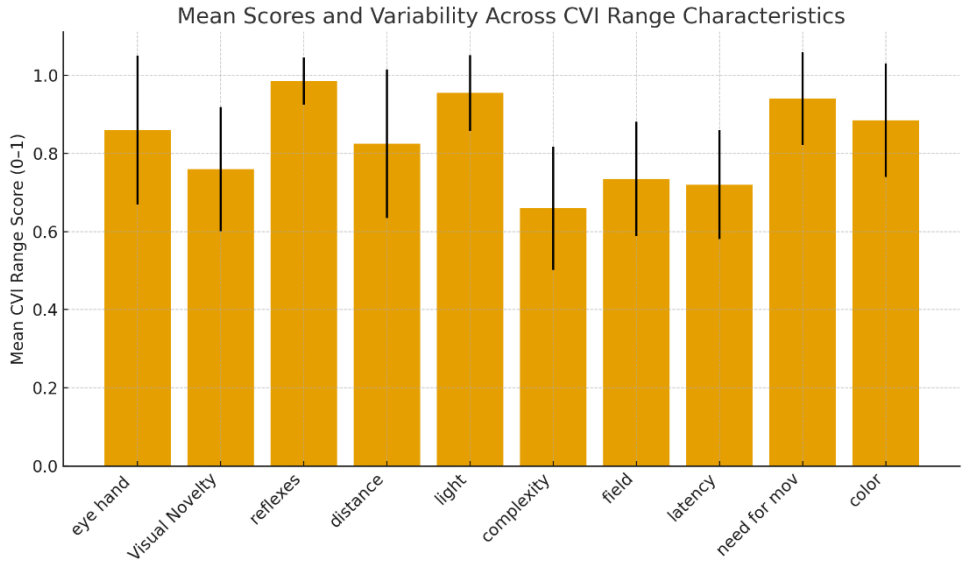
3.2.1.1 Body Structure &Functions Measures (ICF) – Visual Processing/CVI Measures

3.2.1.1.1 CVI Range 2 Scores Distribution Across Characteristics. To examine differences across the 10 CVI Range 2 characteristics, each scored on a 5-point ordinal scale (0, 0.25, 0.5, 0.75, 1), a Friedman nonparametric repeated-measures test was conducted. The results indicated a statistically significant difference among the mean scores of the 10 characteristics, χ^2 (9) = 213.40, $p < .001$, suggesting that the characteristics did not contribute equally to children's visual functioning profiles (Figure 11).

Subsequent Wilcoxon signed-rank pairwise comparisons with Bonferroni correction ($\alpha = .001$) revealed 29 significant pairwise differences, confirming heterogeneity across visual domains. Characteristics such as visual field, latency, and complexity showed the lowest mean scores, indicating greater difficulty, this followed by visual novelty, whereas color preference and need for movement demonstrated relatively higher mean scores.

Figure 11

CVI Range 2 10 Characteristics Distribution



3.2.1.1.2 Oddball Pointing Discrimination Task. Children with CP-CVI demonstrated significantly lower accuracy and slower reaction times compared with the neurotypical group (Figures 12a and 12b; Figures 13a and13b). In addition, a learning curve across trials was observed in the CP-CVI group (Figures 13a and 13b).

Figure 12 (a & b)

Accuracy in Oddball Visual Discrimination Task by Group

Figure 12a. Accuracy in Oddball Visual Discrimination Tasks, Group Comparison

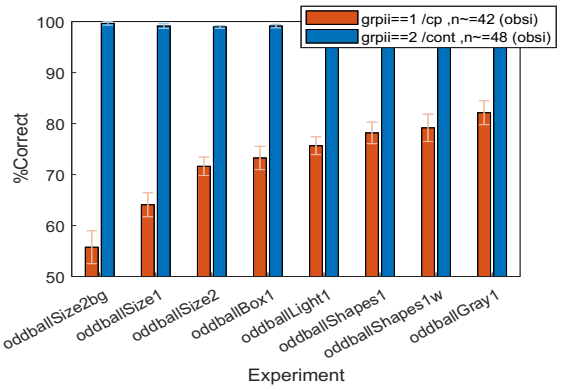


Figure 12b. Accuracy in Oddball Visual Discrimination Tasks, CP Group Distribution

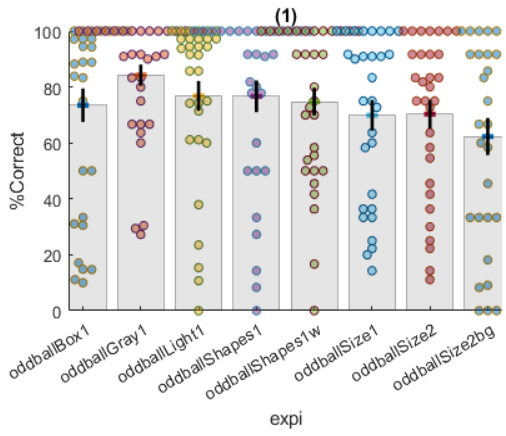


Figure 12a revealed distinct patterns of visual discrimination in children with CP-CVI in comparison to the neurotypicals. The mean composite score across all visual discrimination tasks was 80.30 (range: 62.5–95.0), indicating variable performance across different visual parameters tested. The y-axis represents accuracy as percentage correct, while the x-axis displays the different experimental conditions. Each experiment manipulated specific visual discrimination parameters to assess cortical visual processing abilities. While control participants maintained near-perfect accuracy (approximately 100%) across all conditions, the data reveals a clear hierarchy of visual discrimination performance in children with CP-CVI, with certain visual features showing near-perfect accuracy while others demonstrated significant impairment. Color discrimination (oddballGray1) showed the smallest gap, with CP group achieving approximately 85% accuracy. Luminance discrimination (oddballLight1) revealed moderate impairment (82% accuracy). Shape discrimination (oddballShapes1, oddballShapes1w) and 3D position perception (oddballBox1) showed performance around 76-5% accuracy. Size discrimination (oddballSize1, oddballSize2) demonstrated greater difficulty (68%–72% accuracy). Complex background condition (oddballSize2bg) presented the greatest challenge, with CP-CVI performance dropping to 58% to 60% accuracy. This pattern suggests that while visual discrimination abilities are broadly affected in children with CP-CVI, certain visual features (particularly 3D, size discrimination and figure-ground segregation) appear more vulnerable than others (such as color discrimination). The hierarchy of performance declines may provide insight into the specific visual processing mechanisms most impacted by neurological impairments associated with CP-CVI.

Figure 12b displays the distribution of accuracy scores across eight oddball visual discrimination tasks for children with CP-CVI. All participants performed above chance level on the tasks, but performance varied notably between tasks. Tasks such as oddballGray1 and oddballSize2 showed relatively higher mean accuracy, while

oddballShapes1w and oddballSize2bg yielded lower mean scores. A wide spread of individual scores was observed across all tasks, indicating substantial within-group variability.

Figure 13 (a & b)
Reaction Time Comparison Visual Discrimination Tasks (Pointing)

Figure 13a. Oddball Task Reaction Time

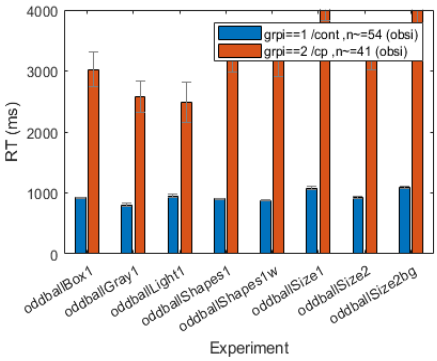
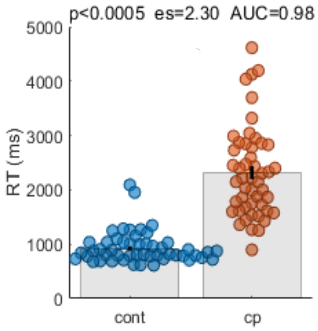


Figure 13b. Reaction Time comparison



Figures 13a and 13b compares reaction times between neurotypically developing children (n = 54 observations) and children with CP-CVI (n = 41 observations) across eight visual discrimination tasks described above. The y-axis represents reaction time in milliseconds (ms), while the x-axis displays the different experimental conditions. Children with CP- CVI demonstrated substantially longer processing times across all conditions. Shape discrimination (oddballShapes1, oddballShapes1w) showed among the largest gaps, with CP& CVI children requiring ~3600ms versus ~900 ms for controls. 3D position discrimination (oddballBox1) revealed CP-CVI reaction times of ~3200 ms compared to ~950 ms for controls. Size discrimination tasks (oddballSize1, oddballSize2) showed CP-CVI processing times of ~3400 ms versus ~1000 ms for controls. Color discrimination (oddballGray1), despite showing the smallest accuracy gap, still revealed substantial timing

differences (2600 ms vs. 850 ms). The complex background condition (oddballSize2bg) presented the greatest challenge, with CP-CVI reaction times reaching ~4000 ms compared to ~1100 ms for controls. While neurotypical children maintained consistent reaction times (850–1100 ms) across tasks, the CP-CVI group showed greater variability (2600–4000 ms) and significantly extended processing times overall. These findings reveal that children with CP-CVI face dual challenges: reduced accuracy and substantially slower visual information processing, suggesting fundamental differences in visual processing efficiency.

Figure 14 (a & b)

Accuracy and Reaction Time Dynamics Across Trials in Oddball Discrimination

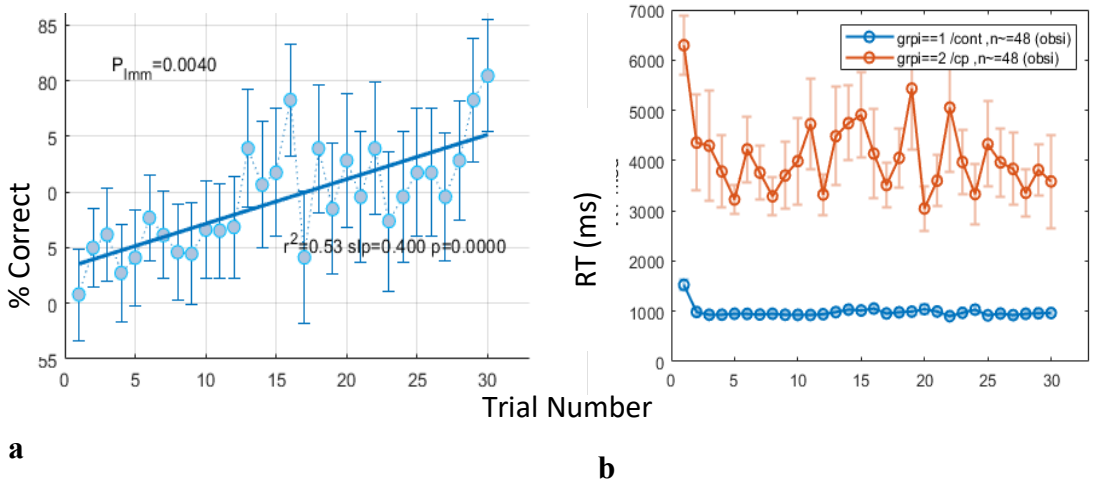


Figure 14 illustrates the accuracy (14a) and RT (14b) trends over the first 30 trials of the visual discrimination (oddball) task in children with CP-CVI. The accuracy data (Figure 14a) demonstrates a significant positive linear trend (LMM $p < .005$), indicating improvement in correct responses with repeated exposure. This suggests that, despite initial challenges, children with CP-CVI exhibit perceptual learning over trials, consistent with implicit visual adaptation mechanisms. The improvement was statistically significant), reflecting meaningful task learning across repetitions. In contrast, the reaction time

(Figure 14b) in the CP-CVI group remained consistently elevated across trials, with no clear downward trend in latency. Median RTs remained substantially higher than those of the neurotypical group across all trials, indicating persistent slowness in processing speed or motor response execution, despite accuracy gains. This dissociation between improved accuracy and sustained RT suggests that the delays may not be primarily motoric, but rather reflect prolonged visual scanning or difficulty in discriminating visual stimuli. These findings highlight the presence of learning potential alongside enduring visual-perceptual processing inefficiencies in children with CP-CVI.

3.2.1.1.3 Oddball Gaze Discrimination Task: Effects of Background Complexity. The CP-CVI group exhibited significantly more gaze errors and fewer correct fixations than neurotypical peers. Reaction times were also slower in the CP-CVI group.

Figure 15 (a & b)
Comparison of Gaze Error Distribution With and Without Background Condition

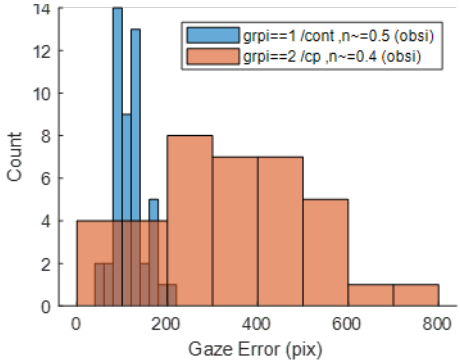


Figure 15a. Comparison of Gaze Error Distribution: No Background Condition

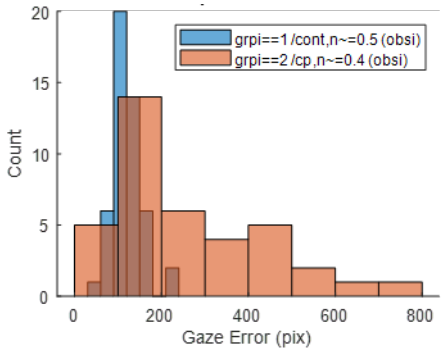


Figure 15b. Comparison of Gaze Error Distribution: Background Condition

Figures 15a and 15b present the gaze error distributions for both experimental conditions across the two participant groups. Children with CP-CVI demonstrated significantly higher gaze error magnitudes compared to neurotypically developing children. Notably, the CP-CVI group exhibited increased error rates in the cluttered background condition (Experiment 2), suggesting particular difficulty with visual discrimination in

complex visual environments. Conversely, the neurotypically developing group showed no significant differences in performance between the two experimental conditions. These findings indicate that children with CP- CVI not only display greater baseline difficulties with gaze accuracy but also experience disproportionate performance decrements when confronted with visual complexity, even in pure eye-gaze tasks without additional motor demands.

Figure 16 (a & b)
Comparison of Gaze Error Ratios With and Without Background Condition

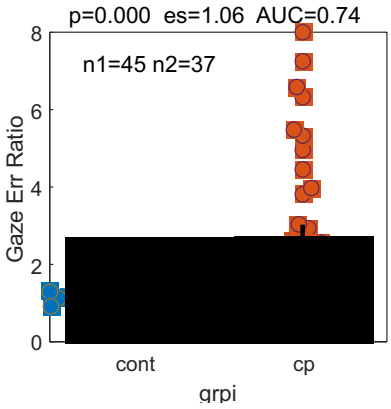


Figure 16a. Comparison of Gaze Error Ratios: No Background Condition

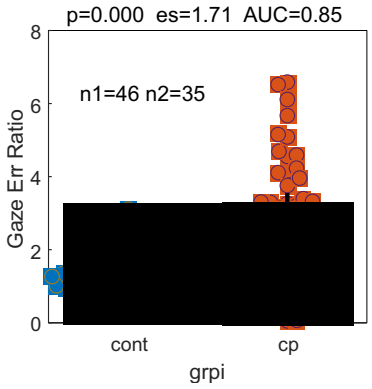


Figure 16b. Comparison of Gaze Error Ratios: Background Condition

Figures 16a and 16b images compare gaze error ratios between control and CP-CVI groups, but with different testing conditions. Image 16a (no background) shows significant differences between groups ($p < .001$) with a large effect size (es = 1.06) and good discrimination ability (area under the ROC curve [AUC] = .74). The CP-CVI group ($n = 37$) demonstrates higher error ratios (ranging approximately 0.5–8) and greater variability compared to the control group ($n = 45$), which shows consistent lower error ratios (.5–2.5). Image 16b (with background) reveals an even more pronounced difference between groups under this more complex visual condition. With the addition of background visual

information, the CP-CVI group shows increased error ratios compared to Image 1, while the control group maintains similar performance. This is reflected in the higher effect size (es = 1.71) and better discrimination ability (AUC = .85).

These findings suggest that children with CP-CVI experience greater visual processing difficulties when background visual information is present. This background interference effect was not observed in the neurotypical group, highlighting a specific visual processing vulnerability in children with CP-CVI that becomes more apparent in visually complex environments.

Figure 17 (a & b)
Comparison of Gaze Time Ratios With and Without Background

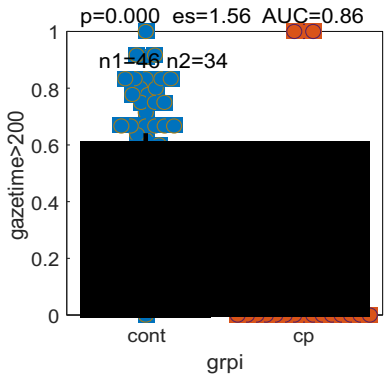


Figure 17a. Comparison of Gaze Time Ratios: No Background

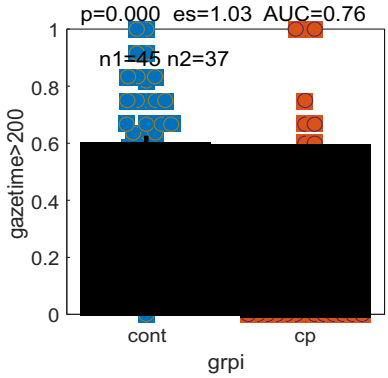


Figure 17b. Comparison of Gaze Time Ratios: With Background

Graphs 17a and 17b measure gaze time on the oddball target, comparing the control and CP-CVI groups with and without background. The measure reflects the proportion of trials for which the gaze was on the target for more than 200ms. Graph 17a (without background) shows superiority of the controls ($p < .001$) with a large effect size (es = 1.03) and good discrimination ability (AUC = .76). Many participants in the CP-CVI group register at or near zero, indicating minimal sustained visual gaze on target above the 200 ms threshold. Graph 17b (with background) shows that the addition of background visual information leads to reduced values (worse performance) for the CP-CVI group ($n = 37$)

compared to the no-background condition, with a statistical significance ($p < .001$), and a higher effect size (es = 1.56).

3.2.1.1.4 Tracking Task: Effect of Occlusion on Smooth Pursuit Eye Movements.

Children with CP-CVI showed reduced tracking accuracy, with significantly larger deviations from the target trajectory compared with the neurotypical group. Six oculomotor measures that reflect the quality of tracking in the two experiments (with and without occlusion) were calculated and are listed together with a description of their exact computation method (see Table 8). An additional measure quantified the head movement (distance change to screen). All measures were computed per epoch and then averaged across epochs per participant and condition with outlier rejection (see methods in Table 8).

Table 8
Description and Method Details of Measurements Applied

Measure	Description	Method details
1stSpeed (A)	Initial track speed	The time course of total eye movement speed (drift, pursuit, saccades) as first calculated per epoch (Figure 4c and Methods). The maxima were then calculated in the window 200–1000 ms post stimulus and averaged across epochs per participant.
OccDev (B)	Occluder-induced deviation from unoccluded pursuit	Deviation from unoccluded tracking when tracking with occlusion (Experiment 2). First, a baseline control group average for unoccluded tracking is calculated from data from Experiment 1, separately for the horizontal and vertical traces in absolute values. Then, the average deviation of traces from the baseline in degrees of visual angle is calculated in the time window of 0.6-1.5s per epoch (separate for each occlusion width) and averaged across epochs per observer with outlier rejection (> 2 *SD*).
sacRT (C)	Initial sac. latency (catchup)	A measure of the saccade response time, calculated per epoch as the latency of the first saccade in the time window of 250–800 ms relative to the onset of the pursuit target. It measures the speed of the open-loop process, in a condition in which the target direction is unknown in advance.
FixError (D)	Fixation error at stimulus onset	The average distance of the left eye from central fixation in the time window -50 to 100 ms relative to stimulus onset, with outliers (> 2 *SD*) excluded.
Vergence (E)	Interocular-lag variability	The horizontal interocular lag between the leading and the other eye time-course was first calculated per epoch, and normalized to time zero (stimulus onset). Then, the maxima in the 125–-2000 poststimulus interval were calculated and averaged across epochs.
Pgood (F)	Tracking quality	The proportion of valid eye tracking data, computed per epoch and averaged across epochs. Invalid data include blinking time.
HeadMov (G)	Head movement	The derivative of the head distance to the screen provided by the eye tracker reflects head movement back and forth. It's average converted to mm/deg was computed per epoch in the interval +/-150 ms around stimulus onset, with outliers (> 2 *SD*) excluded.

The listed oculomotor and head movement measures were calculated based on the defined methodology and are presented in this chapter through a series of figures.

Figure 18 (a & b)
Eye-Tracking Quality and Head Movement During the No-Occlusion Experiments: Comparison Between Groups

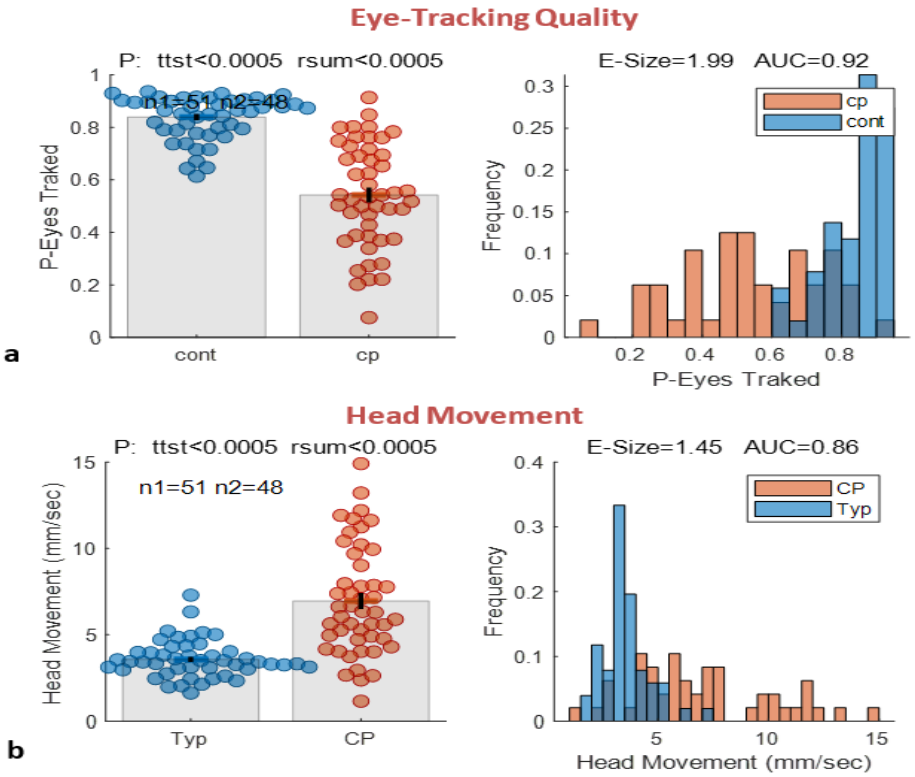


Figure 18 presents the comparison between groups for (a) eye-tracking quality and (b) head movement during the visual tasks. *Eye-tracking quality* (a) is defined as the proportion of time the eyes were successfully tracked during each trial, averaged across all trials. Tracking loss could result from blinking or the participant moving outside the effective tracking range. *Head movement* (b) was measured in a window of -150 to +150 ms relative to stimulus onset. Movement was quantified as the absolute derivative of the

distance between the head and the screen, measured in mm/s (see Methods for details). Each subplot presents individual data points using bee-swarm plots (left, one dot per participant), and histograms of the distribution (right). Key statistics are provided in the figure titles: *t* test, *p* value, and rank-sum *p* value both indicate statistically significant group differences ($p < .0005$). Effect size (Cohen's *d*) shows large effects (1.99 for eye tracking; 1.45 for head movement). AUC values further support strong group separation (.92 for eye tracking; .86 for head movement). These findings confirm reduced tracking quality and increased head movement in the CP-CVI group relative to neurotypical peers.

Figure 19 (a–c)
Pursuit Gain Performance During the No-Occlusion Smooth Pursuit Task

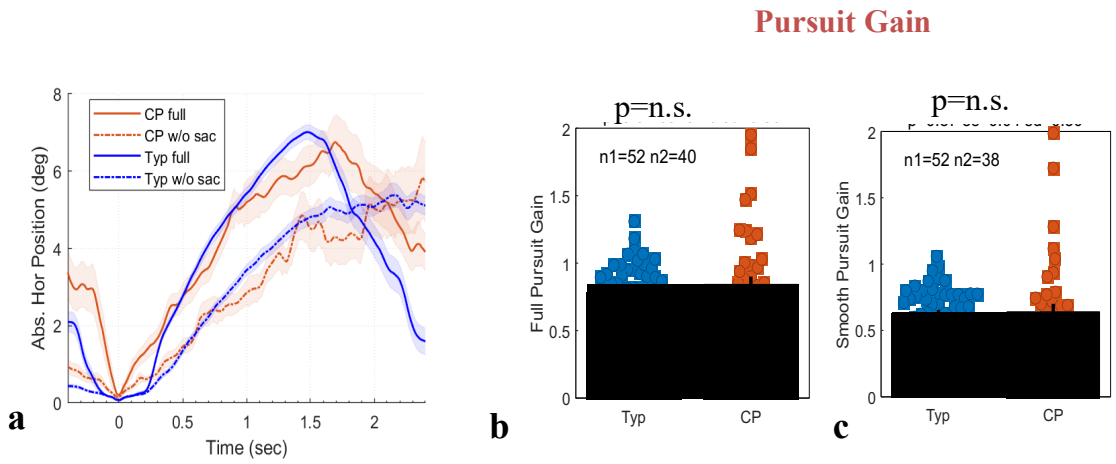


Figure 19 presents the results of horizontal smooth pursuit and catch-up saccade performance in the no-occlusion condition. (a) shows the average horizontal gaze position over time (excluding vertical tracking), aligned to stimulus onset (time = 0) and expressed in absolute degrees of visual angle. The curves represent the average across all valid trials and observers, with shaded areas indicating ±1 standard error across participants. Solid lines represent full pursuit (including saccades), while dashed lines represent smooth pursuit only

(with catch-up saccades removed). Data are shown separately for the neurotypicals control group (blue) and the CP-CVI group (red). Notably, CP-CVI participants demonstrated a more variable pursuit patterns (a) compared to controls. (b) and (c) display individual performance distributions in bee-swarm plots, comparing groups on full pursuit gain (b) and smooth pursuit gain after removing saccadic contributions (c). Participants with less than 40% valid data or with extreme pursuit gain values (> 2) were excluded from the analysis, resulting in a slightly smaller CP-CVI sample. Although a visual inspection of the traces in panel (a) suggests noisier pursuit behavior in the CP-CVI group, no statistically significant differences were observed between groups in either full or smooth pursuit gain, as shown in (b) and (c).

Figure 20 (a–d)
Tracking Under Occlusion: Deviation from Target Trajectory During Smooth Pursuit

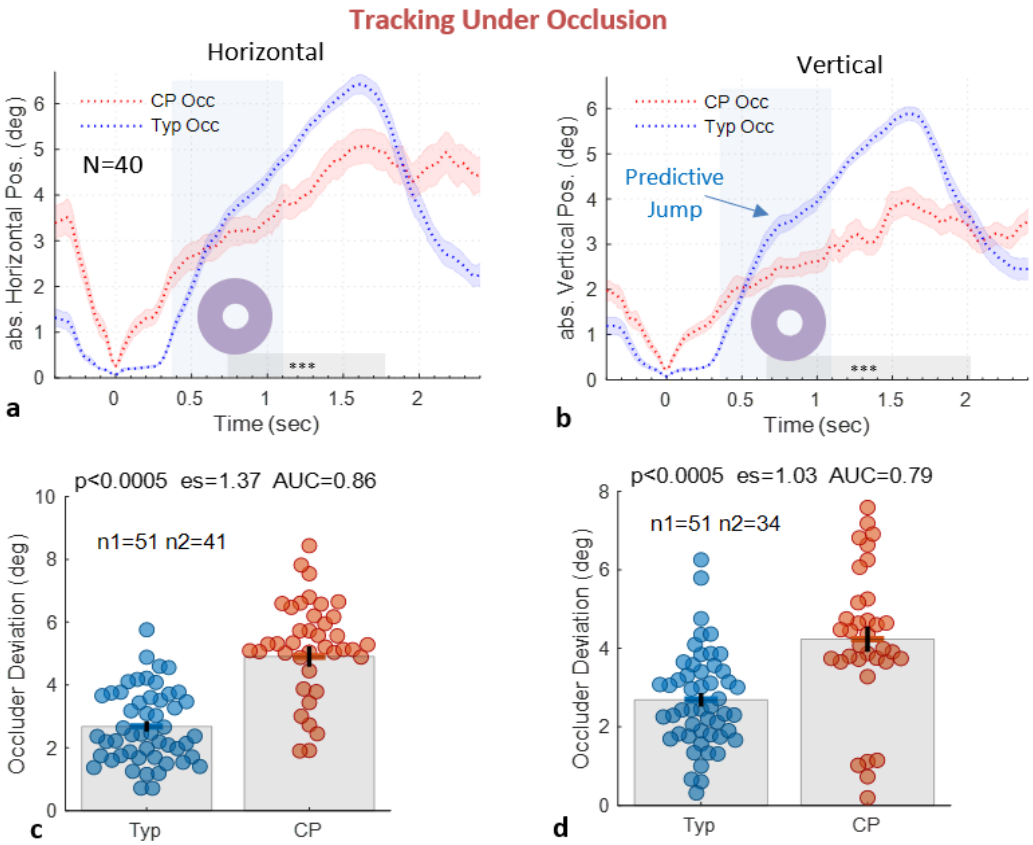


Figure 20 presents the results of the experiment which assessed smooth pursuit performance under occlusion in both horizontal and vertical motion conditions. (a) and (b) display the average horizontal and vertical gaze trajectories, respectively, for the CP-CVI group (red) and the neurotypical control group (blue). Traces represent the absolute horizontal/vertical position over time, aligned to stimulus onset (time = 0), and averaged first within trials and then across participants. Shaded bands indicate ±1 standard error across participants. Data are plotted separately for the occlusion condition, with the occlusion window indicated in gray and the occluder icon shown for illustration. Significant group differences in gaze position were identified using permutation testing ($p < .001$), with periods of significance marked by gray bars below the x-axis. Notably, the control group showed a more precise and predictive trajectory, particularly evident in vertical tracking (b), where a predictive jump was observed. (c) and (d) show bee-swarm plots representing the distribution of occluder-induced deviation—defined as the minimal deviation per trace during occlusion—for the horizontal and vertical conditions, respectively. Each dot represents a participant. CP-CVI participants exhibited significantly greater deviation in both conditions, as supported by high statistical significance ($p < .0005$), large effect sizes (Cohen's $d = 1.37$ and 1.03), and strong group separation (AUC = .86 and .79). These findings indicate that children with CP-CVI show reduced tracking accuracy under occlusion, consistent with impaired predictive visual processing.

Figure 21 (a–f)

Oculomotor Measures During Smooth Pursuit Experiment

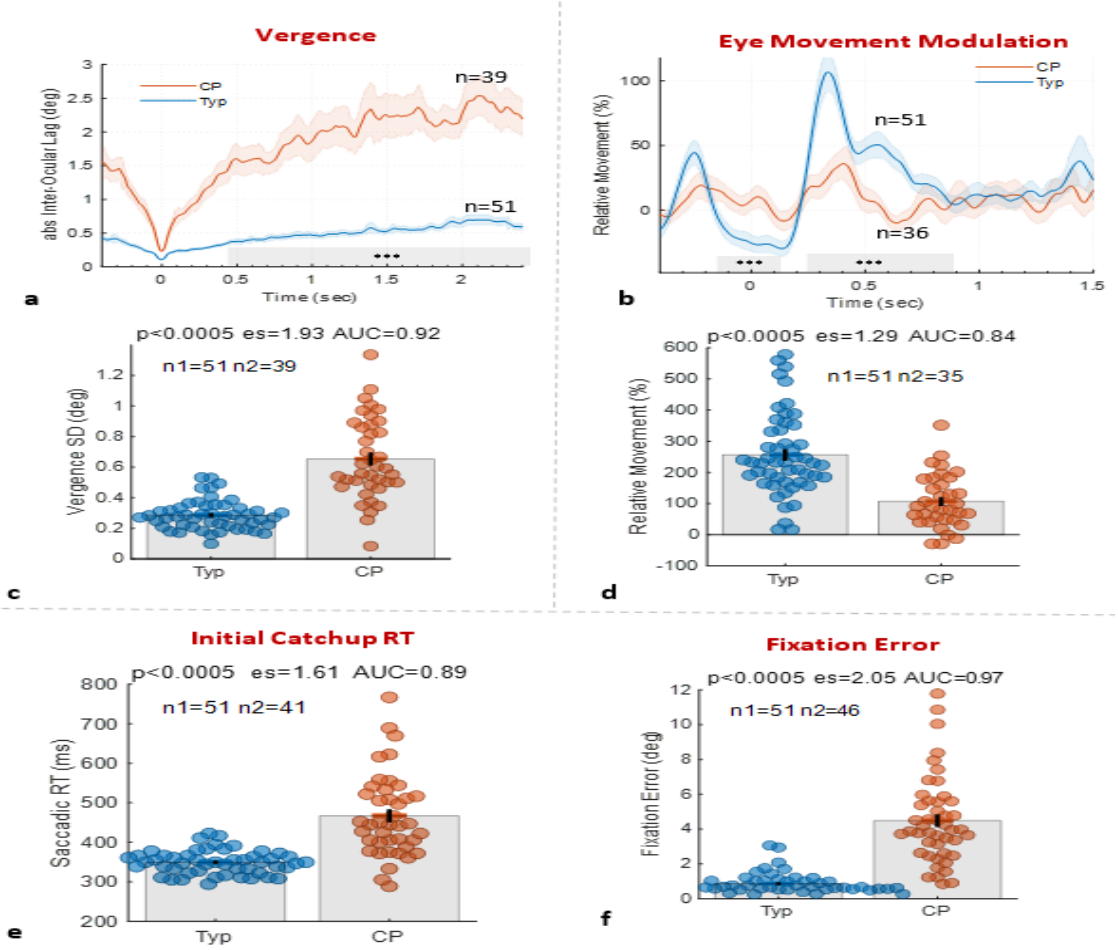


Figure 21 presents group comparisons of key oculomotor metrics common to both visual pursuit experiments. (a) shows the vergence lag time-course, calculated as the absolute horizontal difference between the two eyes across time, normalized to stimulus onset (time = 0). (b) illustrates the total eye movement modulation (including saccades, drift, and smooth pursuit), expressed as a percentage change relative to a pretrial baseline. In both (a) and (b), shaded areas indicate ±1 standard error across participants, and gray bars along the x-axis mark time points with statistically significant differences between groups based on permutation tests ($p < .001$). (c–f) display bee-swarm plots for individual participants comparing the CP-CVI and neurotypical groups across four oculomotor metrics:

(c) Vergence variability (*SD*) derived from the traces shown in (a). (d) Peak modulation in overall eye movement, corresponding to (b). (e) Initial catch-up saccade RT, reflecting the latency to first saccadic correction. (f) Fixation error, defined as the positional deviation at stimulus onset.

All measures revealed significant group differences with high effect sizes (Cohen's d = 1.29–2.05) and strong classification performance (AUC = .84–.97), indicating robust oculomotor deficits in the CP-CVI group across vergence control, eye movement regulation, and fixation accuracy.

3.2.1.1.5 Video Clip Viewing Task. During free viewing of the animated clip, children with CP-CVI displayed less efficient scene exploration as assessed via a set of computed oculomotor measures.

Table 9 includes the oculomotor measures used in the study. Oculomotor measures that reflect the quality of tracking in the two experiments are listed together with a description of their exact computation method. An additional measure quantified the head movement (distance change to screen). All measures were computed per epoch and then averaged across epochs per participant and condition with outlier rejection (see Methods).

Table 9

Oculomotor Measures in the Tracking Video Clip Assessment

Measure	Details
% tracked	The percentage of time during which valid eye-tracking data was recorded. It is calculated per segment and averaged across all segments. Invalid data include blinks, signal loss, or occlusion.
Sit distance/*SD*	The average sitting distance from the screen, continuously recorded by the eye tracker during the session, along with its standard deviation (*SD*) to reflect variability.
Head movement	The derivative (rate of change) of the head-to-screen distance, indicating forward and backward head movements. Expressed in mm/degree of visual angle.
Saccade velocity	The average speed of eye movements (saccades) measured in degrees per s. It reflects how rapidly the eye moves between two fixation points.
Saccade distance	The straight-line angular distance between the start and end points of a saccade, measured in degrees of visual angle.
Vergence SD	The standard deviation of vergence angles between the two eyes during viewing, indicating variability in binocular alignment.
Vergence disparity	The average absolute difference in gaze position between the eyes (i.e., binocular disparity), with outliers (>2 *SD*) excluded. Converted to log units for analysis.
Blink duration	The average duration of a blink, typically measured in ms, calculated across the viewing segments.
Blink rate	The number of blinks per min, reflecting oculomotor and attentional regulation.
Pupil size	The average diameter of the pupil, measured in millimeters, as an indicator of arousal or visual processing load.
Saccadic vigor	A combined measure of saccade speed and amplitude, reflecting the strength or energy of eye movements. Typically calculated as peak velocity divided by amplitude.
Sac. time randomness	A measure of the temporal irregularity or unpredictability in saccade timing, potentially indicating cognitive or attentional fluctuations.
Gaze correlation to typical mean	A similarity index comparing the participant's gaze pattern to a normative dataset (i.e., typical gaze trajectory during the same visual stimulus). Higher values indicate more typical visual behavior.
Binocular vergence deficiencies	Instances of significant mismatch between the two eyes' gaze positions, indicating potential deficits in binocular coordination or depth perception.

Figure 22 (a–d)
Eye-Tracking Quality and Head Movement

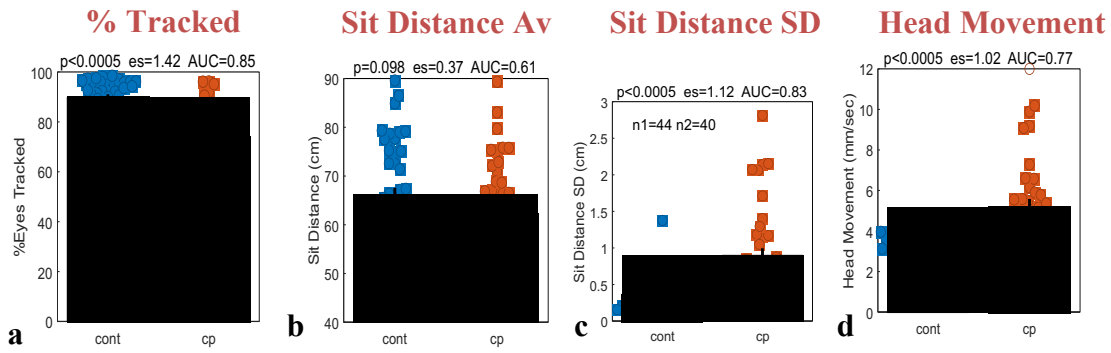


Figure 22 presents the eye-tracking quality and head movement. Group comparison is shown for four measures in bee-swarm plots with a dot per participant: (a) percentage of valid data, (b) average sitting distance, (c) variability (*SD*) of sitting distance across time samples, (d) head movement (forward/backward). The *p* value (*t* test), effect size (Cohen's *d*), and AUC are shown on the top of each plot. As shown, the average sitting distance did not differ significantly between groups but the other measures showed significant group differences.

Figure 23 (a-d)
Basic Oculomotor Measures–Similar To Neurotypical

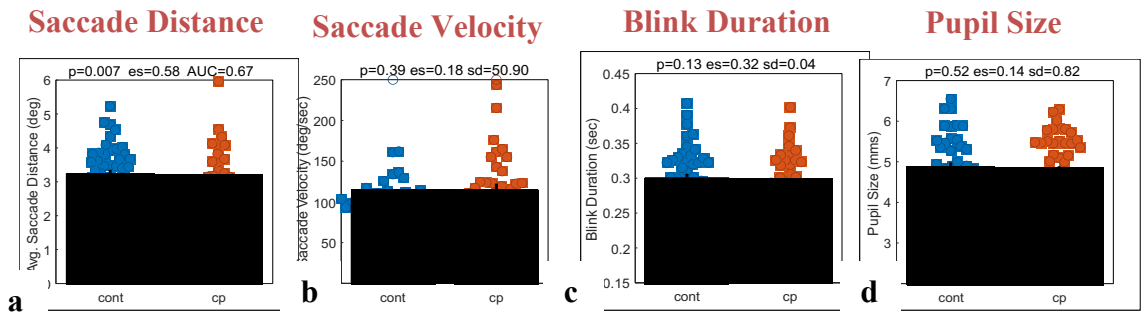


Figure 23 presents basic oculomotor measures, mostly typical. Group comparison is shown for four oculomotor measures in bee-swarm plots with a dot per participant: (a) saccade distance (average), (b) saccade velocity (average), (c) blink duration (average), (d) pupil size (average across all samples). The *p* value (*t* test), effect size (Cohen's *d*) and AUC are shown on the top of each plot. As shown, there was no significant difference between measure except for the saccade distance.

Figure 24 (a–c)
Basic Atypical Oculomotor Measures–Comparison to Neurotypical

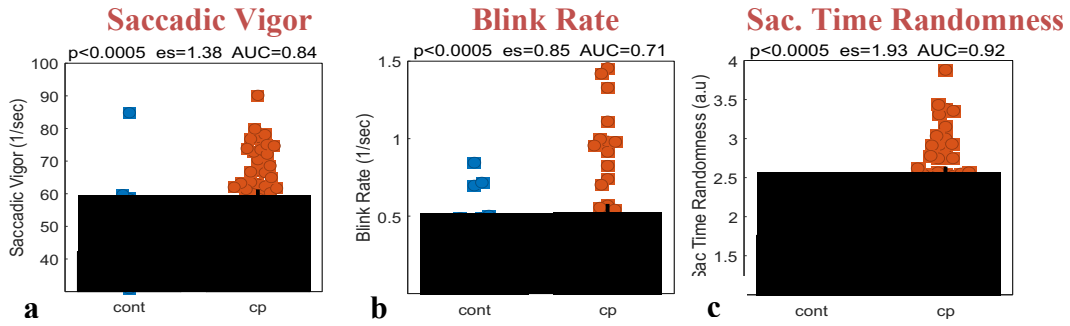


Figure 24 shows basic oculomotor measures, atypical. (a–c) Group comparison for three oculomotor measures in bee-swarm plots with a dot per participant: (a) saccadic vigor (saccade peak velocity divided by the distance), (b) blink rate, (c) saccade time randomness. The *p* value (*t* test), effect size (Cohen's *d*) and AUC are shown on the top of each plot. As shown, these three measures show highly significant differences between groups (AUC of .84–.92).

Figure 25 (a–e)

Gaze Pattern Correlation to the Typical Mean

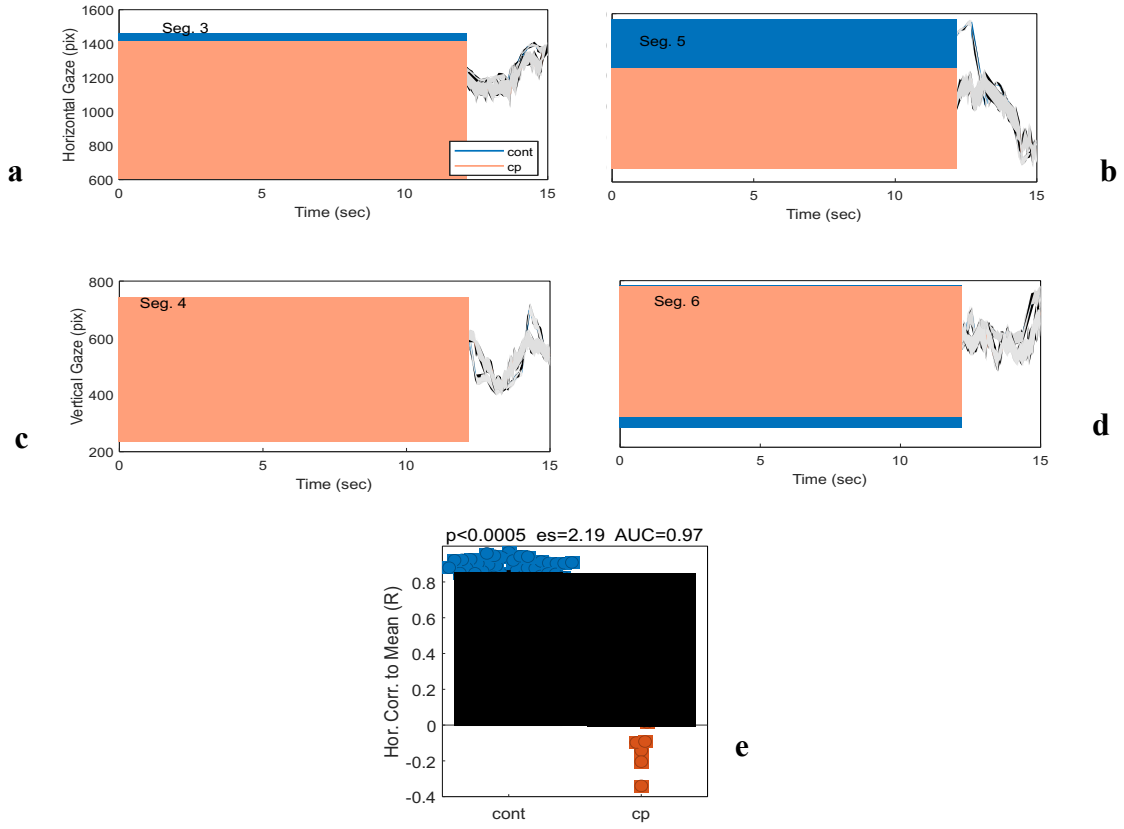


Figure 25 presents an analysis of gaze pattern similarity across participants, comparing children with CP-CVI to typically developing controls. Gaze data were segmented into six 15-s intervals. For each segment, horizontal and vertical gaze traces from individual participants were correlated (Pearson's *r*) with the corresponding mean trace of the control group. (a) Representative horizontal (top) and vertical (bottom) gaze traces from two segments (Seg. 3–6) are shown for the control group (blue) and the CP-CVI group (red). Control group traces show stronger alignment with the group average and reduced within-group variability, while the CP-CVI group exhibits more variability and weaker correspondence with the control average. (b) Bee-swarm plot comparing correlation coefficients (*r*) between the two groups, with each dot representing a participant's average horizontal correlation. The CP-CVI group showed significantly lower correlations than

controls ($p < .0005$), with a very large effect size (Cohen's $d = 2.2$) and excellent classification accuracy (AUC = .97). These results reflect a marked divergence in gaze behavior in children with CP-CVI, indicating reduced synchronization and predictability in their oculomotor patterns compared to typically developing peers.

Figure 26
Binocular Vergence Deficiencies

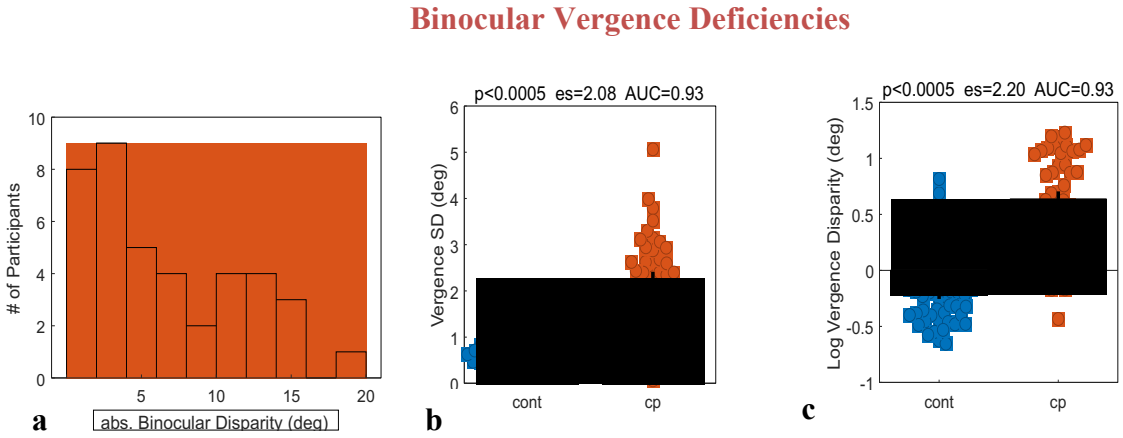


Figure 26 illustrates group differences in binocular vergence function between the CP-CVI and neurotypical control groups. The left panel shows the distribution of absolute binocular disparity (in degrees) across participants with CP-CVI revealing substantial variability and a noticeable subset with marked divergence from expected alignment. The middle panel presents the standard deviation of vergence (vergence *SD*), representing instability in binocular alignment. Children with CP-CVI demonstrated significantly greater vergence variability compared to the control group, indicating reduced control over binocular coordination. The right panel shows the average vergence disparity, transformed to a logarithmic scale. Again, the CP-CVI group exhibited significantly higher vergence disparities than controls, with almost all values shifted above the 0 line, suggesting a

systematic misalignment between the eyes. This pattern confirms a robust impairment in binocular vergence control in the CP-CVI group, with potential consequences for depth perception and visual comfort during near tasks.

Together, these findings indicate that binocular vergence deficits are prevalent and pronounced in children with CP-CVI, highlighting the importance of assessing and addressing binocular function in clinical evaluations and intervention planning.

3.2.1.2 Activity and Participation (ICF): Visual Processing/CVI Measures

3.2.1.2.1 Insight Inventory Parents Questionnaire. Comparison of IIQ domain scores between CP-CVI and neurotypical groups (Table 10).

Table 10
Comparison of IIQ Domains Between CP-CVI and Neurotypical Groups

IIQ domain	CP group (*n* = 51)			Control group (*n* = 48)			*z*	*r*
	M (*SD*)	IQR	*Mdn*	*M* (*SD*)	IQR	*Mdn*		
Visual fields	2.25 (.58)	.75	2.25	1.72 (.220)	0.33	0	-8.46	.85
Perception of movement	2.00 (.88)	1.20	2.00	0.62 (.160)	0	0	-8.43	.85
Search	2.25 (.73)	.79	2.22	0.44 (.156)	0	0	-8.83	.89
Guidance of movement	2.39 (.56)	.78	2.50	0.14 (.250)	0.22	0	-8.65	.87
Attention	1.61 (.73)	.75	1.50	0.14 (.320)	0	0	-8.17	.82
Crowded scenes	0.69 (.72)	1.25	5.00	0.41 (.170)	0	0	-5.91	.59
Recognition and navigation	0.95 (.58)	.88	0.87	0.05 (.190)	0	0	-8.27	.83
Total score	1.84	.56	1.86	0.10 (.150)	.13	.49	-8.55	.86

Note: *M* = mean; IQR = interquartile range; *Mdn* = median; *z* = Z score; *r* = effect size.
$p < .01$.

Table 10 presents the comparison of the impact of IIQ domains between children with CP-CVI and neurotypically developing children. Statistical analysis using Mann-Whitney U tests revealed significant differences across all domains. The CP-CVI group demonstrated significantly higher scores across all measured domains compared to the control group. The

largest discrepancy was observed in the Search domain (Z = -8.83, r = .89) and Guidance of movement (Z = -8.65, r = .87), indicating profound differences in these functional areas. The Visual fields domain showed substantial differences (Z = -8.46, r = .85), as did Perception of movement (Z = -8.43, r = .85).

The domain with the smallest significant difference between groups was Crowded scenes (Z = -5.91, r = .59), representing a medium to large effect size. All other domains demonstrated very large effect sizes (r > .80), highlighting the substantial functional impact of CP- CVI on various visual perceptual and attentional processes. The total IIQ score showed a marked difference between groups (Z = -8.55, r = .86), with the CP-CVI group (M = 1.84) scoring significantly higher than the control group (M =.10), further confirming the comprehensive impact of CP-CVI on visual functional abilities across multiple domains. These findings underscore the significant challenges faced by children with CP-CVI, across various visual perceptual domains compared to their neurotypically peers.

3.2.1.3 Body Functions & Activity (ICF): Sensory Processing and Modulation

3.2.1.3.1 Sensory Profile Assessment. Children with CP-CVI demonstrated significantly different sensory profiles scores compared to neurotypical children across all measured domains (p < .001). Atypical patterns were more prevalent among the CP-CVI group, this group showed markedly elevated percentages in the More than Others category, particularly in muscle tone modulation (98%), sensory registration (98%), and behavior outcomes (96.1%) domains. Conversely, neurotypical children predominantly scored within the Similar and Less than other categories. The most striking difference was observed in the response level domain: while 100% of neurotypical children scored within the Similar to others category, only 60.8% of children with CP-CVI did so. These results are summarized in **Table 11**.

Table 11

Comparison of Sensory Profile Category Distribution Between the CP-CVI and Neurotypical Groups

Sensory profile domain	More than others % (*n*)		Similar to others % (*n*)		Less than others % (*n*)		*df*	Asymptotic significance (2-sided)
	Typical	CP	Typical	CP	Typical	CP		
Sensory profile processing sections								
Auditory processing	2.1 (1)	**70.6 (36)**	54.2 (26)	21.6 (11)	43.8 (21)	7.8 (4)	2	< .001
Visual processing	2.1 (1)	**58.8 (30)**	25.0 (12)	35.3 (18)	72.9 (35)	5.9 (3)	2	< .001
Vestibular processing	10.4(5)	47.1 (24)	89.6 (43)	52.9 (27)	0 (0)	0 (0)	1	< .001
Touch processing	6.3 (3)	39.2 (20)	39.6 (19)	58.8 (30)	54.2 (26)	2.0 (1)	2	< .001
Multisensory processing	4.2 (2)	**72.0 (36)**	50.0 (24)	28.0 (14)	45.8 (22)	0 (0)	2	< .001
Oral sensory processing	2.1 (1)	33.3 (17)	35.4 (17)	52.9 (27)	62.5 (30)	13.7 (7)	2	< .001
Sensory processing related to endurance/tone	6.2 (3)	**98.0 (50)**	93.8 (45)	2.0 (1)	0 (0)	0 (0)	1	< .001
Sensory profile modulation sections								
Modulation related to body position and movement	4.2 (2)	**73.5 (36)**	47.9 (23)	20.4 (10)	47.9 (23)	6.1(3)	2	< .001
Modulation of movement affecting activity level	2.0 (1)	**61.2 (30)**	39.6 (19)	34.7 (17)	58.3 (28)	4.1(2)	2	< .001
Modulation of sensory input affecting emotional responses	0 (0)	**80.4 (41)**	10.0 (48)	19.6 (10)	0 (0)	0 (0)	1	< .001
Modulation of visual input affecting emotional responses and activity level	2.1(1)	**56.9 (29)**	20.8 (10)	41.2 (21)	77.1 (37)	2.0 (1)	2	< .001
Emotional/social responses	12.5 (6)	**54.9 (28)**	37.5 (18)	45.1(23)	50.0 (24)	0 (0)	2	< .001
Behavioral outcomes of sensory processing	4.2 (2)	**96.1 (49)**	35.4(17)	3.9 (2)	60.4 (29)	0 (0)	2	< .001
Item indicating thresholds for response	0 (0)	39.2 (20)	100.0 (48)	60.8 (31)	0 (0)	0 (0)	1	< .001

Sensory profile quadrants sections								
Registration	4.2 (2)	**98.0 (50)**	39.6 (19)	2.0 (1)	56.3 (27)	0 (0)	2	< .001
Seeking	2.1 (1)	49.0 (25)	22.9 (11)	43.1(22)	75.0 (36)	7.8 (4)	2	< .001
Sensitivity	4.2 (2)	**68.6 (35)**	37.5 (18)	31.4 (16)	58.3 (28)	0 (0)	2	< .001
Avoiding	8.3 (4)	**76.5 (39)**	22.9 (11)	23.5 (12)	68.8 (33)	0 (0)	2	< .001

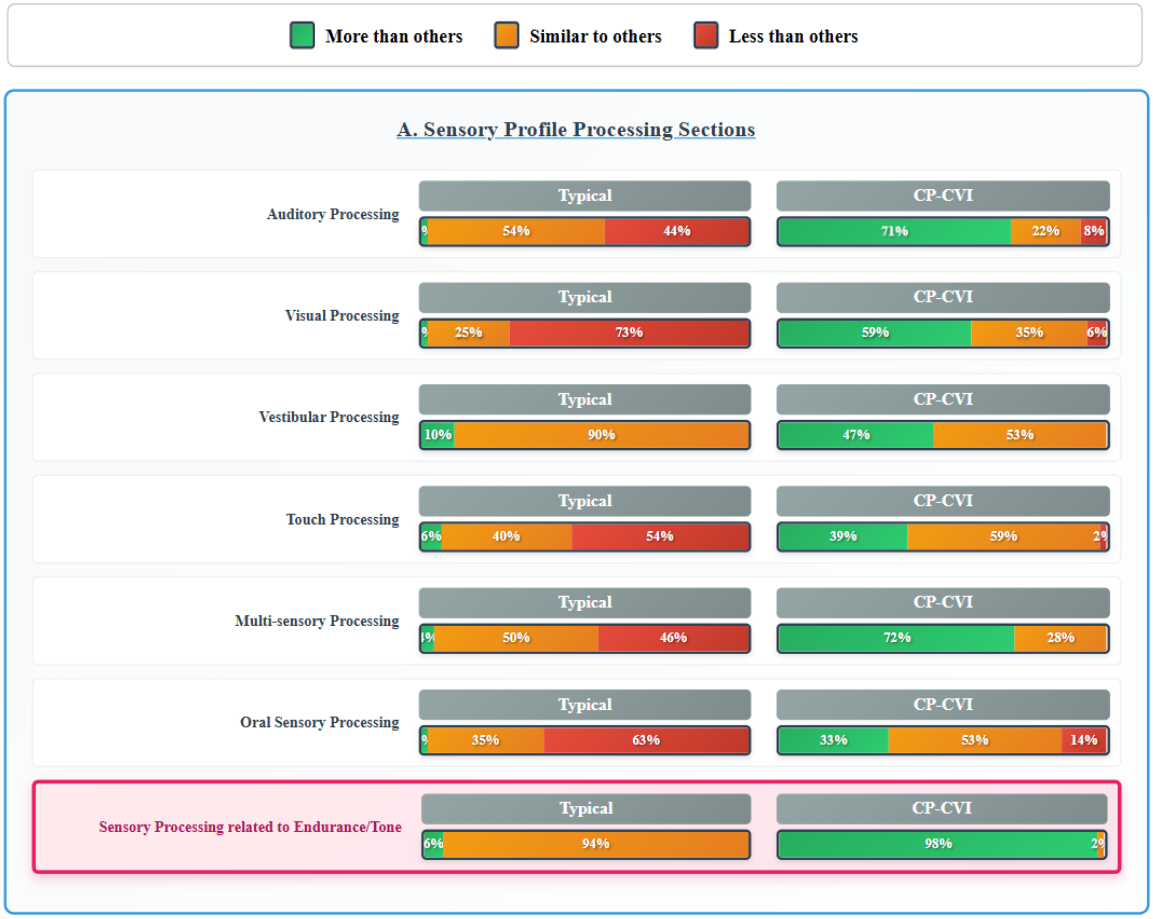
Note: CP = cerebral palsy with cerebral visual impairment; *df* = degrees of freedom. All comparisons were statistically significant at $p < .001$. Highlighted rows indicate the most severely impaired domains with ≥ 80% of CP-CVI children scoring "More than others." Bold values in the CP "More than others" column indicate domains where > 50% of children scored at this level.

Figure 27 illustrates the distribution of SP scores and visually highlights the differences between the groups across the various domains. Most severely impaired domains were registration (98% vs. 4%), endurance/tone (98% vs. 6%), behavioral outcomes (96% vs. 4%), and emotional responses (80% vs. 0%). The graph demonstrates pervasive sensory processing differences across all 18 domains of the SP, with the CP-CVI group consistently showing elevated "More than others" category indicating heightened sensory responsiveness and processing challenges.

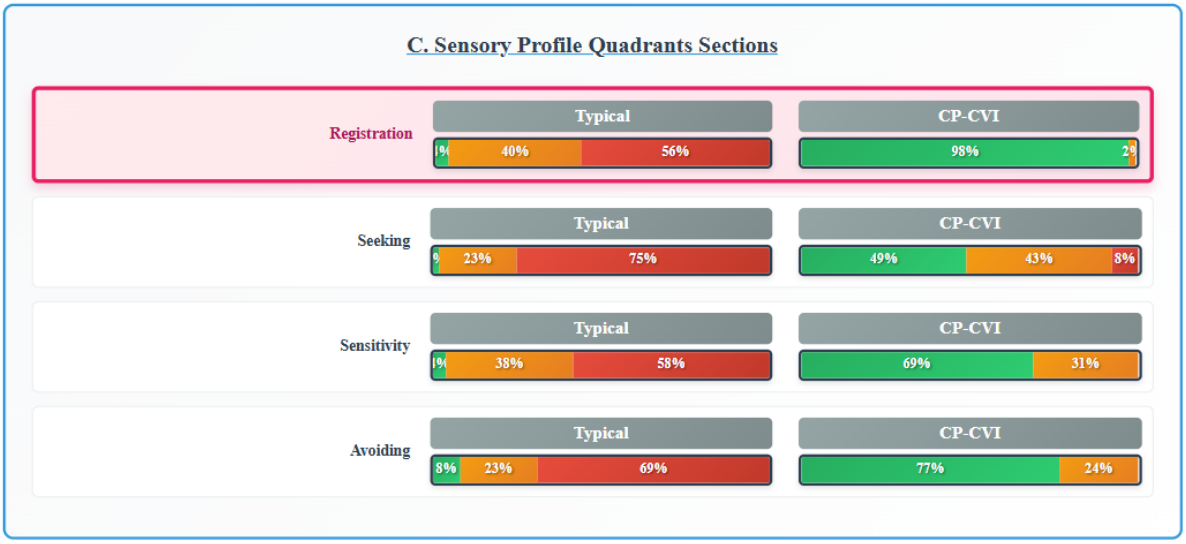
Figure 27

Distribution of Sensory Profile Categories in CP-CVI Group and Neurotypicals

Comprehensive comparison between CP-CVI group (n = 51) and neurotypical children (n = 48) showing percentage distribution across all sensory profile categories (1 = more than others, 2 = similar to others, 3 = less than others) for processing, modulation, and quadrants sections







Note. CP-CVI = cerebral palsy with cerebral visual impairment. **Pink highlighted** domains indicate the most severely impaired areas where ≥ 80% of CP-CVI children scored "more than others" compared to typical children. All comparisons were statistically significant at $p < .001$.

3.2.1.4 Sensory Profile and Visual Processing Correlations

The analysis reveals several significant relationships between sensory profile and IIQ. Notably, hearing processing domain in the SP (low score mean more difficulties) correlate negatively with IIQ domains (high scores mean more difficulties, thus, opposite scoring direction between the two measures) with visual recognition (r = -.322, p = .022), recognition under specific conditions (r = -.285, p = .045), navigation (r = -.284, p = .046), and total visual scores (r = -.334, p = .018). See Table 12.

Table 12
Correlations Between Sensory Profile Scores and IIQ Visual Assessments

Sensory profile domain	**IIQ**						
	Visual recognition	Recognition -specific conditions	Navigation	Visual field	Complex visual processing	Motion perception	Total visual score
Hearing processing	**–.322***	**–.285***	**–.284***	ns	ns	ns	**–.334***
Vision processing	ns	Ns	**–.280***	**–.370***	**–.334***	ns	**–.388****
Vestibular processing	**–.280***	Ns	ns	ns	ns	**–.290***	ns

Note. *p < .05, **p < .01.

Vision processing domain in the SP, show significant negative correlations with visual field perception (r = -.370, p = .010), complex visual processing (r = -.334, p = .019), navigation (r = -.280, p = .049), and total visual scores (r = -.388, p = .005), indicating that higher sensory processing difficulties in vision (low score) correspond with higher visual function scores (more difficulties). Vestibular processing in the SP negatively correlates with motion perception (r = -.290, p = .041) and visual recognition (r = -.280, p = .049).

3.2.1.5 Correlations Between Sensory Profile and CVI Ranges. Analysis of the relationships between CVI ranges and sensory profile domains reveals only one significant correlation. Modulation position activity domain show a moderate positive correlation with

CVI Range 1 ($r = 0.313$, $p = 0.028$), suggesting that higher scores in activity modulation, thus better modulation, are associated with better functioning in the CVI range.

Table 13
Correlation Between the SP and the Psychophysical Computerized Experiments

Sensory profile domain	Psychophysical Computerized Experiment						
	Oddball exp			Oddball gaze exp		Tracking	Video Clip
	Pcor	Pcor8	RT	Gaze error	Gaze OK	RT	
Touch processing	ns	ns	ns	Ns	ns	-.50**	ns
Vision processing	ns	ns	ns	-.32*	ns	ns	ns
Behavior response	ns	ns	ns	-.31*	-.31*	ns	ns
Modulation muscle	ns	ns	ns	-.42**	-.37*	ns	ns
Registration	ns	ns	ns	-.34*	ns	ns	ns

Note. *$p < .5$, **$p < .01$.

Table 13 presents correlations between sensory profile domains and performance on computerized psychophysics visual experiments. Several significant associations emerged. Greater difficulty in the SP touch domain, correlated negatively with increasing error rates in the video clip task ($r = –.50$, $p = .01$), indicating that greater difficulties with tactile input were linked to poorer accuracy in dynamic visual scenes. Greater difficulty in the SP vision processing domain showed a modest negative correlation with increased gaze error in the tracking task ($r = -.32$, $p = .036$). Increased difficulty in the SP behavioral responses domain, was significantly associated with both tracking error ($r = -.31$, $p = .047$) and video clip accuracy ($r = -.31$, $p = .045$), suggesting that difficulties in regulating behavior co-occur with challenges in sustaining accurate visual responses. Similarly, modulation of muscle

tone domain correlated with tracking (r = –.42, p = .006) and video clip performance (r = -.37, p = .015), highlighting the link between sensory–motor modulation and dynamic visual engagement. Finally, SP registration quadrant difficulties, correlated with tracking error (r = -.34, p = .03), whereas no significant associations were observed with the other tasks. Together, these results demonstrate that multiple sensory processing domains and pattern, particularly touch, modulation, and behavioral responses are systematically linked with visual task performance, supporting the view that sensory processing and modulation difficulties contribute to visual challenges in children with CP-CVI.

Table 14

Sensory Profile and Functional Classification Systems Correlations in the CP-CVI Group

Sensory profile domain	**Functional classification**				
	GMFCS	MACS	CFCS	VFCS	EDACS
Processing/muscle modulation	**–.44*****	**–.45*****	**–.38****	**–.42****	ns
Activity modulation	**–.38****	**–.41****	ns	**–.38****	**–.30***
Behavioral response	**–.36****	**–.34***	ns	**–.33***	ns
Sensory registration	**–.34***	**–.33***	ns	**–.32***	ns

Note. * $p < .5$, ** $p < .01$, ***$p < .001$.

Analysis of relationships between functional classification systems and sensory processing patterns reveals several significant correlations. Muscle modulation processing demonstrates strong negative correlations with multiple functional classifications: GMFCS (r = -.443, p = .001), MACS (r = -.451, p = .001), CFCS (r = -.381, p = .006), and VFCS (r = -.421, p = .002), indicating that children with greater functional limitations across motor, manual, communication, and visual domains experience more difficulties with muscle-based sensory processing. Activity modulation similarly shows significant negative correlations with GMFCS (r = -.375, p = .008), MACS (r = -.406, p = .004), VFCS (r = -

.376, p = .008), and EDACS (r = -.304, p = .034), suggesting that children with more severe functional impairments have greater challenges regulating activity levels. Behavioral results correlate negatively with GMFCS (r = -.359, p = .010), MACS (r = -.337, p = .016), and VFCS (r = -.325, p = .020), while sensory registration shows similar negative correlations with GMFCS (r = -.342, p = .014), MACS (r = -.333, p = .017), and VFCS (r = -.315, p = .024). No significant correlations emerged between functional classifications and other sensory processing domains. These findings highlight the specific relationship between functional abilities and sensory processing, particularly in domains related to motor control, activity regulation, and sensory registration

3.2.2 Hypothesis 2: Correlations Between Visual Objective and Subjective Measures

Hypothesis 2 proposed that subjective and objective measures of visual processing would be significantly correlated, thereby contributing to the validation of these measures. The findings presented in this chapter support this hypothesis, showing that several visual performance parameters from the four psychophysics computerized assessments were significantly correlated with both subjective and functional visual measures. The subjective and functional tools included the CVI Range, the VFCS (conducted by the researcher), and the IIQ (completed by parents). Meaningful associations were found across multiple domains, highlighting the complementary value of combining objective and subjective assessments. The correlation results are organized and presented across the four computerized visual assessments in a Matrix figure, providing an integrative view of how objective performance aligns with functional visual abilities in everyday life. The Pearson correlation measures (R) are shown in the lower part of the correlation table, while the p values (FDR-corrected for multiple comparisons) are shown in their upper part. Significant correlation values are denoted in red, with the standard star notation. The regression lines represent “orthogonal regression”, and outliers (> 3 *SD*) were excluded from the correlation calculation. Each dot represents one child. Notably, the correlations were computed with

Pearson's *r* (lower triangle of the matrix) and corrected *p* values (upper triangle), and regression lines were derived using orthogonal regression. Outliers beyond 3 *SD* were excluded.

Figure 28

Correlation Matrix of Oddball Discrimination by Pointing Variables With CVI Range, VFCS, IIQ

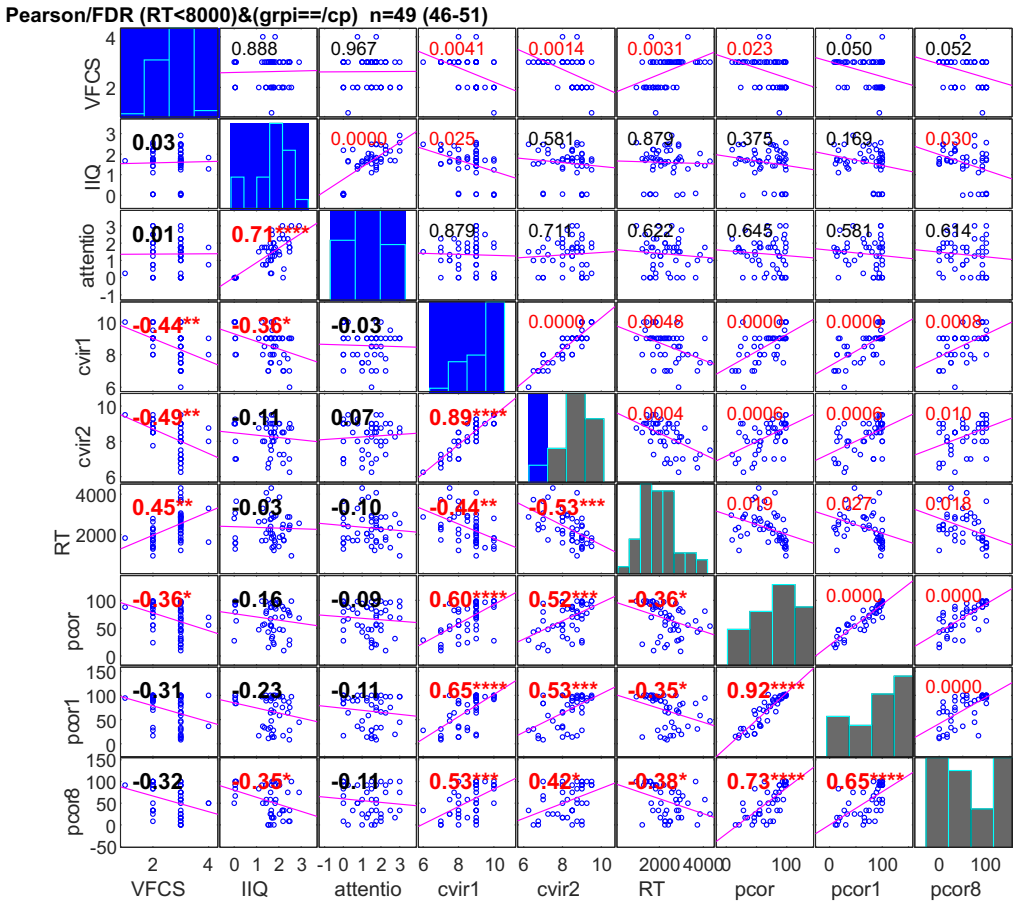


Figure 28 (matrix) and the subject-level distributions (dist. figures) show that mean accuracy across all trials mean (pcor) correlated with VFCS ($r = .36$, $p < .01$), CVI Range 1

(r = .60, p < .001), and CVI Range 2 (r = .52, p < .01). Accuracy in the color condition (pcor1) correlated with CVI Range 1 (r = .65, p < .001) and CVI Range 2 (r = .53, p < .01). Under complex background (pcor8), performance was associated with IIQ mean score (r = .35, p < .01), CVI Range 1 (r = .53, p < .001), and CVI Range 2 (r = .42, p < .01). Reaction time correlated with VFCS (r = .45, p < .01), CVI Range 1 (r = .44, p < .01), and CVI Range 2 (r = .53, p < .01), highlighting RT as a sensitive indicator of function in daily life.

Figure 29

Correlation for Oddball Discrimination Via Gaze–With CVI Range, VFCS, IIQ

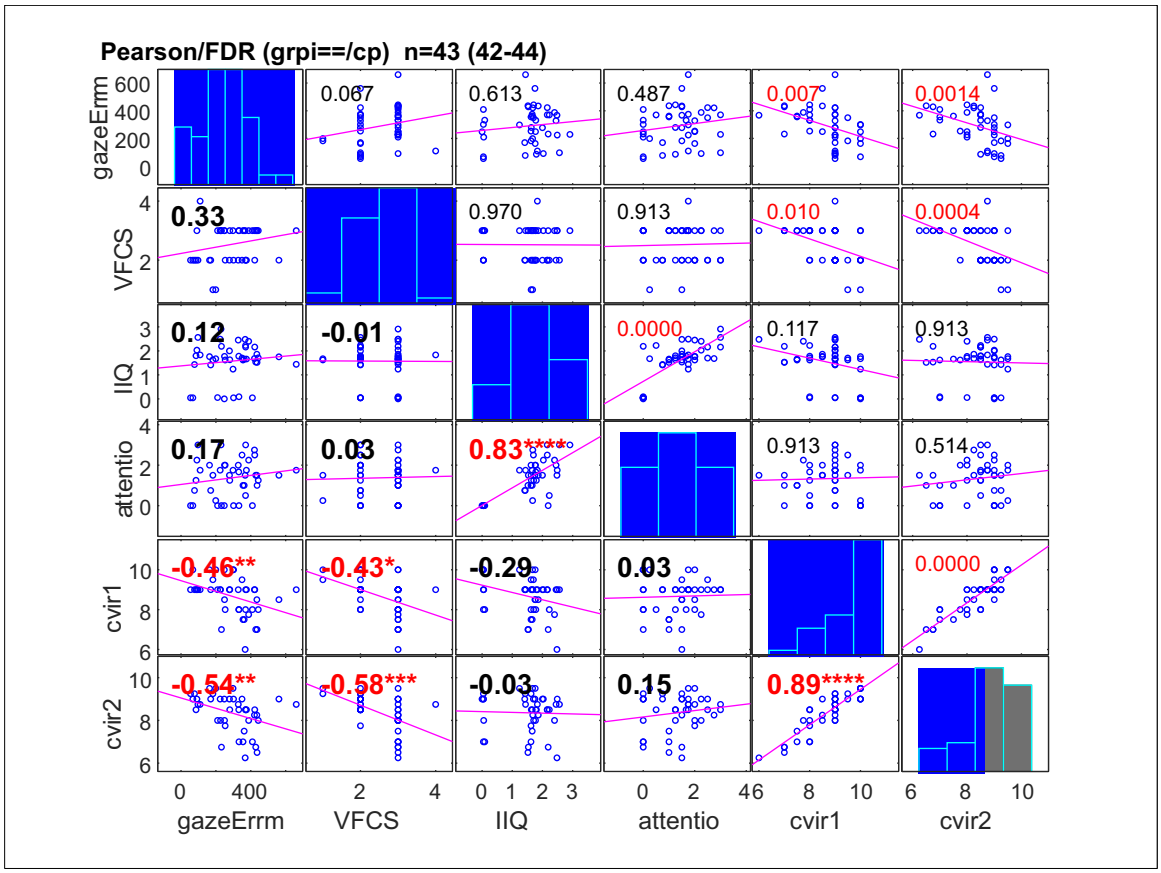


Figure 29 presents the correlation matrix for gaze-based oddball discrimination. Gaze error to the visual target correlated significantly with CVI Range 1 (r =.46, p < .01) and CVI Range 2 (r = .54, p < .01). No significant correlations were observed with VFCS or IIQ scores, suggesting that gaze-based oddball detection is specifically aligned with visual efficiency captured by the CVI Range in a clinical setting, rather than broader clinical or parent-reported outcomes.

Figure 30

Correlation of Eye Tracking Variables With CVI Range, VFCS, IIQ

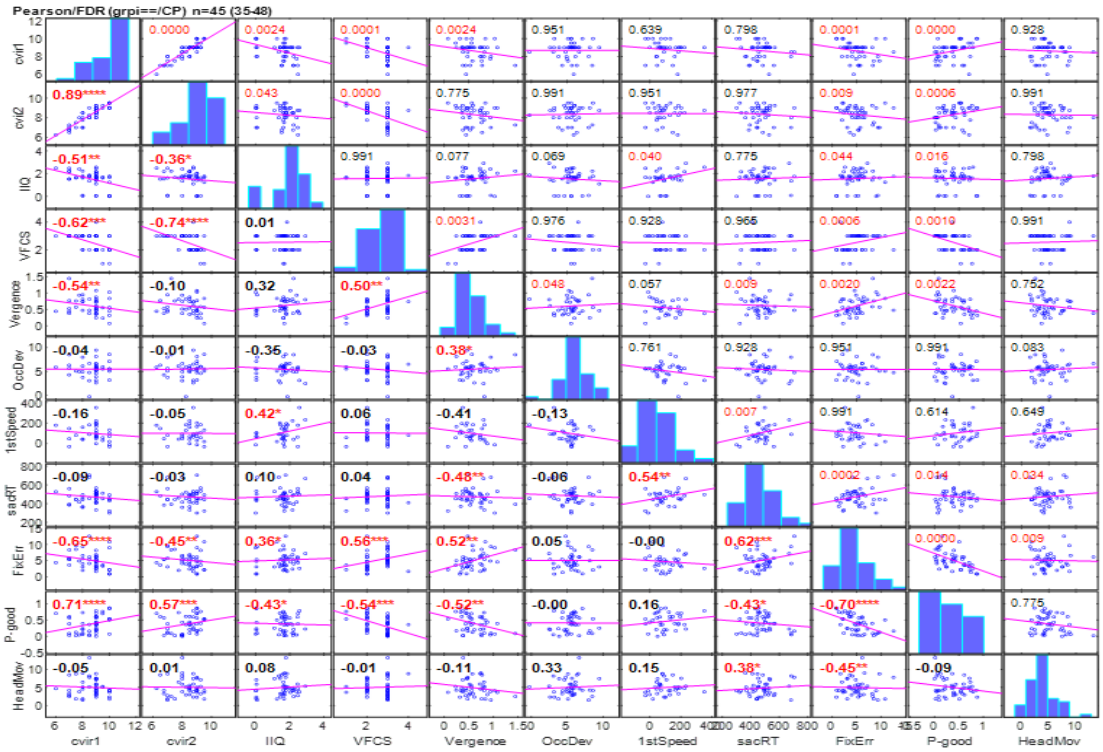


Figure 30 presents the correlation matrices between computerized eye-tracking measures and clinical assessments of visual function (CVI Range, VFCS, IIQ). Several significant associations were observed. CVI Range 1 and 2: Strong negative correlations were found with error rates in pursuit (FixErr; r = -.65, p < .001; r = -.45, p < .01) and (P-

good; r = -.71, p < .0001; r =-.57, p < .001), and CVI Range 2 also correlated with Vergence (r = -.54, p < .01). The correlation indicates that higher CVI Range scores (better functional vision) associated with more accurate oculomotor control. Higher VFCS (greater visual impairment) significantly associated with poorer performance on motion-related measures, including P-good (r = -.54, p < .001) and FixErr (r = -.56, p < .01). IIQ mean score, correlated positively with several eye-tracking outcomes, including gaze accuracy P-good (r =.43, p < .05) and pursuit performance (1ststpeed; r =.42, p < .01), supporting the convergent validity of the IIQ with objective measures. Collectively, these results indicate that pursuit and oculomotor quality are closely tied to functional vision.

Figure 31

Correlation of Gaze Patterns and Oculomotor Variables During Video Viewing With VFCS, CVI Range and IIQ

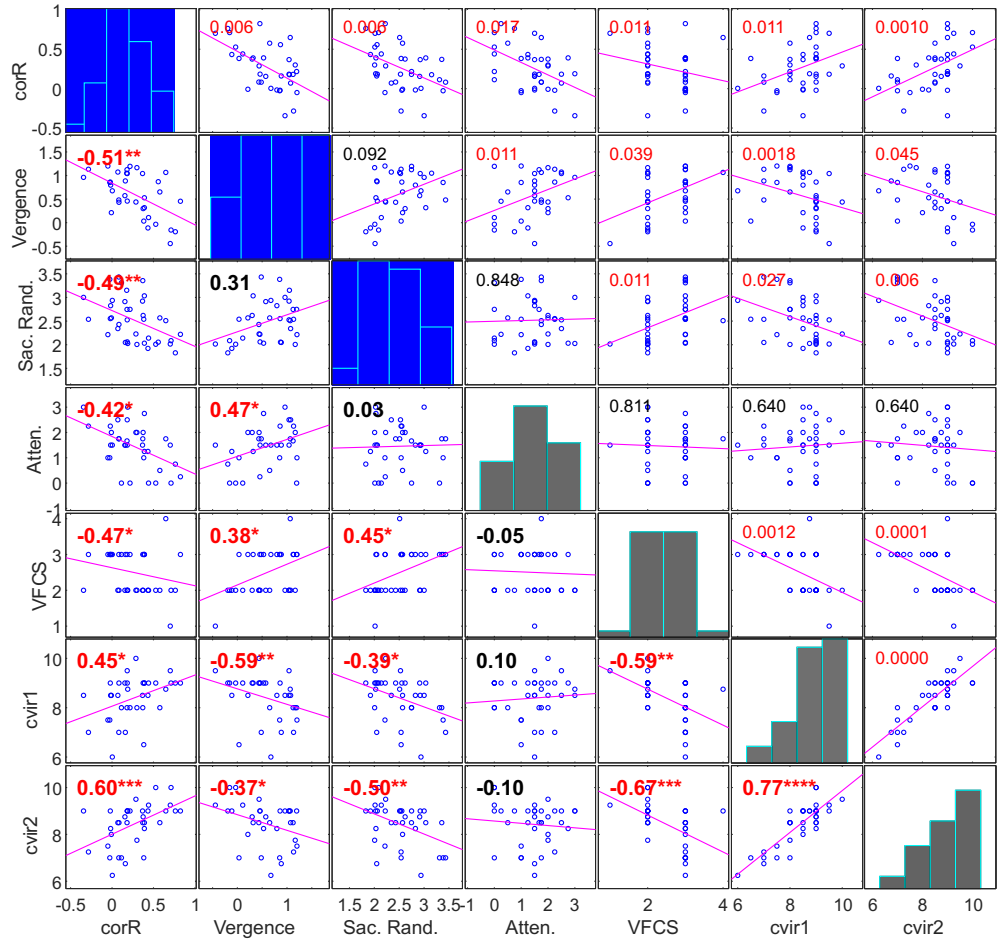


Figure 31 presents the correlation matrix between three oculomotor indices during naturalistic video viewing-correlation-to-mean gaze trajectory (CorR), vergence stability, and saccadic randomness (SacRand), and functional measures (VFCS, CVI Range 1, CVI Range 2 Attention subscale of IIQ). Correlation-to-mean (CorR) showed significant associations with VFCS ($r = .47$, $p < .01$), CVI Range 1 ($r = .45$, $p < .01$), and CVI Range 2 ($r = 0.60$, $p < 0.001$). Vergence stability was also significantly correlated with VFCS ($r = .38$, $p < 0.01$), CVI Range 1 ($r = .59$, $p < .001$), and CVI Range 2 ($r = .37$, $p < .001$). Saccadic randomness (SacRand) demonstrated significant correlations with VFCS ($r = .45$, $p < .01$), CVI Range 1 ($r = .39$, $p < .01$), and CVI Range 2 ($r = .50$, $p < .001$). In addition, both CorR and vergence were significantly associated with the IIQ Attention subscale ($r = .42$, $p < .01$; $r = .47$, $p < .01$), linking naturalistic oculomotor dynamics with parent-reported attentional functioning.

In summary, across all four psychophysical experiments, convergent patterns of association were observed between computerized visual performance and established functional measures (VFCS, CVI Range, and IIQ). The oddball paradigms (Experiments 1–2) demonstrated that both manual and gaze-based discrimination accuracy were significantly linked with CVI Range levels, while reaction time emerged as a sensitive correlate of VFCS and daily functional capacity. Eye-tracking measures during pursuit (Experiment 3) revealed robust correlations with both CVI Range 2 and parent-reported IIQ scores, underscoring the clinical relevance of oculomotor control and head movement as indicators of functional vision. Finally, naturalistic video viewing (Experiment 4) showed that global gaze coordination (CorR), vergence stability, and saccadic randomness each correlated with VFCS and CVI Range, with additional associations to IIQ Attention, directly linking laboratory-derived indices to everyday attentional functioning.

Together, these findings validate the psychophysical battery as a sensitive and ecologically meaningful tool for quantifying visual processing in children with CP-CVI.

Importantly, the convergence between objective and subjective assessments suggests that these computerized tasks capture functional aspects of vision that are observable in daily life and relevant to family perspectives. This integrative framework provides a solid foundation for examining, in the following section, how visual processing capacities relate to participation and QOL outcomes (Hypothesis 3).

3.2.3. Hypotheses 3: Correlations Between Visual Processing/CVI measures and SPD, Participation, and QOL

This section presents a comprehensive analysis of participation and QOL among children with CP-CVI, in line with Hypothesis 3. The chapter begins by comparing participation levels, environmental support, and QOL between the CP-CVI group and a neurotypical control group. The findings indicate significantly reduced participation and QOL, alongside limited environmental support, in the CP-CVI cohort. Next, the chapter explores the relationships between visual functioning and outcomes in participation and QOL. Correlational analyses are conducted between computerized objective visual measures, functional assessments from the IIQ, and CVI Range scores, with both participation and QOL indicators. Additionally, associations between these visual measures and functional classification systems (GMFCS, MACS, CFCS, VFCS, EDACS) are examined to provide a more integrated understanding of functional status. This sequential analytical approach forms the basis for the subsequent predictive modeling, aimed at identifying the contribution of visual and sensory functions to participation and QOL outcomes in children with CP- CVI.

3.2.3.1 Comparison of QOL Between Children With CP-CVI and Neurotypicals

To identify differences in QOL measures between the groups, Mann-Whitney U tests were performed. The results of these analyses are presented in Table 15.

Table 15
PedsQL Domain Differences Between Typical Group and CP

PedsQL domain	CP-CVI group (*n* = 51)			Control group (*n* = 48)			*Z*	*r*
	M (*SD*)	IQR	*Mdn*	*M* (*SD*)	IQR	*Mdn*		
Physical	24.2(16.05)	12.50	20.30	96.10 (8.40)	5.47	100.00	-28.16***	2.83
Emotional	59.7(16.14)	16.25	60.00	80.06 (18.00)	25.00	90.0	-5.91***	.59
Social	39.62(19.13)	25.00	37.50	94.92 (8.90)	6.25	100.00	-18.61***	1.87
School	58.2(16.71)	25.00	57.50	86.97 (14.01)	20.00	90.00	-9.30***	.93
Psycho-social	52.5(10.70)	12.60	49.79	88.65 (11.61)	12.71	91.25	-16.08***	1.62

Note. M = mean; IQR = interquartile range; *Mdn* = median; *z* = Z score; *r* = effect size.
***$p < .001$.

Table 15 shows statistically significant differences between the CP-CVI and control groups in all PedsQL domains ($|Z| > 1.96$). The effect sizes are very large across all domains ($r > .5$) with the Physical functioning domain shows the largest difference ($Z = -28.16$, $r = 2.83$). The Emotional functioning domain, while still significant, shows a relatively smaller difference compared to other domains ($Z = -5.91$, $r = .59$). These results provide strong evidence of substantial differences in health-related QOL between the two groups.

3.2.3.2 Comparison of Participation Levels Between Children With CP-CVI and Neurotypical Children

To identify differences in participation measures between the groups, Mann-Whitney U tests were performed. The results are presented in Tables 16 and 17.

Table 16 presents the comparison of general differences in participation between the two groups. Most comparisons show medium to very large effect sizes. The strongest effects are seen in: The desire for change in the community ($r = -.70$), community participation involvement ($r = -.69$), and community participation frequency ($r = -.65$). The negative *r* values indicate lower scores in the CP-CVI group for participation compared to the controls.

Table 16

Comparison of Differences in Participation Measures Between the Two Groups in PEM-CY Assessment Across Environments

PEM-CY domain	CP-CVI group (*n* = 51)			Control group (*n* = 48)			*z*	*r*
	M (*SD*)	IQR	*Mdn*	*M* (*SD*)	IQR	*Mdn*		
Home								
Participation number (0–10)	8.24 (2.75)	2.00	8.0	9.23 (1.50)	2.0	10.0	-3.49***	-.35
Participation frequency (0–7)	4.61 (1.14)	1.80	4.8	5.76 (0.97)	1.5	5.9	-4.79***	-.48
Participation involvement (0–5)	2.87 (0.77)	1.10	2.9	4.21 (0.70)	1.3	4.5	-6.50***	-.65
Desire for change (0–10)	5.91 (2.24)	2.00	6.5	2.46 (2.43)	5.0	2.0	-5.76***	-.58
School								
Participation number (0–5)	3.60 (0.80)	1.00	4.0	4.25 (0.87)	2.0	5.0	-3.41***	-.34
Participation frequency (0–7)	3.83 (0.90)	1.40	3.8	4.68 (1.19)	1.8	4.4	-3.38***	-.34
Participation involvement (0–5)	3.08 (0.93)	1.20	3.0	3.95 (0.96)	2.0	4.0	-3.86***	-.39
Desire for change (0–5)	2.30 (1.62)	3.00	2.0	0.48 (1.07)	0	0	-5.59***	-.56
Community								
Participation number (0-–0)	5.02 (1.80)	2.50	5.0	7.93 (1.68)	2.0	8.0	-6.30***	-.63
Participation frequency (0–7)	2.02 (0.81)	1.20	1.9	3.67 (1.08)	1.4	3.6	-6.56***	-.66
Participation involvement (0–5)	1.99 (0.77)	1.25	1.9	3.62 (0.86)	1.3	3.8	-6.90***	-.69
Desire for change (0–10)	5.43 (2.16)	3.00	5.0	1.28 (1.97)	2.0	0	-6.96***	-.70

Table 17

Comparison of General Differences in Environmental Support Measures Between the Two Groups in PEM-CY Assessment Across Environments

PEM-CY domain	CP-CVI group (*n* = 51)			Control group (*n* = 48)			*Z*	*r*
	M (*SD*)	IQR	*Mdn*	*M* (*SD*)	IQR	*Mdn*		
Home								
Environment support	3.97 (1.46)	2	4	6.65 (0.89)	0	7	-7.51***	-.75
Environment barrier	3.02(1.46)	2	3	0.34 (0.89)	0	0	-7.51***	-.75
Environment resources support	2.85 (1.39)	2	3	2.60 (1.64)	3	3	-0.51***	-.05
Environment resources barrier	1.71 (1.39)	1	1	0.25 (0.49)	0	0	-5.96***	-.60
School								
Environment support	6.00 (2.40)	4	6	8.30 (1.20)	1	9	-5.42***	-.54
Environment barrier	3.00 (2.40)	4	3	0.65 (1.20)	1	0	-5.42***	-.54
Environment resources support	5.75 (1.60)	2	6	3.97 (2.54)	4	4	-3.56	-.36
Environment resources barrier	1.40 (1.73)	2	1	0.40 (0.76)	1	0	-3.42***	-.34
Community								
Environment support	4.02 (2.10)	3	4	8.58 (1.00)	0	9	-7.99***	-.80
Environment barrier	4.97 (2.10)	3	5	0.41 (1.00)	0	0	-7.99***	-.80
Environment resources support	3.00 (1.24)	2	3	4.37 (2.50)	5	5	-3.32***	-.33
Environment resources barrier	3.30 (1.22)	1	3	0.30 (.63)	0	0	-8.04***	-.81

Table 17 presents the comparison of general differences in environment support measures between the two groups in PEM-CY assessment across environments. Most comparisons show medium to very large effect sizes. The strongest effects are seen in: community environment resource barriers (r = -.81), community environment

support/barriers (r = -.80), and home environment support/barriers (r = -.75). Only one comparison shows a negligible effect size: home environment resources support (r = -.05), indicating no significant difference between the groups on this measure. The negative r values indicate lower scores in the CP-CVI group for supportive measures and higher scores for barrier measures compared to the control group.

3.2.3.3 Correlations Between Visual Processing and CVI Measures (Computerizes, IIQ, CVI Range), Sensory Profile and Functional Classifications With Participation and QOL in the CP-CVI group

Table 18 correlation analysis reveals several significant relationships between PEM-CY variables and IIQ subscores. In the home setting, both participation frequency (r = .281, p = .048) and number of participation activities (r = .338, p =.016) positively correlate with visual attention, suggesting children with better visual attention engage more frequently in home activities. The community setting shows the strongest correlations, with environmental resource support positively correlating with visual recognition (r = .421, p = .002) and visual recognition under specific conditions (r = .388, p = .005). Conversely, environmental barriers in the community negatively correlate with complex visual processing (r = -.288, p = .045), visual recognition (r = -.370, p = .008), and visual recognition under specific conditions (r = -.379, p = .007). These findings suggest that environmental factors, particularly in community settings, may significantly influence visual processing abilities in children, with supportive environments enhancing visual recognition and barriers potentially hindering visual processing. School-related variables showed no statistically significant correlations with visual measures, though several approached significances.

Table 18

Correlations Between PEM-CY Domains and IIQ Scores

PEM-CY domain	IIQ				
	Visual attention	Visual recognition	Specific conditions/ recognition under	Complex visual processing	Total IIQ score
Home					
Participation frequency	**.28***	ns	ns	Ns	ns
Number of activities	**.34***	ns	ns	Ns	ns
Community					
Environmental resources support	ns	**.42****	**.39****	Ns	ns
Environmental barriers	ns	**–.37****	**–.38****	**–.29***	ns

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 19

Correlation Between PEM-CY and Visual Psychophysical Computerized Experiments

PEM-CY domain	Oddball exp			Oddball gaze exp	Track	Video clip
	Pcor	Pcor8	RT	Gaze error		IGR
Home						
Change desire	ns	ns	ns	**.48*****	Ns	ns
Participation number	ns	ns	**-.31****	ns	Ns	ns
Participation frequency	ns	ns	**-.30****	ns	Ns	ns
Participation involvement	ns	ns	**-.39*****	ns	Ns	ns
Environmental barriers	**.41*****	ns	ns	ns	Ns	ns
School						
Change desire	ns	ns	ns	**.31***	Ns	ns
Environmental barrier	ns	ns	ns	**.26***	Ns	ns
Participation frequency	ns	ns	ns	ns	Ns	**.49***
Community						
Change desire	ns	ns	**.36****	ns	Ns	ns

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 19 revealed several significant associations. At home, greater visual gaze error in the oddball gaze experiment correlated with stronger parental reports of the child's desire for change ($r = .48$, $p = .00016$), suggesting that difficulties in visual attention may increase parental perception of unmet needs. Within the tracking task, poorer reaction times correlated with fewer participation activities ($r = -.31$, $p = .01$), lower frequency of participation ($r = -.30$, $p = .01$), and reduced involvement ($r = -.39$, $p = .001$). Conversely,

barriers at home correlated positively with performance in the oddball experiment (r = .41, p = .001), indicating that children facing more environmental obstacles also showed greater difficulties in discriminating visual stimuli. At school, the oddball gaze error correlated positively with parents' perception of the child's desire for change (r = .31, p = .047). A trend-level association was also observed between gaze error and school environmental barriers (r = .26, p = .094). Importantly, the video clip task showed a significant positive correlation with school participation frequency (r = .49, p = .019), suggesting that more adaptive visual scene processing may support greater engagement in the school setting. In the community domain, tracking performance was associated with parents' reported desire for change (r = .36, p = .01), highlighting the interplay between visual task performance and participation aspirations.

Table 20

PEM-CY and Sensory Profile Correlations in the CP-CVI Group

PEM-CY domain	Sensory profile domain					
	Sensory seeking	Sensory avoiding	Vision processing	Body movement modulation	Behavioral responses	Registration
Home						
Participation frequency	**-.27 ***	ns	**-.26***	ns	Ns	ns
Participation number	ns	ns	ns	**.29***	Ns	ns
Environment resources support	ns	**.39****	ns	ns	Ns	ns
School						
Involvement	ns	ns	ns	ns	**.30***	ns
Environment resources support	ns	ns	ns	ns	Ns	ns
Desired changes	ns	ns	ns	ns	**.35****	ns
Environmental barriers	**-.28***	ns	ns	ns	**.31***	**-.29***
Community						
Participation frequency	ns	ns	ns	ns	**.28***	ns

Note. *p < .05, **p < .01, ***p < .001.

Table 20 correlation reveals several significant relationships between sensory profile patterns and PEM-CY. In the home environment, frequency of participation negatively correlates with sensory-seeking in SP (r = -.267, p < .05), number of participation activities negatively correlates with vision processing in SP (r = -.264, p<.05), home support positively correlates with body movement modulation in SP (r = .286, p < .05), and environmental barriers strongly correlate with avoiding in SP (r = .392, p < .01). For school settings, behavioral responses in SP positively correlate with school involvement (r = .296, p < .05) and support (r = .354, p < .05), while desired changes in school participation show negative correlations with registration (r = -.286, p < .05), emotional modulation (r= -.386, p < .01), and visual-emotional modulation (r = -0.408, p < .01) in SP. School environmental resource support correlates with behavioral results in SP (r = 0.306, p < .05), and environmental barriers correlate with seeking (r = -.276, p < .05) and multisensory processing (r = .279, p < .05) in SP. In community environments, involvement negatively correlates with hearing processing in SP (r = -.294, p < .05), desired changes negatively correlate with multisensory processing in SP (r = -.373, p < .01), and environmental resource barriers positively correlate with multisensory processing in SP (r = .384, p < .01). Additionally, activity modulation shows significant correlations with community frequency (r = -.334, p< .05), while behavioral responses correlate with community number of participation activities (r = .277, p < .05). The strongest correlations appear between sensory avoiding and home barriers (r = .392, p < .01), visual-emotional modulation and school desired changes (r = -.408, p < .01), and multisensory processing and community environmental barriers (r = .384, p < .01), suggesting that sensory processing significantly impacts participation across various environments in distinct ways. The complex pattern of correlations indicates that sensory processing abilities play an important role in children's participation across home, school, and community contexts.

Table 21

Correlations Between PEM-CY and Functional Classifications in CP-CVI Group

PEM-CY domain	CP functional classification				
	GMFCS	MACS	CFCS	VFCS	EDACS
School					
Environmental support	ns	.29*	ns	ns	ns
Environmental resources	ns	ns	.30*	ns	ns
Environmental barriers	ns	ns	-.28*	ns	ns
Community					
Participation involvement	ns	-.28*	.29*	ns	ns

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 21 analysis reveals limited but notable relationships between functional classification systems in CP (GMFCS, MACS, CFCS, VFCS, EDACS) and PEM-CY. The MACS shows a significant negative correlation with involvement in community activities (r = -.278, p = .048) and a positive correlation with school support (r = .294, p = .036), suggesting that children with more limited manual abilities experience less involvement in community activities but receive more support in school environments. The CFCS also correlates significantly with school support (r = .289, p = .040), environmental resource support at school (r = .303, p = .031), and negatively with environmental barriers at school (r = -.276, p = .050), indicating that children with more severe communication limitations receive greater support in school settings. No significant correlations were found between any functional classification system and home participation measures, nor between the GMFCS, VFCS, or EDACS and community participation variables. These findings suggest that school environments may be more responsive to functional limitations than community settings.

Table 22
Correlations Between PedQL and IIQ Domains

PedsQL domain	IIQ				
	Total IIQ score	Body movement	Visual field perception	Complex visual processing	Navigation
Emotional QOL	ns	.34*	Ns	Ns	ns
Social QOL	-.30*	ns	-.22 trend	-.25 trend	-.27 trend

Note. *$p < .05$, **$p < .01$, ***$p < .001$.

Table 22 presents a few significant correlations: emotional QOL and body Movement: There is a significant positive correlation between emotional QOL domain and the body movement subscores of the IIQ ($r = .342$, $p = .015$). Thus, children with better emotional well-being (as reported by mothers) demonstrate better visual-motor coordination. Social QOL and overall visual function: A significant negative correlation exists between social QOL domain and the total IIQ score ($r = -.297$, $p = .036$). This finding indicates that children with higher social quality of life (as reported by mothers) tend to have lower scores on overall visual function measures, which could suggest different patterns of visual processing in children with stronger social skills. Furthermore, though not reaching statistical significance, there are notable negative correlation trends between social QOL and several visual measures, including visual field perception ($r = -.221$), complex visual processing ($r = -.254$), and navigation ($r = -.265$).

Table 23
Correlation Between QOL and Psychophysical Computerized Experiments

PedsQL domain	**Computerized experiment**						
	Oddball			Oddball gaze	Tracking	Video clip	
	Pcor	Pcor8	RT	Gaze error		Vergence	
QOL total score	ns	ns	ns	.39***	ns	Ns	ns
Social QOL	ns	ns	ns	.35*	ns	Ns	ns
Physical QOL	0.42***	0.43***	-0.42***	.31*	ns	Ns	ns
Emotional QOL	ns	ns	ns	ns	ns	.43*	ns

Table 23 presents the correlations between QOL domains and the computerized psychophysical experiments. Significant associations emerged mainly in the physical domain. Higher accuracy in both oddball tasks (r = .42, p = .001; r = .43, p = .001) and reduced tracking reaction time (r = –.42, p = .001) were all correlated with better physical QOL, while increased gaze error in the oddball gaze task was also linked to lower physical QOL (r = .31, p = .049). The total QOL score correlated positively with gaze error (r = .39, p = .0012), and social QOL showed a similar positive correlation (r = .35, p = .023). Finally, emotional QOL was positively associated with vergence performance in the video clip task (r = .43, p = .042).

Table 24

Correlation Between PedsQL and Sensory Profile Domains in the CP-CVI Group

PedsQL domain	SP domain and quadrant					
	Vision processing	Vestibular processing	Touch processing	Seeking quadrant	Avoiding quadrant	Behavioral responsiveness
Emotional functioning	ns	ns	Ns	ns	ns	.33*
Social functioning	.29*	.37**	.28*	.30*	.41**	.38**
Psychosocial QOL	.36**	.42**	.45***	.42**	.41**	.47***
Total QOL score	ns	ns	Ns	.36**	.39**	.38**

Note. *p < .05, **p < .01, ***p < .001.

Table 24 analysis reveals significant relationships between sensory profile domains and PedsQL domains as reported by the parents. Vision, vestibular, and touch processing domains in the SP show positive correlations with multiple PedsQL domains, particularly social functioning (r = .292, p = .038; r = .372, p = .007; r = 0.282, p = .045, respectively) and overall psychosocial (r = .358, p = .010; r = .418, p = .002; r = 0.450, p = 0.001, respectively) domains. Among sensory profile quadrants, both seeking and avoiding demonstrate

significant positive correlations with social functioning (r = .304, p = .030; r = .409, p = .003), psychosocial (r = .420, p = .002; r = .407, p = .003) domains, and PedsQL total score (r = .360, p = .009; r = .386, p = .005). Behavioral responsiveness domain in the SP, shows strong positive correlations with emotional functioning (r = .333, p = .017), social functioning (r = .381, p = .006), psychosocial (r = .467, p = .001) domains, and total score (r = .383, p = .006) in the PedsQL. These findings suggest that children's sensory processing domains, particularly those related to vision and vestibular processing, as well as their sensory-seeking and avoiding patterns, may significantly influence their QOL across various domains as perceived by their parents.

Table 25
Correlation Between PedsQL and Functional Classifications in the CP Group

PedsQL domain	CP functional classification				
	GMFCS	MACS	CFCS	VFCS	EDACS
Physical QOL	-.61***	-.49***	-.40**	-.34*	-.35**

Note. *p < .05, **p < .01, ***p < .001.

Table 25 analysis of relationships between functional classification systems and quality of life measures reveals that physical QOL demonstrates strong negative correlations with all functional classification systems: GMFCS (r = -.607, p < .001), MACS (r = -.493, p < .001), CFCS (r = -.397, p = .004), VFCS (r = -.339, p = .015), and EDACS (r = -.353, p = .011). These consistent correlations indicate that children with greater functional limitations across gross motor, manual, communication, visual, and eating/drinking domains experience significantly poorer physical quality of life as reported by mothers. Notably, no significant correlations emerged between any of the functional classifications and emotional, social, school, psychosocial, or total QOL measures, suggesting that while functional limitations strongly impact physical well-being, they may not have as direct an influence on psychosocial aspects of QOL in this population.

3.2.4. Hypotheses 4: Visual Processing/CVI Measures, and SPD Predict Participation and QOL in the CP-CVI Group

We hypothesized that visual processing and CVI measures, and SPD would predict participation and QOL levels in children with CP-CVI. Regression analyses were performed to identify the main predictors of participation and QOL. Variable selection was based on both statistical and clinical reasoning. Predictors showing significant correlations with participation or QOL were entered, together with additional variables of theoretical importance within the ICF and PEOP frameworks. Due to relatively small sample size, stepwise regression models were conducted separately for functional classifications, visual–sensory processing, and environmental factors, with up to 10 to 12 predictors entered in each domain. Only variables that remained significant ($p < .05$) were retained in the final model. This combined empirical and theory-driven approach allowed identification of the key factors influencing participation and QOL among children with CP-CVI.

3.2.4.1 Participation Prediction

Three stepwise multiple regression models were performed to identify predictors of participation outcomes among children with CP-CVI, based on the PEM-CY questionnaire. Variables that showed significant correlations with the PEM-CY participation measures were entered into the regression models to determine the factors most strongly associated with participation and additional variables of theoretical importance were also added.

For the three regression analyses we enter the following variables: (1) GMFCS, (2) MACS, (3) VFCS–functional classifications, PEM-CY environmental domains (4) home environment resources barriers, (5) school environmental resources barriers, and (6) community environmental resources barriers. Vision IIQ domains of (7) attention, (8) perception of movement, (9) recognition and navigation, and SP domains of (10) vision and (11) behavior response and (12) seeking and (13) registration quadrants (the regression results are presented in Table 26).

Table 26

Stepwise Regression Analyses for Participation Domains in the CP–CVI Group

Assessment	Predictor domain	*β*	*T*	*p*
Dependent variable: Home participation number, $F(1,48) = 8.064$, $p < .007$, $R^2 = .144$				
IIQ	Visual attention	.379	2.840	.007
Dependent variable: Home participation frequency, $F(1,48) = 4.456$, $p < .04$, $R^2 = .085$				
IIQ	Visual attention	.291	2.111	.040
Dependent variable: School participation number, $F(3,43) = 8.375$, $p < .001$, $R^2 = 369$				
IIQ	Visual perception of movement	-.470	-3.700	.001
IIQ	Visual recognition and navigation	.506	3.843	.000
Functional classification	VFCS	-.361	-2.860	.007

Table 26 presents the results of the regression analyses identifying predictors of participation within the CP–CVI group. For participation at home prediction, IIQ attention domain emerged as a significant predictor. It explained 14.4% of the variance in the number of home activities, $F(1,48) = 8.064$, $p = .007$, $R^2 = .144$, and 8.5% of the variance in the frequency of home participation, $F(1,48) = 4.456$, $p = .040$, $R^2 = .085$. Higher visual attention score was associated with greater frequency and number of home participation activities ($\beta = .379$, $t = 2.84$, $p = .007$; $\beta = .291$, $t = 2.11$, $p = .040$, respectively).

For participation at school, the final regression model was significant, $F(3,43) = 8.375$, $p < .001$, $R^2 = .369$, accounting for 36.9% of the variance. Three predictors contributed significantly: IIQ-visual perception of movement domain ($\beta = -.470$, $t = -3.70$, $p = .001$), IIQ-visual recognition and navigation domain ($\beta = .506$, $t = 3.84$, $p < .001$), and VFCS ($\beta = -.361$, $t = –2.86$, $p = .007$).

Better scores of the IIQ domains of visual attention, recognition, and navigation, were associated with greater participation number of activities at school, whereas poorer

perception of movement domain and lower functional visual classification (VFCS) were linked with reduced school participation.

3.2.4.2 QOL Prediction

Four stepwise multiple regression models were performed to identify predictors of participation outcomes among children with CP-CVI, based on the PedsQL questionnaire. Variables that showed significant correlations with the PedsQL domains were entered into the regression models to determine the factors most strongly associated with QOL and additional variables of theoretical importance were also added.

For the four regression analyses we enter the following variables: (1) GMFCS, PEM-CY domains: (2) home environment resource barriers, (3) community environment resource support, (4) community participation frequency, (5) community desire for change, and (6) home participation number. SP domains entered were: (7) behavior response domain, (8) avoiding quadrant, and (9) seeking quadrant. The IIQ domains were (10) visual attention, (11) visual field, (12) visual guidance of movement, and (13) visual search. The regression results are presented in Table 27.

Table 27

Stepwise Regression Analyses for PedsQL Domains in the CP–CVI Group

Assessment	Predictor domain	*β*	*t*	*p*
Dependent variable: Physical QOL, $F(7,41) = 14.33$, $p < .001$, $R^2 = .71$				
Functional classification	GMFCS	-.544	-6.049	< .001
	Home environment resource barriers	.429	4.756	< .001
PEM-CY	Community participation frequency	.215	2.467	.018
	Community desire for change	-.262	-2.872	.002
IIQ domain	Guidance of movement	.393	3.695	< .001
	Visual search	-.324	-2.968	.005
PEM-CY	Home participation number	.197	2.245	.030
Dependent variable: Social QOL, $F([6,40) = 9.46$, $p < .001$, $R^2 = .587$				
SP	Emotional and social response	.388	3.562	< .001
PEM-CY	Community environment resource support	-.322	-3.011	.004
IIQ domain	Visual attention	.325	2.859	.007
SP	Seeking quadrant	.352	2.946	.005
IIQ domain	Visual filed	-.291	-2.779	.080
PEM-CY	Home environment resource support	-.309	-2.647	.012
Dependent variable: Emotional QOL, $F(3,46) = -5.597$, $p < .002$, $R^2 = .267$				
PEM-CY	Community environment resource support	-.308	-2.437	.019
IIQ domain	Guidance of movement	.286	2.261	.029
SP	Emotional and social response	.272	2.151	.037
Dependent variable: Total mean QOL, $F(4,44) = 6.302$, $p < .0.01$, $R^2 = 364$				
SP	Avoiding quadrant	.235	1.762	.085
PEM-CY	Community environment resource support	-.329	-2.707	.010
IIQ domain	Visual attention domain	.340	2.716	.009
SP	Seeking quadrant	.301	2.199	.033

Note: GMFCS = Gross Motor Function Classification System; IIQ = Insight Inventory Questionnaire; SP = Sensory Profile.

Table 27 presents the regression models identifying predictors of different domains of QOL in the CP-CVI group.

For physical QOL, the regression model was highly significant, explaining 71% of the variance ($R^2 = .71$). The strongest predictor was GMFCS ($\beta = -.544$, $t = -6.05$, $p < .001$), indicating that greater motor impairment was associated with lower physical QOL. Other significant predictors included PEM-CY domains, at home environmental barriers at home domain ($\beta = .429$, $p < .001$), and home participation number ($\beta = .197$, $p = .030$), community participation frequency ($\beta = .215$, $p = .018$), and community desire for changes ($\beta = -.262$, $p = .002$) domains. IIQ domains which found to predict QOL levels are visual guidance of

movement domain (β = .393, $p < .001$), and visual search domain (β = -.324, $p = .005$). These results suggest that better visual–motor guidance and fewer environmental barriers are associated with higher physical QOL, while increased desire for changes in community participation and poorer visual search relate to lower QOL.

For social QOL, the model was also significant, $F(6,40) = 9.46$, $p < .001$, explaining 58.7% of the variance ($R^2 = .587$). Significant predictors included SP domain-behavioral response (β = .388, $p < .001$), and sensory-seeking quadrant (β = .352, $p = .005$). IIQ predictor domains are visual attention domain (β = .325, $p = .007$), and visual field domain (β = -.291, $p = .008$). PEM-CY predictor domains found are community environmental resource support (β = -.322, $p = .004$) and home environmental resource support (β = -.309, $p = .012$) domains. Together, these findings highlight the contribution of sensory regulation, visual attention, and environmental support to social well-being.

For emotional QOL, the regression model was significant, $F(3,46) = 5.60$, $p = .002$, $R^2 = .267$. The main predictors were PEM-CY domain-environmental support in the community (β = -.308, $p = .019$), IIQ domain-visual guidance of movement (β = .286, $p = .029$), and SP domain-behavioral response (β = .272, $p = .037$). These results indicate that better visual-motor guidance and adaptive sensory responses are associated with improved emotional well-being, whereas limited environmental support in the community is related to lower emotional QOL. Finally, the model for total QOL was significant, $F(4,44) = 6.30$, $p < .01$, $R^2 = .364$, accounting for 36.4% of the variance. Significant predictors included IIQ domain of visual attention (β = .340, $p = .009$), sensory profile-seeking quadrant (β = .301, $p = .033$), and avoiding quadrant (β = .235, $p = .085$) approached significance, and PEM-CY included Community Environmental Support domain (β = -.329, $p = .010$). These findings suggest that stronger visual attention and sensory active patterns-seeking and avoiding are associated with higher overall QOL, whereas reduced community support relates to lower QOL levels.

Chapter 4: Discussion

4.0 Preface

Cerebral visual impairment is recognized as the most prevalent cause of visual dysfunction in children with CP, surpassing ocular causes (Chang et al., 2024; Dutton & Jacobson, 2001; Sakki et al., 2021). Unlike classical ocular impairments, CVI arises from dysfunction in the cerebral pathways and visual processing centers. Despite growing recognition and rapid advances in research (Gamage et al., 2024; Jayasinghe et al., 2025), CVI remains frequently underdiagnosed and misattributed to cognitive or attentional problems, particularly in children with CP (R. G. Bennett et al., 2025; Kılıç et al., 2025). Although some visual functions (e.g., oculomotor control, acuity, contrast sensitivity) may improve over time**,** children with CP-CVI often develop persistent higher-order perceptual deficits that become especially evident in school years (Galli et al., 2024). Prevalence estimates suggest that 60% to 80% of children with CP present with CVI (Boonstra et al., 2022; S. S. Philip et al., 2014), underscoring the urgent need for accurate assessment and intervention.

Assessment remains a central challenge. While recommendations often call for multidisciplinary batteries (Boonstra et al., 2022; McConnell et al., 2021; Pilling et al., 2022), these are rarely feasible in everyday practice. Existing tools do not always provide actionable information for intervention (Ben Itzhak et al., 2023; Manley et al., 2022). Thus, there is a pressing need for comprehensive yet practical methods that capture both functional vision and broader processing deficits. Furthermore, considering visual processing within the broader context of sensory processing difficulties in the CP population, appears essential. While the literature increasingly acknowledges that sensory processing challenges in children with CP may significantly influence daily activities (Dan et al., 2025; Pavão et al., 2021), most research has focused primarily on the somatosensory aspect (Hawe et al., 2020). Only recently have studies begun to expand this perspective by using comprehensive

tools such as the SP in the CP population (Mishra et al., 2020) and show a benefit combining sensory integration program within the CP population (Cemali et al., 2022).

Sensory processing has also been examined in children with visual impairments, emphasizing its links to social engagement and participation (Galiano et al., 2024). However, very few studies to date have explored the integrated sensory processing profile of children with co-occurring CP and CVI. The present study is among the first to apply the ICF-CY and PEOP frameworks to children with CP-CVI. Rather than focusing solely on prevalence, it examined how body-level dysfunctions in visual and sensory processing manifest in everyday activities, participation, and QOL. By integrating subjective (parent-report) and objective (computerized psychophysical) assessments, the study created a multidimensional profile of visual-sensory function. This approach validated new tools, highlighted patterns of co-occurrence between CVI and SPD, and demonstrated their combined impact on participation and QOL.

As hypothesized, significant differences emerged between CP-CVI and neurotypical children across all domains of visual function, sensory processing, participation, and QOL. Within the CP-CVI group, heterogeneity was evident in both visual and sensory profiles, as well as in how these domains interacted. These findings provide novel insight into the complex ways in which CVI and SPD co-occur, reinforcing the importance of addressing both together in clinical practice.

The remainder of this chapter is structured as follows. First, we address group differences in visual and sensory processing, highlighting the contributions of novel objective assessment tools and their clinical implications (Hypotheses 1 and 2). Second, we examine the associations between visual and sensory functions, functional classifications, participation patterns, and QOL outcomes (Hypothesis 3). Finally, we evaluate the predictive role of visual and sensory impairments, environmental support and barriers, and

functional classification levels in participation and QOL (Hypothesis 4) and conclude with implications for clinical practice and directions for future research.

4.1 Hypothesis 1 Part One: Visual Processing CP–CVI vs. Typically Developing Peers

Our first hypothesis proposed that children with CP-CVI demonstrate significant impairment in visual and sensory processing, relative to neurotypically developing peers- was strongly supported. Using an ICF and PEOP based, multimodal battery -including structured clinical observation, parent reported questionnaires, and novel psychophysics computerized tasks, we captured both body-level dysfunctions and their consequences for activities and participation. This multidimensional approach provided an ecologically valid profile of each child's visual-sensory abilities. Beyond confirming group differences, the results highlight three main themes. The first is a persistent dorsal-stream vulnerability in the CP-CVI group, thus, visual functions such as movement detection, space orientation or ability to detect figure in a complex scene, are more involved in comparison to color and figure recognition. The second is a context-dependence expression of visual difficulties, thus different tasks in different settings influence different visual processing. Last, a distinct sensory processing profile as registration quadrant, behavioral emotional-social responsiveness, and visual, auditory and vestibular domains that co-occurs in with visual impairment in the group of children with CP-CVI. Each of these findings carries important implications for theory, clinical assessment, and intervention.

4.1.1 Visual Processing in Children With CP-CVI

4.1.1.1 Visual Characteristics of the CP-CVI Group by CVI Range

The CVI Range served as a clinical anchor for understanding visual functioning in our CP-CVI group. Most children were classified within Phase III, characterized by relatively preserved low level order visual functions (e.g., light, color, simple recognition), but persistent difficulties with higher order domains such as distance viewing, visual complexity, and novelty response. Only two children fell in upper Phase II, indicating more

global visual impairments. This distribution reflects the established hierarchy of vulnerability in CVI. Lower-level visual functions, which depend primarily on the occipital cortex and ventral stream networks, often show partial recovery over time (Galli et al., 2024). In contrast, dorsal-stream mediated abilities such as simultaneous perception, movement perception, and spatial orientation, tend to remain impaired throughout childhood and into adolescence (Chandna et al., 2024; Manley et al., 2022). Neuroanatomically, these patterns align with the high prevalence of PVL and posterior white matter injury in children with CP, both of which disproportionately affect posterior parietal pathways (C. R. Bennett et al, 2020; Fazzi et al., 2004; Guzzetta et al., 2009).

Clinically, the CVI Range pinpointed which characteristics were resolved versus persistently fragile. This level of precision is rarely achievable with standard ophthalmological examinations, which tend to underestimate functional limitations in CP-CVI (Boonstra et al., 2022). Its feasibility depends on trained administration (Roman-Lantzy, 2018) but, when available, it adds the first fine-grained functional insight essential for intervention planning. Importantly, the heterogeneity of CVI Range scores across our sample in our study, reinforces the need for comprehensive, domain-specific assessments rather than reliance on a single classification of "visual impairment."

4.1.1.2 Visual Behavior by the Parent Reports (IIQ)

While the CVI Range captures structured observations at the body function level, the IIQ revealed an ecological perspective by reflecting parents' observations of visual behavior in everyday contexts. Across all domains, children with CP-CVI scored significantly higher than controls, with large effect sizes (r = .59–.89). The largest differences were found in search, guidance of movement, perception of movement, and attention, all of which correspond to higher-order visual–perceptual and attentional functions. These findings align with earlier reports that children with CP-CVI, even those with normal acuity, struggle with everyday visual-perceptual tasks (Hokken et al., 2025; Merabet et al., 2023, 2025; Ortibus

et al., 2012; Pamir et al., 2024). Parents described characteristic challenges such as difficulty locating objects in cluttered spaces, using vision to guide mobility, sustaining focus, and interpreting movement in the environment. These findings align with Ortibus et al. (2012) and Hokken et al. (2025), who reported that even children with normal acuity demonstrate real-world visual-perceptual limitations.

Interestingly, no significant correlation was observed between CVI Range and IIQ scores, despite both targeting high-order visual difficulties. However, rather than representing inconsistency, this is likely to reflect context-dependence. The CVI Range assesses body-level functions under structured, controlled conditions, whereas the IIQ captures how vision breaks down in complex, dynamic, real-world settings.

Parental awareness may also influence IIQ outcomes. Some parents in our study were highly attuned to subtle visual behaviors, while others reported few difficulties, possibly due to structured routines or limited exposure to visually demanding contexts. Furthermore, children at GMFCS IV–V levels also presented interpretation challenges: many IIQ items assume independent mobility, reducing sensitivity for nonambulant children. Despite these limitations, the IIQ remains valuable when interpreted alongside professional assessments and structured observation (Chandna et al., 2021; Dutton, 2015b; Macintyre-Beon et al., 2012;). Interpreted together, the CVI Range and IIQ offer a multilayered picture, controlled function versus ecological performance.

4.1.1.3 Visual Functions by Psychophysical Computerized Tasks

4.1.1.3.1 Oddball Discrimination Task: Hierarchy of Vulnerability. The oddball discrimination paradigm yielded one of the clearest functional profiles. The neurotypical children performed near ceiling (100%) accuracy across all discrimination conditions, with short reaction time which reduce with age as expected (Donnelly et al., 2007; Williams et al., 2015). In comparison, children with CP-CVI demonstrated progressively lower accuracy and longer reaction times as task demands increased, as previously reported (Zhang et al.,

2022). Performance was relatively preserved for color discrimination (~85%), declined for shape and 3D perception (~75%), and dropped further for size discrimination and figure-ground segregation in cluttered backgrounds (~58%–60%).

The oddball experiment was adapted from a paradigm originally designed to monitor visual perception recovery following cataract surgery in children (McKyton et al., 2015). By adding figures to 12 per trial (in comparison to six figures with the original group) and adding more visual aspects (Figure 6), we got a just the "right challenge," succeeding in detecting the group variability across the functional level of school-aged children with CP-CVI. This is aligning with previous findings that CVI is a heterogeneous condition, consisting of multiple subtypes affecting lower, higher, or combined levels of visual processing have been previously clustered (J. Phillip et al., 2023).

This gradient of decline is highly informative. It demonstrates that low-level feature detection (color, luminance) is relatively preserved, while mid- and high-level integration tasks show disproportionate impaired. Developmental studies support this interpretation, demonstrated that early visual pathways (retina, LGN, V1) are relatively mature at birth, but higher-order cortical functions such as contour integration, figure-ground segregation, and global motion perception mature late into childhood (Kiorpes, 2016; Teller & Movshon, 1986). Basic spatial resolution and contrast sensitivity develop along relatively fast trajectories, reaching near-adult levels within the first year in humans, whereas higher order abilities, such as contour integration, figure-ground segregation, stereopsis, and global motion or form perception, emerge later and require prolonged refinement in extrastriate cortical areas (Braddick & Atkinson, 2011; Kiorpes & Bassin, 2003). These functions depend heavily on the maturation of dorsal and ventral stream networks and on recurrent processing loops that integrate information over space and time.

Given that our oddball experiment conditions were designed to progress from low-level feature discrimination to tasks requiring mid- and high-level integration, the sharper

drop in performance for complex conditions in children with CP-CVI may reflect the dual impact of developmental vulnerability and the neurological insult. Our results therefore align with developmental vulnerability models and reinforce the dorsal stream deficit hypothesis.

4.1.1.3.1.1 Perceptual Learning Capacity in the Oddball Discrimination Task.

Another important contribution of the oddball task in our study was evidence of perceptual learning within sessions. Despite initial deficits, CP-CVI children's accuracy improved across trials, indicating retained capacity for adaptation through practice. Reaction times remained elevated, reflecting persistent slowness in processing or motor planning, but the accuracy gains underscore the potential for training-based rehabilitation (Figure 14). This pattern mirrors findings in perceptual learning literature (Sagi, 2011), where repeated exposure enhances discrimination even in neurologically vulnerable groups. In CP, structured repetition has been shown to promote motor and cognitive gains (Ortibus et al., 2009; Van der Zee et al., 2012). Our results extend this to vision, suggesting that targeted visual training protocols could harness residual plasticity in CP-CVI.

4.1.1.3.1.2 Visual Scanning Strategies in the Oddball Task: A Reverse Hierarchy Theory Perspective.

The behavioral strategies observed in our oddball task support reverse hierarchy theory (Hochstein & Ahissar, 2002). Neurotypical children in all ages tested in our group, detected targets rapidly via feedforward salience ("vision at a glance"), with no need for any other physical strategy. Whereas CP-CVI children often engaged in slow, serial scanning ("vision with scrutiny"), sometimes using finger- pointing across items. This reliance on slower, feedback-driven processing reflects impaired bottom-up salience detection and increased dependence on recurrent loops (Hochstein & Ahissar, 2002; Lamme & Roelfsema, 2000). In reverse hierarchy theory terms, the initial feedback from retina → LGN → V1 → extrastriate areas is degraded, forcing earlier reliance on recurrent loops for detail extraction. Damage to long-range dorsal-stream connections in CP likely exacerbates this inefficiency (Lamme & Roelfsema, 2000). Manley et al. (2022) described

similar impaired salience processing and reliance on serial search in CVI. These observations highlight the practical need for reducing clutter, increasing spacing, and enhancing salience in educational and therapeutic environments.

4.1.1.3.2 Oddball by Gaze Task: Expand the Inclusion. The gaze-based oddball task confirmed the vulnerability profile while removing motor demands, a crucial adaptation for children with CP (Chokron & Dutton, 2016). Accuracy remained higher in the typically developing group and lower in CP-CVI, particularly for figure-ground discrimination, and inefficient scanning strategies persisted. Importantly, this version included children with GMFCS IV-V, who are often excluded from visual research (Ciman et al., 2018; Ben Itzhak et al., 2025). The oddball by gaze experiment further emphasis the difficulty for some of the children using their index finger of item-to-item search as a strategy. Secondly, the task was restricted to time in comparison to the pointing task which was not limited to time. This as expected did not influence the typical developing children, however, increased the difficulty for some of the slower children from the CP-CVI group. Although very short and simple, this experiment is very near the demands of the real world for quick response to fast moving complex visual environment. With almost all the children in the CP-CVI group had high score in the recognition (IIQ and CVI Range), The ability to capture the same vulnerability profile through eye gaze highlights the feasibility of motor-free visual assessment in CP-CVI and reinforces the robustness of the findings.

These results highlight the importance of addressing both visual difficulties and the strategies children with CP-CVI use in daily life. The findings could reflect for example on choosing between technological support such as an iPad, computer, or eye-gaze games for play, or adapting visual stimulation during activities such as television viewing.

4.1.1.3.3 Tracking Task: Effect of Occlusion on Smooth Pursuit Eye Movements. Smooth pursuit eye movements provide a critical window into the integration of visual, oculomotor, and cognitive systems (Thier & IIg, 2005). Our smooth pursuit tasks

probed visuomotor integration and predictive control. In the nonoccluded condition, children with CP-CVI exhibited significantly reduced eye tracking quality compared to neurotypical controls that showed no differences. Measures such as fixation error, vergence lag, modulation of eye movements, and latency of catch-up saccades were all impaired only in the CP-CVI group compared to controls (Figure 21). While the basic pursuit gain (velocity matching) was relatively preserved in the CP-CVI group compared to controls (Figure 19), pursuit was more variable, and in the CP-CVI group. This pattern may suggest that brainstem and subcortical oculomotor control mechanisms remain partly intact, but cortical control of attention, prediction, and sustained tracking is compromised. In the occluded condition task, group differences were even more striking (Figure 20). Neurotypical children demonstrated anticipatory pursuit, smoothly extrapolating the trajectory of the target even when visual input was briefly absent.

By contrast, CP-CVI children showed greater trajectory deviation, with erratic and delayed re-engagement once the target reappeared. This aligns with Barnes' (2008) model of pursuit as a closed-loop predictive system that depends on visual working memory, attentional control, and feedforward modeling of target motion. In conditions where a moving target is briefly occluded or disappears, individuals can often maintain accurate pursuit by relying on internal models of the target's trajectory. These models are informed by previous sensory input and are continuously updated through experience-dependent learning. The brain anticipates the target's future position using predictive mechanisms localized in regions such as the frontal eye fields, posterior parietal cortex, and the cerebellum-areas crucial for integrating visual motion signals with motor planning. Barnes highlights that during occlusion, visual working memory plays a critical role in maintaining a representation of the target's motion characteristics (e.g., velocity and direction). This memory buffer allows the pursuit system to extrapolate the target's path and generate anticipatory motor commands. Smooth pursuit under occlusion demonstrates the operation

of both feedback (reactive) and feedforward (predictive) control systems. While visual feedback adjusts eye velocity in response to actual target motion, the feedforward system enables the eyes to stay “on track” when visual input is momentarily unavailable.

This framework is highly relevant to children with CP-CVI, where both oculomotor, sensory integration system and higher-order visual-cognitive systems may be compromised. In such populations, the ability to maintain smooth pursuit during occlusion may serve as a sensitive indicator of disrupted visuospatial prediction and sensorimotor integration**,** particularly in cases where the dorsal visual stream is impaired. Deficits in CP-CVI reflect impaired access to these predictive circuits, which involve posterior parietal cortex, frontal eye fields, and cerebellum.

Head movements were also more prominent in CP-CVI, likely serving as compensatory strategies when eye movements alone were insufficient (Figure 18b). While this adaptation extends tracking capacity (Tychsen & Lisberger 1986) or helps to maintain target fixation due to reduces vestibulo-ocular reflex or postural adjustments difficulties (Porro et al., 2005; Saavedra et al., 2010), it underscores how children with CP-CVI must exert additional effort for tasks that neurotypical children perform automatically. Functionally, such pursuit deficits translate into difficulties with reading fluency, sports, mobility in dynamic environments, and visually guided interactions, ultimately impacting educational participation and QOL. Together, the pursuit findings highlight the multilevel disruption in CP-CVI: preserved subcortical velocity matching, but impaired cortical prediction and integration. These results extend prior work (Kooiker et al., 2014; Tychsen & Lisberger, 1986), adding evidence that pursuit under occlusion may serve as a **s**ensitive marker of higher-order visual-cognitive dysfunction in CP-CVI. The results further emphasize the need for comprehensive, multidisciplinary approaches that address the intricate relationships between sensory processing, motor control, and cognitive function.

4.1.1.3.4 Watching a Video Clip: Successful Group Clustering in an Ecological and Inclusive Way.

Our findings demonstrate that the paradigm successfully characterized visual attention patterns in both neurotypical and CP-CVI groups. Neurotypical children exhibited highly consistent gaze patterns, with fixation distributions tightly clustered around the group mean throughout the clip and unaffected by participant age. In contrast, the CP-CVI group demonstrated reduced gaze similarity to controls, higher blink rate and saccadic vigor (higher saccadic velocity for shorter distance), vergence deficiencies, and higher saccade time "randomness" as previously found in autism (Ziv et al., 2024). (See Figures 24–26.) These differences were stable across the viewing period and showed no age-related variation, suggesting they reflect underlying visual-attentional limitations rather than developmental delay. These behaviors are consistent with earlier experiments in this study, displaying slower and less efficient visual tracking, reliance on serial search, and reduced ability to maintain fixation under increasing visual demands. Thus, reinforcing the theme of dorsal stream mediated attentional inefficiency and reliance on compensatory strategies.

The video clip paradigm was designed as a passive**,** naturalistic measure of visual attention and scene exploration. Unlike the tightly controlled stimuli of the oddball or pursuit tasks, the clip required children to engage with dynamic, multimodal content that mirrored real-world challenges: moving characters, shifting scenes, background complexity, and synchronized audio. The animated, humorous clip proved highly engaging across ages and abilities, minimizing data loss while enabling participation across all GMFCS and MACS levels, including children with limited or absent hand function. Similar engagement effects have been observed in Play with Eyes (De Bortoli & Gaggi, 2011), Ciman et al. (2013), and Ben Itzhak et al. (2021), where visually rich stimuli increased cooperation and data quality. The clip format reduced performance anxiety by framing the task as entertainment rather than a test. While assessment through video viewing has been reported

in children with ASD and typically developing peers (Cilia et al., 2019; Gong et al., 2021), its application in CP-CVI had not been documented prior to this study.

Unlike feature-specific paradigms (Ben Itzak et al., 2023) (e.g., pursuit tracking or discrimination against a single feature), the clip required simultaneous processing of multiple visual and auditory inputs reflects the real-world demands, such as shifting perspectives, scene transitions, foreground-background complexity, dynamic object movement, and synchronized audio. Such demands are analogous to everyday challenges for children with CP-CVI, including navigating crowded and cluttered classrooms, finding objects in busy environment, or following conversations in visually dynamic setting. Thus, it is not surprising that a correlation was found with the functional visual tools (IIQ, VFCS, CVI Range) in the CP-CVI group.

Our assessment differs from active, game-like assessments, such as McDowell & Butler's (2023) Austin Assessment, which combine gaze recording with manual interaction, as our approach eliminated motors confound entirely. While passive tasks are less likely to induce visual learning compared to active engagement (Gibson, 1979; Sagi, 2011), they provide an essential motor-free baseline in heterogeneous clinical groups and isolates visual-attentional performance from motor execution capacity. Importantly, it proved both time-efficient and engaging-lasting only 1.5 min compared to ~35 min for other recent eye gaze batteries (Hokken et al., 2025), while maintaining high discriminative power.

4.1.1.3.4.1 Watching a Video Clip: Alignment with Existing Literature. Several recent studies reinforce the value of our approach. Chang (2025) confirmed the quantitative sensitivity of eye-tracking metrics in CVI, and further clustered CVI participants into prognostically meaningful subgroups based on oculomotor metrics such as fixation latency, saccade latency, and off-screen gaze proportion. Hokken et al. (2024) found that children with CVI showed broader gaze dispersion and slower target recognition in complex scenes-mirroring our findings. The stable, narrow neurotypical gaze pattern in our study highlights

the potential for rapid classification of CVI behavior in a clinical setting. Gamage et al. (2025) identified a lack of assistive technology tailored to CVI, underlined the timeliness of our work. Intervention-focused studies (Walker & Wegner, 2021; Hsieh, 2024) further show that training gaze control can enhance participation, suggesting that our findings could inform future gaze-based therapies.

Dynamic, naturalistic paradigms have been used to reveal diagnostic patterns in CVI and other developmental disorders. Walter et al. (2024) reported that children with CVI rely more on bottom-up salience and less on top-down scene guidance in complex visual scenes. Manley et al. (2022) linked similar behavioral profiles to reduced dorsal stream activation in immersive virtual reality tasks. In ASD research, video-based paradigms (Kojovic et al., 2024; Kong et al., 2022) have uncovered distinctive gaze patterns and higher engagement than static image tasks. Ben Itzhak. (2023) recommended including preferential looking paradigm-style gaze tests in CVI screening batteries and assessing variability in eye movements in both controlled and naturalistic settings. Our study extends these approaches to a homogeneous CP-CVI population and, uniquely, correlates passive-viewing gaze metrics with functional vision measures (VFCS, CVI Range) and parent-reported visual difficulties (IIQ).

4.1.1.3.4.2 Watching a Video Clip: Clinical Potential and Future Direction. The brevity (1.5 min) and high sensitivity of the clip paradigm suggest its feasibility as a rapid clinical screening tool. Coupled with evidence from CVI and ASD literature on dynamic scene viewing (Chang, 2020; Hokken et al., 2024; Walter et al., 2024; Kojovic et al., 2024), this study demonstrates that such paradigms can yield sensitive measures of functional vision and as a diagnostic marker. Our findings extend this evidence to CP-CVI, demonstrating that a simple, enjoyable paradigm can capture core visual-attentional limitations and correlate with functional tools such as the IIQ and CVI Range. Future research should evaluate its utility in children with CP without a CVI diagnosis, examine its

predictive value for educational outcomes, and explore gaze-controlled adaptive games that combine inclusivity with the perceptual benefits of active engagement.

4.1.1.3.5 Synthesis of Results Across Computerized Psychophysical Tasks. Across our psychophysical computerized assessment battery, a consistent theme emerged that maps well onto the feedforward recurrent processing framework described by Lamme and Roelfsema (2000). Tasks relying primarily on feedforward salience detection (simple feature pop-out, basic luminance or color discrimination) showed the smallest performance gaps between CP-CVI and neurotypical controls, whereas tasks requiring recurrent processing for feature integration, figure-ground segregation, or search in cluttered scenes revealed the largest deficits. This gradient suggests that while some bottom-up, pre-attentive mechanisms remain functional in many children with CP-CVI, the slower, top-down recurrent processes needed to bind features across space and resolve competition in complex displays are disproportionately affected. Such a profile is consistent with dorsal stream vulnerability, white matter injury, and disrupted long-range feedback connections often seen in CP-CVI. Framing our findings in this model provides a mechanistic explanation for both the heterogeneity observed and the specific conditions under which visual performance breaks down, guiding for more targeted adaptations in educational and therapeutic settings.

Notably, even though all participating children had functional vision and could read at varying levels, many relied on partially adapted tools (e.g., iPads, large print books). In several cases, the experimental findings prompted referrals to vision teachers or parents to consider further adaptation, especially when errors became evident during testing. This illustrates the real-world value of objective testing in identifying unmet support needs.

All four experiments were successful in detecting within-group variability, confirming CVI is a heterogeneous condition, possibly consisting of multiple subtypes affecting lower, higher, or combined levels of visual processing have been previously clustered (J. Philip et al., 2023). Each experiment highlights a different aspect of visual

functions. Running all experiments is recommended as it supports the need for a comprehensive assessment battery rather than a single screening tool in order to make a precise intervention program (Boonstra et al., 2022).

4.1.2 Hypothesis 1 Part Two: Sensory Processing in Children With CP-CVI

Alongside visual processing difficulties, our findings demonstrated a broader pattern of impaired sensory processing and sensory modulating across multiple modalities, with clear implications for daily life functioning. Sensory processing disorders were highly prevalent in children with CP-CVI. The CP-CVI group demonstrated reduced processing of visual, vestibular, auditory sensory information, and proprioception information, accompanied by difficulties in maintaining postural tone and sustaining physical effort.

These difficulties present in 54% to 76% of the children reflect challenges in activity endurance, postural control, and modulation of sensory input. The most severely affected domain was the sensory registration quadrant, with 98% of the children showing low registration, meaning a high threshold for noticing incoming sensory information. These findings align with emerging literature in the CP population. Dhiman et al. (2025), in their systematic review, reported that 55% to 83% of children with spastic CP exhibit clinically significant sensory processing difficulties, especially low registration and impaired modulation of body position. Gaurav et al. (2023) similarly described high rates of sensory under-responsiveness, and Barakat et al. (2021) and Pavão & Rocha (2017) highlight marked difficulties in tactile, proprioceptive and vestibular processing compared to the normative data.

Our findings extend this literature showing that sensory registration and muscle and activity Modulation, were strongly correlated with the severity of motor impairment (GMFCS and MACS). This supports the view that sensory and motor dysfunction in CP share common neurodevelopmental origins. Children with higher GMFCS/MACS levels typically exhibit more extensive white-matter and thalamocortical pathway injury (Dhiman

et al., 2025; Knijnenburg et al., 2023; Reid et al., 2014), reduced opportunities for self-generated movement exploration (H. K. Graham et al., 2016; Lew et al., 2015; McClelland et al., 2006), and diminished proprioceptive and vestibular input and sensory registration capacities (Mishra et al., 2020; Park, 2017; Pavão et al., 2015). In other words, children with more severe CP have both fewer sensory experiences and less efficient neural pathways for processing them, creating a neurobiological basis for impaired sensory modulation.

Regarding sensory responsiveness, behavior and emotional response domains showed higher prevalence than reported in the CP literature. Ericson et al. (2023) reported elevated sensory emotional and social responsiveness in 55% of children with CP, our CP-CVI group show 55% to 96% across behavioral emotional domains. These behaviors: emotional outbursts, social withdrawal, rigidity, and extreme responses to sensory input, appear to reflect over-responsivity during sensory overload, even against a background of baseline under-responsiveness with prevalence 68% to 76 % of sensitivity and avoiding quadrants in the CP-CVI group.

Thus, our findings stress dual sensory pattern observed in children with CP-CVI. With baseline of low registration and under responsivity, reflecting reduced detection of sensory cues across systems, episodes of sensory over responsivity, reflected in emotional and social dysregulation behaviors, when visual, auditory or multisensory input become unpredictable or overwhelming. This dual pattern is consistent with injury to thalamocortical sensory pathways, which affects both sensory integration and modulation. When sensory information is poorly integrated at lower levels, unmodulated input reaches higher cortical areas, contributing to dysregulated emotional and social behavior.

Furthermore, emotional and social response domain in our study were highly correlative with visual aspects, participation and QOL social aspects. This highlights the aspect of sensory modulation difficulties as a core function to ensure participation and QOL in social demanding environment more than the ability to process visual information solely,

that was correlated with participation at home environment. This is an important finding emphasizing further the important role of the environment in controlling sensory information to support top-down the ability to modulate multisensory incoming information.

These findings are also consistent with recent research among children with visual impairment. Galiano et al. (2024) reported that children with visual impairment (no CP, with only five children from 37 with CVI), show highly atypical sensory profiles, with patterns often intermediate between typically developing peers and children with ASD. Crucially, they found that sensory processing difficulties were more strongly predictive of autistic-like behaviors in visually impaired children than in either ASD or neurotypical groups, and that these behaviors stemmed primarily from deficits in sensory information processing rather than emotional regulation. This suggests that visual impairment alters developmental pathways for social communication through its effects on multisensory integration.

Applying this to our population, the high prevalence of SPD across visual and nonvisual modalities further supports the idea that CVI may reflect one manifestation of broader multisensory network disruption. Dhiman et al. (2025) reported that the visual domain is involved alongside body position and tactile processing difficulties across all CP types, raising the possibility that SPD may be under-recognized in CP or that undiagnosed CVI contributes to sensory complexity in this population. Either way, it emphasizes our results which highlight the complex relationship between the visual system and broader sensory processing challenges, emphasizing that SPD is significantly more prevalent in the CP group and especially in the CP-CVI group, compared to the neurotypical population.

While there is growing research on the sensory processing in CP, far fewer studies focus on children with both CP and CVI. Notably, our CP-CVI group included children with functional vision (CVI Phase III), and adequate cognitive and communication, yet sensory processing difficulties remain highly prevalent. This suggests that CVI may reflect one manifestation of widespread multisensory network disruption and underscores the

importance of systematically profiling the sensory system in CP-CVI, even when visual functional vision appears relatively preserved.

These findings raise a central theoretical and clinical question: can we fully understand visual processing mechanisms without considering underlying sensory processing functions? Our results suggest that the answer is no. Sensory modulation difficulties, not only visual processing deficits, play a foundational role in shaping participation, especially in socially and sensory-rich environments. This represents a key clinical message for both clinicians and researchers working with CP, and especially CP-CVI populations (Dan et al., 2025; Waiserberg et al., 2025).

4.1.2.1 A Distinct Sensory Signature With Individual Variation in the CP-CVI Group

The most prevalent sensory quadrant across studies was Registration, indicating that many children with CP "miss" sensory cues and require stronger or clearer input to respond, reflecting a high neurological threshold and passive self-regulation style (Dhiman et al. 2025). However, our subgroup analysis revealed that while the majority of children appeared to demonstrate low registration patterns (98%), approximately 60% showed mixed profiles including seeking behaviors, avoiding responses in specific contexts, or domain-specific variations in sensory processing.

Despite the apparent overall consistency of sensory processing patterns in our CP-CVI cohort, important individual differences emerged that may have significant implications for intervention planning. This heterogeneity could reflect the complex interplay of lesion location, extent of white matter involvement, compensatory neural plasticity, and individual differences in attentional and regulatory capacities (Alvarado-Cando et al., 2025; Knijnenburg et al., 2023, VerMaas et al., 2021).

It is not sufficient to describe CP-CVI children as having "sensory difficulties"; or "expected CVI behavior." Rather, each child presents a unique combination of hyper- and hyporesponsivity with different strategy in different setting. This finding mirrors Dunn's

(1997) model of sensory processing and later refinements by Miller et al. (2007), which emphasized the interplay between neurological thresholds and self-regulation strategies. Clinically, interventions must reflect this diversity. For example, reduction of sensory load, and gradual exposure with high avoiding in comparison to structured opportunities for safe stimulation with high seeking. The different quadrant and observed pattern of sensory processing implies that standard environmental cues, instructional methods, and therapeutic intensities may fail to activate the neural networks necessary for learning and participation. Furthermore, considering the visual abilities and difficulties and the adapted learned strategies in a specific environment each child experienced, the challenge is even bigger. This represents a paradigm shift in understanding CP-CVI, moving from a model focused primarily on visual deficits to one that recognizes the pervasive impact of sensory processing dysfunction, including vision, across multiple domains of functioning.

The variability in sensory profiles may have direct clinical implications, as it suggests that standardized intervention approaches might be insufficient for addressing the diverse needs within the CP-CVI population. Some children may require environmental enrichment and enhanced sensory input to achieve adequate neural activation due to reduce registration, while others might benefit from carefully controlled sensory environments that prevent overwhelming their processing, modulation and integration capabilities. Additionally, the potential interaction between sensory processing patterns and environmental contexts could add another layer of complexity to interpretating the child's behavior. Thus, a child who demonstrates seeking behaviors in a structured therapeutic setting might show avoiding responses in chaotic environments where their visual processing system is overwhelmed.

Understanding this heterogeneity also highlights the possible importance of comprehensive, individualized assessment that goes beyond simple categorization into sensory processing types. The environmental context, task demands, and interaction between

different sensory systems may all influence how a child's sensory processing dysfunction manifests in daily activities. This complexity could underscore the need for assessment tools and intervention approaches specifically designed for the CP-CVI population that can capture these nuanced patterns and their functional implications. These findings echo into a recent editorial by Dan et al. (2024), which argues that acknowledging the breadth of sensory integration challenges in CP is essential, not only for therapeutic targeting, but also for advancing ethical, inclusive models of disability. Incorporating comprehensive sensory assessments and addressing SPD through individualized interventions holds substantial promises for improving participation, motor learning, and overall QOL in this population.

4.1.2.1.1 Sensory Processing in CP-CVI: Developmental Considerations and Neurophysiological Findings. The marked sensory processing difficulties observed in CP-CVI likely reflect both a combination of direct neurological injury and reduced opportunities for sensory-motor experiences. Children with CP often engage in limited active movement, restricting the experience-dependent calibration of proprioceptive, vestibular, and visual systems (Barakat et al., 2021; Hadders-Algra, 2000). Evidence from motor-induced neuroplasticity further demonstrates that sensorimotor cortices adapt with practice, and that sensory integrity of sensory pathways strongly influences motor learning capacity (Kurz et al., 2024; Kurz & Busboom, 2024). These findings are aligned with developmental theories. Ayres' sensory integration framework emphasizes early movement as foundational for organizing sensory networks (Ayres, 1972, 1979, 1985), while embodied cognition models highlight how the co-develop of perception and action (Smith & Gasser, 2005). Neuroanatomical evidence provides additional support for this layered model. Hoon et al. (2009) demonstrated that injury to the posterior thalamic radiation is associated with poorer contralateral touch threshold, impaired proprioception, and greater motor severity, whereas corticospinal tract injury did not predict sensory outcome. This pattern may explain the low multisensory modulation scores observed in our cohort. Timing of injury is also critical.

Early third-trimester thalamocortical injury affects fundamental sensory development, whereas later cortical or subcortical lesions produce more selective deficits (Knijnenburg et al., 2023). Such developmental variability may underline the heterogeneous quadrant profiles observed in our sample.

The co-occurrence of sensory processing difficulties and visual impairments in CP-CVI is consistent with shared neurophysiological mechanisms. Neuroimaging studies in CP demonstrate widespread white matter damage, particularly to the posterior thalamic radiation, posterior corona radiata, and splenium of the corpus callosum (Hoon et al., 2002; Ricci et al., 2006). Forty to fifty percent of children present with PVL (Dhiman et al., 2025; Reid et al., 2014), disrupting thalamocortical connectivity critical for multisensory integration. Because these pathways support both visual and somatosensory processing, impairments across visual, tactile, vestibular, and auditory domains frequently co-occur.

Several studies directly support this multisensory relationship. Papadelis et al. (2014) identified abnormal thalamocortical connectivity associated with atypical sensory responses, Guzzetta et al. (2009) linked parietal injury to dorsal-stream visual deficits. Arrigoni et al. (2016) demonstrated that tactile-proprioceptive integration deficit arises from abnormalities in posterior thalamic and callosal fibers. Knijnenburg et al. (2023) further reported that children with PVL may exhibit better hand and sensory function than those with cortical/MCA lesions, reflecting compensatory reorganization of S1. Electrophysiological work echoes these findings. Reduced alpha and beta modulation during sensory-motor tasks Kurz et al. (2018) and diminished poststimulus alpha desynchronization during visual search in CVI (Bennett et al., 2021) and reduced induced alpha modulation reflecting higher-order integration deficits (Federici et al., 2023). Together, these findings indicate impaired attentional engagement and help explain the low sensory registration scores typical in CVI.

Theoretical models further clarify how these mechanisms unfold. Lakatos et al. (2009) proposed that sensory systems rely on a dominant “leading sense” to synchronizes

neural excitability across modalities. When visual networks, typically dominant, are disrupted, as in CP-CVI, the loss of this cross-modal coordination may produce widespread disruption in multisensory processing and regulation. These correlations we observed in our study between visual and nonvisual sensory domains are consistent with this hypothesis.

Taken together, these findings suggest that SPD and CVI arise from shared disruptions of multisensory networks, where white matter injury and abnormal oscillatory dynamics produce the pervasive sensory processing and modulation difficulties observed in our cohort, despite variability in cognitive or motor profiles. This neurobiological framework helps explain why children with CP-CVI exhibit broad sensory vulnerabilities that extend well beyond the visual system.

4.2 Hypothesis 2: Validation of Innovative Psychophysics Computerized Assessment Detecting Visual Processing and Vision Daily Function

We hypothesized that subjective functional assessments (VFCS, IIQ, CVI Range) would correlate significantly with objective psychophysical computerized measures, thereby supporting the validation of the computerized tools. Our findings confirmed this expectation: many parameters from the computerized experiments correlated with the CVI Range, VFCS, and selected IIQ domains.

All four objective tasks were sensitive to CVI-related difficulties, reinforcing knowledge from previous literature while also providing unique contributions. Oddball (pointing), distinguished between low- and high-order perception. Oddball (gaze), isolated visual processing using only eye movements, independent of motor demands. Eye-tracking pursuit with occlusion, tested prediction and sustained tracking. Video viewing integrated these challenges into a naturalistic, ecologically valid context.

The combination of all experiments strengthens the potential ability to address different life situations, although in front a computer screen. Together, these assessments address aspects of oculomotor control and perceptual processing, providing a richer picture

of functional vision. Importantly, many of their parameters correlated with subjective classifications, thereby supporting the validity of both traditional tools and the new computerized methods.

A particularly noteworthy finding was the consistent correlation with the CVI Range, even in children with relatively high visual function (Phase III). This underscores the strength of the CVI Range in detecting both the severity and heterogeneity of CVI characteristics. Given that up to 40% of the brain is involved in visual processing (Lueck & Dutton, 2015), multiple pathways of disruption are expected; thus, tools capable of identifying subtle but functionally significant deficits are essential.

Correlations with the IIQ were more variable, often specific to certain domains rather than the overall score. This emphasizes the importance of interpreting parent-report tools in the context of daily routines, environmental exposure, and parental awareness. As previous work has shown (Chandna et al., 2021; Dutton, 2015b; Macintyre-Beon et al., 2012), the IIQ gains strength when combined with structured observation and professional assessment.

Overall, the four experiments provided important insight into visual processing in CP-CVI. While they correlated with functional classifications, their greatest utility may be as initial screening tools that identify vulnerabilities and direct further context-specific assessment (e.g., perceptual or functional vision tasks relevant to the child's daily life). This aligns with recent data-driven approaches (J. Philip et al., 2023), which demonstrated that comprehensive batteries allow more precise identification of CVI subtypes than limited assessments. Based on these findings, we recommend a two-step assessment approach: initial psychophysical computerized screening with all children with CP, followed by individualized follow-up assessments to capture the child's everyday visual functioning.

4.3 Hypothesis 3: CVI and SPD Correlation with Participation and QOL in Children With CP-CVI

Framing the hypothesis participation is central to child development and is considered a primary outcome in pediatric rehabilitation. Lower participation levels in children with disabilities, including CP, have been consistently documented and are linked to reduced QOL and social inclusion (Fauconnier et al., 2009; Imms et al., 2017; Michelsen et al., 2009). The ICF (WHO, 2007) emphasizes that participation results from dynamic interactions among body functions, activity limitations, environmental facilitators or barriers, and personal factors.

While motor function has traditionally been the focus in CP, relatively few studies have examined how CVI and SPD contribute to participation and QOL (Dan et al., 2025). CVI is the most common cause of visual impairment in CP, affecting up to 60-80% of children (Good, 2001; Sakki et al., 2018), and sensory processing difficulties are present in as many as 90% (Cooper et al., 1995; Pavão & Rocha, 2017). Yet the combined effect of CVI and SPD on participation patterns and perceived QOL has received little attention.

Our findings provide evidence that lower participation, higher environmental barriers, and reduced QOL in CP-CVI are linked not only to gross motor severity but also to distinct visual and sensory profiles. This section discusses these associations in relation to existing literature and highlights their implications for clinical practice.

4.3.1 Participation Patterns Across Environments

Participation outcomes differed meaningfully across home, school, and community settings, reflecting the unique sensory, visual, and social demands of each environment. In home setting, participation frequency and number of activities correlated positively with visual attention, suggesting the sustained engagement in familiar daily routines depends on attentional capacity and the child's ability to maintain visual focus and resist attentional fatigue. In contrast, community participation was associated with visual recognition,

complex visual processing, and environmental barriers. This aligns with previous literature showing that community environments require children to navigate unfamiliar, visually cluttered, and socially demanding contexts (Anaby et al., 2014; Law et al., 2007). For children with CVI, known difficulties in object and face recognition and processing visual complexity (Matsunaga et al., 2025; J. Philip et al., 2023) may further explain why community participation was particularly restricted. Recent scoping evidence confirms that visual impairment broadly reduces functioning, participation, and QOL across childhood (Lanza et al., 2024) reinforcing the vulnerability of this group.

Our findings highlight the importance of identifying the specific sensory and visual demands of tasks within each environmental context. In home setting, visual attention was positively correlated with, and significantly predicted, home participation frequency and number of activities. This may indicate that in familiar, less stimulating environments, sustaining visual attention plays a central role in supporting engagement in daily routine, where fewer external demands allow vision to function as a more dominant driver of participation. In the school setting, participation related environmental barrier showed a negative correlation with the sensory registration quadrant, the lower the child's sensory registration, the higher the perceived environmental barriers to participation. This pattern underscores the substantial influence of the school environment on the child's ability to detect, interpret and respond incoming sensory information essential for academic learning (Bar-Shalita et al., 2008; Dunn, 2001). Children with poor sensory registration are more likely to miss teacher cues, visual information, and social signals, which in turn compromises their classroom engagement.

Together, these differentiated patterns highlight the need for context sensitive mapping of visual and sensory domains. Assessing how sensory and visual demands unfold in real-life environments, such as home, school, and community, can guide more precise, individualized, and ecologically valid intervention planning. Examples include tracking

attentional fatigue during extended play at home, identifying recognition failures in crowded community settings, or monitoring missed visual cues during classroom learning. This approach aligns with the PEOP model, which emphasizes shifting from broad diagnostic labels to precise, setting specific profiles that guide individualized, occupation-based interventions.

4.3.2 Sensory Processing and Participation

Our findings identified active sensory behaviors-seeking, avoiding, and behavioral emotional-social responsiveness as strongest correlations of participation and environmental engagement. Although such behaviors are often interpreted as problematic, they may instead represent adaptive self-regulation strategies to manage overly intense or insufficient sensory input (Baranek et al., 2002).

The number of activities was correlated with responses in the body movement and position domain, emphasizing the central role of proprioceptive and vestibular processing in daily functioning, consistent with recent work in CP (Ericson et al., 2023). Notably, GMFCS did not correlate with home participation as expected, underscoring sensory aspects of movement, rather than motor ability alone, shape participation. This emphasis on the need of further information more than level of motor function through the GMFCS to direct for improvement in the child participation in all settings.

Participation frequency at home correlated negatively with seeking quadrant. In line with Dunn's model (1997, 2014) and supported by Ayres (1972, 1985), Baranek (2002), and Pavão et al. (2021), sensory-seeking behaviors may serve as active self-regulation strategies, helping children sustain arousal, organize action, and engage in play or social activities. In this sense, such behavior may often represent adaptive efforts rather than maladaptive symptoms. However, given that children with CP frequently demonstrate reduced participation, particularly in community based and socially demanding environment, sensory-seeking behaviors can also become a barrier to forming social connection outside

the familiar and supportive home context. Behaviors that are functional and acceptable at home may be misinterpreted or stigmatized in community settings, limiting opportunities for peer interaction and social inclusion.

Conversely, the registration quadrant was particularly elevated in our sample and correlated positively with school participation, suggesting that registration deficits, i.e., difficulty noticing incoming stimuli, directly impair classroom engagement (Jovellar-Isiegas et al., 2020). This aligns with previous research showing that low registration reduces responsiveness to daily routines and requires increased adult cueing (Ericson et al., 2023; Jovellar-Isiegas et al., 2020). These findings are consistent with broader research showing that sensory modulation affects even basic participation, such as mealtimes (Cemali et al., 2023). Thus, assessments must capture both active (avoiding and seeking) and passive (registration and sensitivity), sensory responses and interpret them within the context as a possible adaptive strategy rather than simply behavioral problems. Such interpretation is essential for designing intervention programs that effectively enhance everyday participation.

Importantly, the emotional and social responsiveness domain was the strongest sensory correlation of school participation and community involvement. Children who overreact to changes, struggle to calm after stimulation, or have difficulty maintaining social engagement are likely to avoid social situations, resist group activities, and find new environments overwhelming, particularly under conditions of sensory overload (noise, crowding, visual clutter).

In this study, participation among children with CP-CVI was low across all settings, but especially in the community. Participation at school and community contexts was linked to both visual characteristics and sensory-behavioral features, particularly social responsiveness and sensory modulation, reflecting children's capacity to notice social cues, manage environmental demands, and remain engaged. These findings are consistent with the

review by Cooper et al. (2024), which show that social participation in adulthood is shaped by experiences and support in childhood. Family environments that promote independence, experimentation, and decision-making predict stronger adult outcomes, including employment, confidence, and social belonging, whereas, overly protective parenting, poor accessibility and stigma restrict participation and lead to social withdrawal, even among motivated individuals (Cooper et al., 2023; Washington-Nortey et al., 2025)

Consistent with the PEOP model, participation emerges from ongoing interaction between the child, their environment, and the opportunities available across developmental time. Therefore, our findings highlight the need for early, developmentally oriented evaluation of factors that may restrict or support participation, as particularly the child's capacity to modulate emotional and social response to incoming multisensory information, and for translating this evaluation into targeted interventions, for providing families, therapists, and teachers with guidance from early childhood onward. Such programs should include supported social groups, parent training, sensory-aware educational practices, environmental adaptations in schools, and promotion of community activities with adequate social support. Our previous research showed reduced community participation even among ambulatory children with CP attending mainstream schools, likely reflecting unmet social needs (Gelkop & Engel-Yeger, 2025). The current study extends this understanding by highlighting how visual and sensory processing further shape participation and social engagement, and often overlooked in CP.

4.3.3 Functional Classifications and Social Participation

The study revealed that MACS and CFCS correlated more strongly with school and community participation than GMFCS. This suggests that manual and communication abilities may act as stronger barriers to social inclusion than gross motor severity (Badia et al., 2011; Hidecker et al., 2011). While GMFCS remains important for predicting mobility-related participation, social participation appears more constrained by

communication and fine motor demands. The VFCS, while useful for categorizing visual impairment, showed limited correlation with specific QOL aspects in comparison to the GMFCS. This confirms that broad functional classification of vision may not capture the nuances of how specific visual deficits affect participation (Dutton & Jacobson, 2001; Sakki et al., 2018). These results argue for the integration of multiple classification systems (GMFCS, MACS, CFCS, VFCS) with sensory and visual mapping, rather than relying on motor function alone. For clinicians, this reinforces that participation barriers may arise from less visible domains-manual dexterity, communication, or visual recognition, necessitating a holistic classification-informed assessment (Rosenbaum & Gorter, 2012).

4.3.4 Visual and Sensory Correlation With QOL in Children With CP-CVI

All functional classifications in our study, associated with physical QOL, this includes also psychophysical tasks which require physical responses (e.g., oddball with pointing), likely to reflect overlap with GMFCS levels. In contrast, social QOL found to be associated with visual aspects, including movement perception (IIQ) and oddball gaze (computerized psychophysical task) consistent with the role of vision in social interaction (McMahon & Isik ,2023), and with sensory-seeking and avoiding quadrants, and behavioral emotional and social responsiveness domain, strengthening previous studies report (Bar-Shalita et al., 2008). Although social challenges increase with greater motor severity (quadriplegia and GMFCS IV, V), challenging behaviors are a widespread feature among children with CP, independent of topography or GMFCS level (Majnemer et al., 2010)

Recent longitudinal evidence from Burgess et al. (2023) demonstrates that the development of social functioning in children with CP is driven primarily by communication ability, as classified by the CFCS which found to be the strongest predictor of social functioning from early childhood to preadolescence, outperforming both gross motor function (GMFCS) and manual ability (MACS), and even exceeding the predictive value of intellectual functioning. These findings align closely with the emerging understanding of

social participation in children with CP-CVI, visual-perceptual difficulties and sensory processing challenges (particularly registration, attention, and visual complexity processing) can disrupt the child's access to social cues, hinder social reciprocity, and reduce engagement in shared activities. Thus, the findings support the interpretation that visual processing limitations and sensory processing difficulties influence social outcomes primarily through their impact on communication functioning, underscoring the need for integrated visuo-sensory and communication-focused interventions to support participation and social development in children with CP-CVI.

Interestingly, the psychophysical oddball gaze tasks correlated with multiple QOL aspects, social, physical and final score, suggesting that the ability to process complex, rapidly changing visual information may be a critical determinant of everyday functioning and child's well-being. This aligns with recent insights by R. G. Bennett et al. (2025), who emphasizes that CVI impacts not only visual function but also cognitive, social, and educational participation domains, with direct consequences for perceived QOL. QOL is shaped not only by motor capacity but also by higher-order visual and sensory abilities. For clinicians, this reinforces the need to assess these domains systematically when planning interventions or evaluating therapy outcomes. Mapping how specific visual functions (e.g., recognition, complex processing) translate into social participation ensure that interventions address the everyday determinants of QOL.

4.4 Hypothesis 4: Predictors of Participation and QOL

Our fourth hypothesis stated that CVI and SPD would predict levels of participation and QOL in children with CP-CVI. The regression analyses supported this hypothesis, although predictive pathways differed across settings and domains.

4.4.1 Participation Prediction

Visual attention (IIQ attention domain) emerged as the strongest predictor of home participation, explaining variance in both the number and frequency of activities. This

finding is consistent with previous research showing that visual attention in children with CP and CVI, is a key mechanism for sustaining engagement in learning, social interaction and daily routines (Dutton & Jacobson, 2001; Matsunaga et al., 2025; J. Philip et al., 2023). Within functional vision frameworks such as the CVI Range, visual attention is a as a central regulatory loop, enabling he child to maintain interaction with materials, people, and the environment demands (Roman-Lantzy, 2007). In the school domain, recognition and navigation abilities (IIQ recognition) were positive predicted participation, whereas impaired perception of movement and higher VFCS severity were negative predictors. This pattern reinforces the essential role of recognition, visuospatial orientation, and motion perception in managing the visually complex crowded environments and socially dense classroom and school environment (McDowell et al., 2024; Ortibus et al., 2012).

The negative effect of VFCS severity suggests that broader functional visual limitations continue to shape school participation, aligning with evidence linking higher VFCS levels to intellectual disability (Baranello et al., 2020). Nonvisual or sensory predictors explained community participation. This absence suggests that community engagement may be more strongly shaped by contextual, socioenvironmental, and family-level factors not fully captured in this study (Anaby et al., 2014). This finding echoes the literature indicating that opportunities, accessibility, transportation, and family routines often outweigh individual functional characteristics in determining community involvement for children with CP.

4.4.2 Quality of Life Prediction

Physical QOL was primarily predicted by GMFCS, confirming the established role of gross motor functioning in shaping physical well-being in CP. Additional predictors included home and community participation (number and frequency), environmental resources and barriers, and specific visual domains of the IIQ, including movement guidance and visual search. These findings illustrate the multidimensional nature of physical QOL,

which reflects a combination of motor ability, environmental opportunities, and visual-perceptual capacity.

Stepwise regression revealed that social QOL was predicted by emotional and social responses (SP), visual attention, visual field and recognition domains (IIQ), sensory-seeking quadrant, and home and community environmental support. Together, these factors explained 58.7% of the variance ($R^2 = .587$)**,** emphasizing the strong contribution of visual and sensory processing and the relative independence from motor severity to social well-being. This aligns with evidence showing that sensory modulation and visual processing are critical for social communication, peer interaction, and inclusion (R. G. Bennett, 2025; Colver et al., 2015). Nevertheless, the mechanism through which each domain contributes to social dimensions of QOL is likely to differ.

Reduction in visual attention, visual field or visual recognition limit the child's ability to detect communication cues such as facial expressions, gestures, and social signals, and thereby reduce the opportunities for social interaction. In some cases, sensory-seeking type behaviors may serve as adaptive strategy that helps the child obtain information and remain engaged. In contrast, heightened emotional and social responsiveness may reflect difficulties in modulating incoming multisensory. When sensory input cannot be effectively regulated, children may display socially withdrawn or disruptive behaviors, which further restrict opportunities for connection and communication. In these situations, environmental supports that adjust sensory load, pacing and predictability can reduce modulation demands and promote greater social engagement. These predictive pattens reflect the central PEOP and ICF premise that participation and QOL emerge from the interplay of child factors and environmental demands. Person factors- difficulties in visual attention, recognition, movement guidance, and visual complexity, along with sensory modulation patterns such as low registration and emotional-social responsiveness, constrained social participation and QOL.

Environmental factors—home and school support in our study—independently predicted higher social QOL, demonstrating that visually simplified, accessible, structured, and socially supportive environments can buffer or compensate child-level visual-sensory vulnerabilities and emotional well-being (Wu et al., 2020).

The convergence between child factors and environmental support reinforces PEOP's core thesis that participation is not determined by impairments alone, but by the fit between the child's abilities and contextual affordances. These results reinforce the need for integrated visuo-sensory and environmental interventions to optimize social engagement and well-being in children with CP-CVI.

The inclusion of the community support domain in the predictive model of total QOL highlights the important role of community in shaping well-being, an effect found to be stronger than school and home contexts, consistent with recent research (Gelkop & Engel-Yeger, 2025). This underscores the need for community level accessibility and support initiatives to enhance QOL for children with CP-CVI.

4.4.3 Theoretical and Clinical Implications

The findings of this study expand the conventional understanding of the CP by demonstrating that visual and sensory processing difficulties in CP-CVI are not merely secondary features but central determinants of participation, engagement and QOL. Participation across home, school and community settings is shaped by distinct visual, sensory and motor pathways, reinforcing the ICF and PEOP perspective that functioning emerges from the dynamic interaction between the child, the environment, and the demands of daily occupations over time.

Our results underscore the need to shift from narrow, motor-centered diagnostic approaches toward multisystem, context-sensitive assessment. Visual attention, sensory modulation, registration, recognition, and environmental accessibility must be systematically mapped across settings to identify the mechanisms through which participation breaks down

whether attentional fatigue during home routines, recognition failures in busy community environments, or missed sensory cues in the classroom. Clinically, these findings highlight the necessity of integrated assessments as a standard practice. Assessment should differentiate sensory from motor and cognitive impairments and interpret behavioral patterns (seeking, avoiding, low registration, emotional-social responsiveness) as potential adaptive strategies rather than purely problematic behaviors. Environmental support and barriers must be mapped to guide intervention that promotes participation and well-being. Achieving this requires close collaboration among neurologists, ophthalmologists, occupational and physiotherapists, teachers, and psychologists.

Importantly, the persistence of SPD despite relatively functional vision (CVI Phase III) indicates that improvements in visual performance do not resolve underlying sensory challenges. Instead, inconsistent or degraded visual input may destabilize multisensory integration and motor planning, emphasizing the central organizing role of vision in shaping sensorimotor function. The predominance of low registration patterns suggests that many children with CP-CVI require more salient, prolonged, and multimodal input to activate engagement thresholds, while avoiding overstimulation that overload compromised visual processing. Environmental design must therefore balance sensory clarity (controlled lighting, reduced clutter, predictable structure) with sufficient intensity to support regulation, attention, and learning.

At the same time, the marked heterogeneity of sensory profiles, even among children with similar motor and visual function, reinforces the need for individualized approaches. Children who display sensory-seeking behaviors may benefit from structured opportunities to pursue sensory input in functional ways. Those who demonstrate avoidance may require gradual exposure and environmental adaptations to prevent sensory overload. Children with low registration require salient cueing, increased intensity, and extended processing across

daily routines. These strategies must be embedded into homes, school and community context rather than restricted to clinical treatment sessions.

Our findings also highlight the limitations of existing sensory assessment tools, which often assume typical mobility or conflict with motor execution, particularly for children classified as GMFCS IV–V. Parent reports add ecological value but are influenced by interpretation, environmental context, and expectations. These limitations support the need for a CP-specific sensory instrument that can (a) distinguish sensory from motor impairment, (b) offer alternative response modes or observational scoring, (c) capture heterogeneity across cognition, communication, and motor profiles and (d) support development of a sensory functional classification system, analogous to GMFCS or VFCS, to enhance decision-making and individualized intervention planning.

The results further emphasize the importance of early, developmentally attuned interventions. Participation in adulthood is shaped by the opportunities, expectations and supports provided in early childhood. Consistent with Cooper et al. (2023) and others, environments that encourage autonomy, exploration, and decision-making form the foundation for social participation, self-efficacy, and later employment. Therefore, families, educators, and therapists require early guidance to address emotional-social responsiveness, sensory modulation needs, and visual processing demands in everyday contexts.

Intervention frameworks for CP-CVI must integrate sensory, visual, motor, and environmental elements rather than treating them as isolated domains. Effective intervention for children with CP-CVI may require reconsideration of environmental design and therapeutic intensity. Sensory experiences may need to be more salient, prolonged, and multimodal input (e.g. involve incorporating vibrotactile feedback into visual learning tasks, using enhanced auditory cues to support visual attention, or providing proprioceptive input to improve sensory awareness and motor planning). This input must be repetitive and intensive enough to overcome high thresholds yet balanced to avoid overwhelming visual

processing. Creating environments that are stimulating yet manageable is a central therapeutic challenge. Understanding these requirements is essential for setting realistic goals, designing treatment schedules, and determining the time and intensity needed to support neural activation and learning.

The pervasive nature of sensory processing dysfunction in CP-CVI suggests that these issues must be integrated into broader therapeutic approaches rather than treated as a separate domain. The interaction between sensory processing and motor function is particularly important, as many motor learning approaches assume typical sensory, including visual, feedback mechanisms that may be compromised in this population. Motor interventions that rely on kinesthetic awareness, proprioceptive feedback, or visual guidance may require substantial modification, especially given a strong association found between the severity of CVI and motor functioning in children with profound intellectual and multiple disabilities (Salavati et al., 2014; Steendam et al., 2025;Van Splunder et al., 2006).

In summary, recognizing sensory processing dysfunction as a **c**ore, interconnected feature of CP-CVI represents a meaningful paradigm shift. Interventions that jointly address sensory and visual systems hold significant promise for improving participation, motor learning, and QOL in this underserved population (Dan, 2025; Waiserberg et al., 2025).

Chapter 5: Conclusion

5.1 Main Finding

This study demonstrated that children with CP-CVI present with a dual pattern of substantial visual processing difficulties and a high prevalence of SPD. Rather than functioning as secondary impairments, these domains act as interconnected determinants of participation and QOL. By identifying how visual and sensory characteristics co-occur and interact, the study provides a comprehensive understanding of the unique sensory profile of children with CP and CVI and the complex mechanisms shaping daily functioning and participation in CP-CVI.

Visual and sensory processing domains were associated with the children's ability to participate in all settings. In addition, environmental factors including barriers, support, and parental desire for change, also linked to participation and emerged as a predictor of QOL, underscoring the role of the environmental accessibility to modulate the sensory demands, within the ICF and the PEOP framework.

Methodologically, this study demonstrated the feasibility and added value of combining objective, short computerized psychophysical assessment with parent-report questionnaires and functional classifications. The 10 to 20 min computerized protocol offers an accessible, ecologically valid screening tool that can support referrals, guide further assessment.

Differences between objective tasks and parent questionnaires highlighted the multilayered nature of functioning: psychophysical tasks isolate specific processing deficits, while questionnaires capture real-world behaviors. This complementarity further supports integrated, context-sensitive assessment models.

By framing assessment within an ICF and PEOP holistic model, this study demonstrates how CVI interacts with sensory and motor systems to limit participation and

QOL and guide clinicians toward a practical, developmentally sensitive battery for identifying challenges to determine meaningful, individualized goals.

The study challenges the applicability of current sensory profile tools and suggests the need for adaptations tailored to the CP population, and particularly to children with CP-CVI, to enable more accurate detection of potential sensory challenges.

Results confirmed significant associations between body functions and participation. Visual attention predicted participation at home (R^2 = .085). Visual motion perception, recognition, navigation, and VFCS scores predicted school participation (R^2 = .369). The physical domain of QOL was predicted by GMFCS and visual motion perception (71%), whereas the social QOL domain was predicted by emotional-social responsiveness, environmental supports, and specific visual functions (59%).

These findings strengthen the linkage between disability, functioning, participation, and well-being. Emotional-social responsiveness emerged as especially critical for participation in school and community contexts and for overall QOL. Sensory processing quadrants (registration, seeking, avoiding) and specific sensory domains (visual, vestibular/body movement) each contributed differently across participation domains, highlighting the specificity of mechanisms rather than a generic effect.

Although not an intervention study, the findings carry meaningful implications for practice. Visual functioning is task-dependent, supporting goal-directed and context-sensitive therapeutic approaches. Different environments place distinct demands on visual and sensory systems; therefore, intervention must include setting-specific adaptations and individualized strategies. Enhancing participation may require classroom-based adaptations targeting attention and recognition for one child, while another may benefit more from gaze-control or navigation-focused supports. Interventions must also address sensory regulation and environmental barriers, moving beyond traditional visually focused therapy to consider the full sensory profile and environmental structure.

5.2 Contributions of the Study

This study offers several important contributions to the field of CP, CVI and pediatric rehabilitation. By integrating the ICF and PEOP frameworks, the findings were interpreted at the level of functioning, participation, environment accessibility, and QOL rather than focusing solely on impairments. This holistic perspective strengthens understanding of how CVI and SPD interact within daily occupations.

The study validated a novel set of short, engaging computerized psychophysical tasks (oddball pointing, oddball gaze, pursuit with occlusion, and video clip viewing). These tasks successfully differentiated children with CP-CVI from neurotypical peers and correlated well with established clinical tools such as CVI Range, VFCS, and IIQ.

The use of gaze-based paradigms promoted inclusivity and allowed meaningful participation of children with severe motor impairments (GMFCS IV–V), reducing motor bias and promoting equitable assessment.

Ecological validity was enhanced using short, engaging tasks that were feasible in both clinical and educational settings (e.g., video clip paradigm).

Finally, combining psychophysics, structured observation, parent report, and functional classifications demonstrated that no single tool could capture the complexity and heterogeneity of CP-CVI. This underscores the need for comprehensive, multimodal assessment approaches.

The study provided evidence for distinct visual and sensory processing mechanisms that influence participation and QOL differently across settings, supporting individualized assessment and intervention.

Environmental support and barriers were shown to significantly influence participation and predict QOL, reinforcing the need for system-level, family-centered, and school-based adaptations.

Findings support the development of integrated visual–sensory–motor intervention models, emphasizing task demands, environmental modification, and individualized sensory regulation strategies.

Figure 32
ICF-Based Model: CVI, SMD, Environmental Influences Participation, and QOL

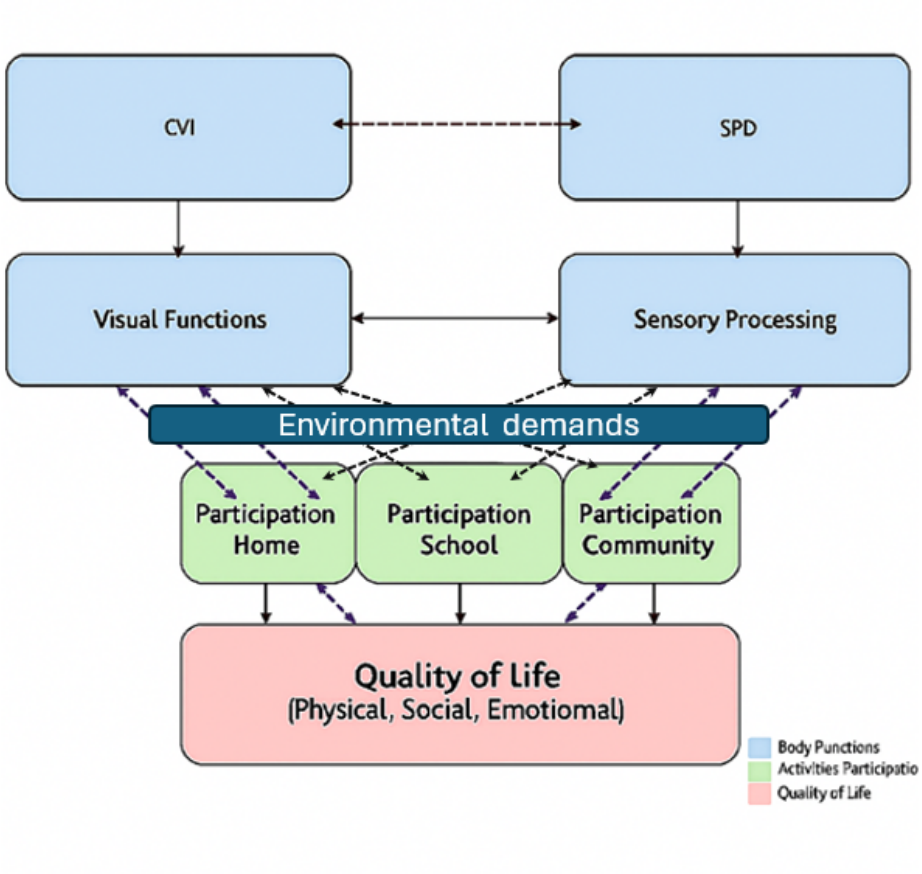


Figure 32 illustrates the ICF-based model of the relationships between CVI, SPD, environment, participation, and QOL. The color coding reflects the ICF framework domains: body functions and activity (blue), participation (green), and QOL (pink). A dashed arrow represents the interaction between CVI and SPD, highlighting their frequent co-occurrence, the solid arrow between visual function and sensory processing highlight the

study findings for connection and mutual influence on multisensory integration. Dashed arrows from visual function and sensory processing represent the interaction with environmental demands influence participation in different settings and emphasizing that participation contexts also feedback to increasing demands on visual and sensory systems, creating a bidirectional relationship. Solid black arrows to QOL, indicate unique direct pathways from body functions different aspects of QOL.

5.3 Limitations and Future Research

This study provides important insights into the interplay between CVI, SPD, participation, environment and QOL within the ICF and PEOP frameworks. Nevertheless, several limitations should be acknowledged. First, participants were recruited through medical, therapy professionals, and vision-education referrals, ensuring that the sample included children with confirmed CVI related difficulties. While this strengthens the internal validity of the findings, it may limit generalizability, as the results may not apply to children who were not referred to or identified. In addition, the sample consisted mainly of children with mild-to-average cognitive levels who attended both mainstream and special education settings, therefore, the findings cannot be generalized to children with significantly lower or higher levels of functioning. Second, the number of participants in the CP-CVI group was smaller than originally planned (51 instead of 60), which may have reduced statistical power. Moreover, the cross-sectional design prevents conclusions about causality or developmental changes over time. Longitudinal studies are needed to examine developmental trajectories and to evaluate how early detection and intervention may affect participation, environmental accessibility, and QOL. Thirdly, several measures relied on parent-report questionnaires, which may be influenced by parental perceptions and expectations. Fourth, although the study combined subjective reports with objective computerized visual tasks, certain potentially relevant domains, such as auditory processing, fatigue, or executive functioning, were not directly assessed.

Lastly, future research should build on the current findings by including larger and more diverse samples across the full spectrum of CP functioning, including children not previously identified with CVI. Population-based surveys could help estimate the prevalence of underdiagnosed visual and sensory processing difficulties, even among children with relatively high sensory and visual functioning. Such studies would strengthen the validity of our multidimensional assessment battery developed in this work and provide a more comprehensive understanding of the hidden burden of CVI and SPD in the CP population.

The findings from our study highlight several important areas for future research that could advance understanding and treatment of sensory processing dysfunction in CP-CVI. First, longitudinal studies to track sensory-visual trajectories and their influence on motor and participation outcomes; Second, combined behavioral-neuroimaging approaches (EEG/DTI/fMRI) to clarify neural networks underlying SPD in CP-CVI. Third, intervention trials specific to CP-CVI, examining sensory-based therapies, environmental modifications, and the optimal intensity of visual and sensory input; Finally, development and validation of CP specific sensory tools and functional sensory classification system. Recognizing sensory processing dysfunction as a core, interrelated feature of CP-CVI represents a meaningful paradigm shift. Integrated visual-sensory-motor interventions hold promise for improving participation, motor learning, and QOL in this underserved population.

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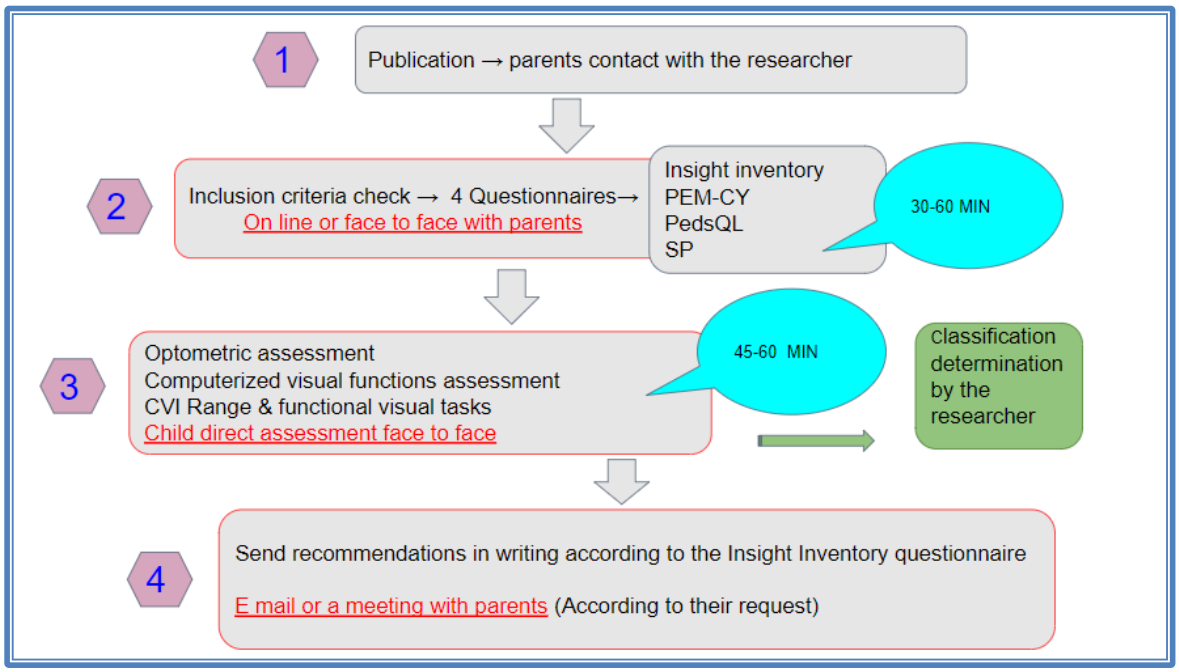
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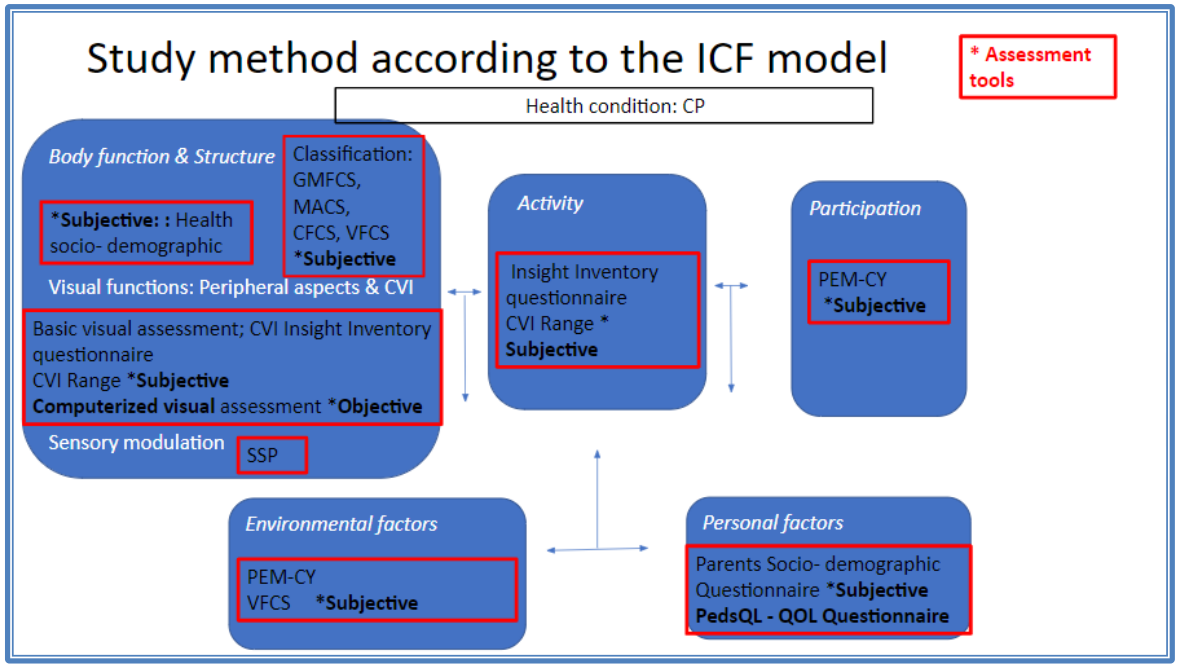
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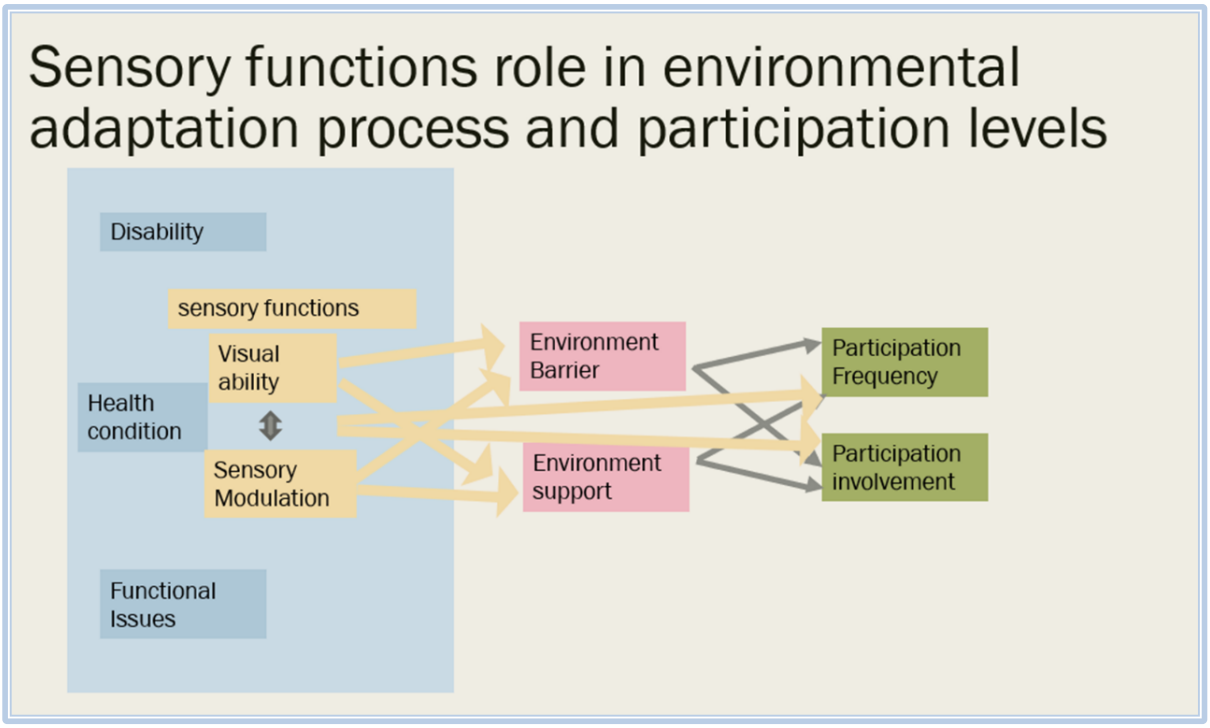
Appendices

Appendix A: Assessment Process





In this model adapted from Anaby et al. (2015), we added and highlighted the sensory functions on the disability part. The model emphasizes environment as a mediator that can support or restrict participation with a specific disability. We stress the importance of detecting and profiling sensory abilities to direct adequate environmental adaptations that might be underdiagnosed until now.



Appendix B: Questionnaire of Details and Suitability for the Study

מספר במחקר: _____

שם:_____ ת.ז_____ ת.ל_____ מין: נ / ז

אבחנה:_____

לומד בבית ספר:_____ בכיתה:____ עיר:_____

פיזור :המיפלגיה ימין ☐ המיפלגיה שמאל ☐ דיפלגיה ☐ קוודריפלגיה ☐

סימפטומים נוירולוגיים דומיננטיים :ספסטיות ☐ אטקסיה ☐ דיסקינזיה/ כוריאה אטטוזיס ☐

שימוש במכשירי עזר _____:

סיווג רמת תפקוד :

GMFCS: I ☐ II ☐ III ☐ IV ☐ V ☐ MACS: : I ☐ II ☐ III ☐ IV ☐ V ☐

CFCS: : I ☐ II ☐ III ☐ IV ☐ V ☐ EDACS: : I ☐ II ☐ III ☐ IV ☐ V ☐

VFCS: : I ☐ II ☐ III ☐ IV ☐ V ☐

פירוט כיצד מתנייד בבית \ביה"ס \מחוץ למבנה (*צורת הניידות המבוצעת באופן הנפוץ ביותר)

מידע על תפקוד קוגניטיבי(IQ) אם יש

_____

_____

מידע על מבחני תפקוד

שנעשו :_____

_____

_____ _____

קשיים נלווים:

קשיי ראיה :_____ קשיי שמיעה:_____

הפרעת שפה:_____ הפרעת קשב :_____

הפרעת למידה :_____קושי תקשורתי:_____

קושי וויסותי :_____

קיום כאב:_____ בחודש האחרון ? כן ☐ לא ☐

מחלות נוספות :_____

אפילפסיה:_____ תדירות פירכוסים בשבוע :_____

אם לא כל שבוע-מהי תדירות הפירכוסים בשנה האחרונה :_____

תרופות באופן קבוע :(פרט_____

היסטוריה רפואית :

נולד בשבוע: ____ משקל לידה: _____

מהלך

ההריון:_____

לידה _____

לאחר הלידה:_____

_____ _____

_____

מידע הדמיות :

_____ MRICS) ☐ V ☐ IV ☐ III ☐ II ☐ I :_____ **:MRI**

VEP : _____

ERG: _____

<u>מידע אופטומטרי אם קיים :</u>

משקפיים:_____

רוחק/קוצר ראיה:_____

פזילה :_____

optokinetic _____

nystagmus ניסטגמוס :_____

Pursuit עקיבה: _____

saccadic movements _____

מיקוד fixation :_____

Visual field שדה ראיה:_____

Stereopsis_____

contrast sensitivity _____

_____

ממצאים נוספים לציין _____ :

<u>תמיכה וטיפולים :</u>

טיפולים מקצועות הבריאות :

_____:מספר פעמים בשבוע: _____

_____:מספר פעמים בשבוע: _____

_____:מספר פעמים בשבוע :_____

טיפולים אלטרנטיביים:_____

מספר פעמים בשבוע:_____

סיוע בכיתה: _____

משתתף בפעילויות אחה"צ :_____

השתתפות בחוגים:_____

חבר בתנועת נוער,פרט_____

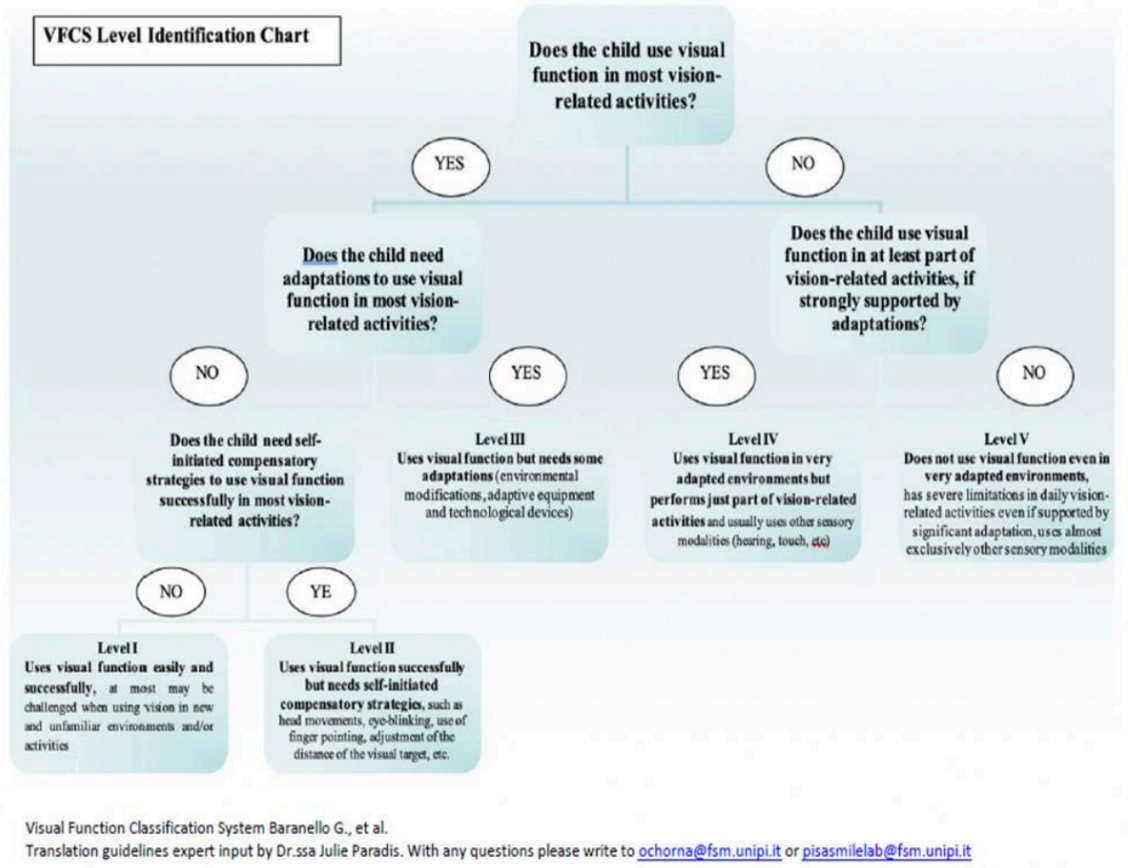
Appendix C: Functional Classifications in CP (Table from Baranello et al., 2020)

Table IV: General summary headings for the GMFCS, MACS, CFCS, EDACS, and VFCS

Level	GMFCS	MACS	CFCS	EDACS	VFCS
I	Walks without limitations	Handles objects easily and successfully	Sends and receives with familiar and unfamiliar partners effectively and efficiently	Eats and drinks safely and efficiently	Uses visual function easily and successfully in vision-related activities
II	Walks with limitations	Handles most objects but with somewhat reduced quality and/or speed of achievement	Sends and receives with familiar and unfamiliar partners but may need extra time	Eats and drinks safely but with some limitations to efficiency	Uses visual function successfully but needs self-initiated compensatory strategies
III	Walks using a hand-held mobility device	Handles objects with difficulty; needs help to prepare and/or modify activities	Sends and receives with familiar partners effectively, but not with unfamiliar partners	Eats and drinks with some limitations to safety; there may be limitations to efficiency	Uses visual function but needs some adaptations
IV	Self-mobility with limitations; may use powered mobility	Handles a limited selection of easily managed objects in adapted situations	Inconsistently sends and/or receives even with familiar partners	Eats and drinks with significant limitations to safety	Uses visual function in very adapted environments but performs just part of vision-related activities
V	Transported in a manual wheelchair	Does not handle objects and has severely limited ability to perform even simple actions	Seldom effectively sends and receives, even with familiar partners	Unable to eat and drink safely – tube feeding may be considered to provide nutrition	Does not use visual function even in very adapted environments

GMFCS, Gross Motor Function Classification System; MACS, Manual Ability Classification System; CFCS, Communication Function Classification System; EDACS, Eating and Drinking Ability Classification System; VFCS, Visual Function Classification System.

Appendix C1: Visual Function Classification System (VFCS; Baranello et al., 2020)



Visual Function Classification System Baranello G., et al.
Translation guidelines expert input by Dr.ssa Julie Paradis. With any questions please write to ochorna@fsm.unipi.it or pisasmilelab@fsm.unipi.it

Appendix C2: Gross Motor Function Classification System (GMFCS; Palisano et al., 2007)

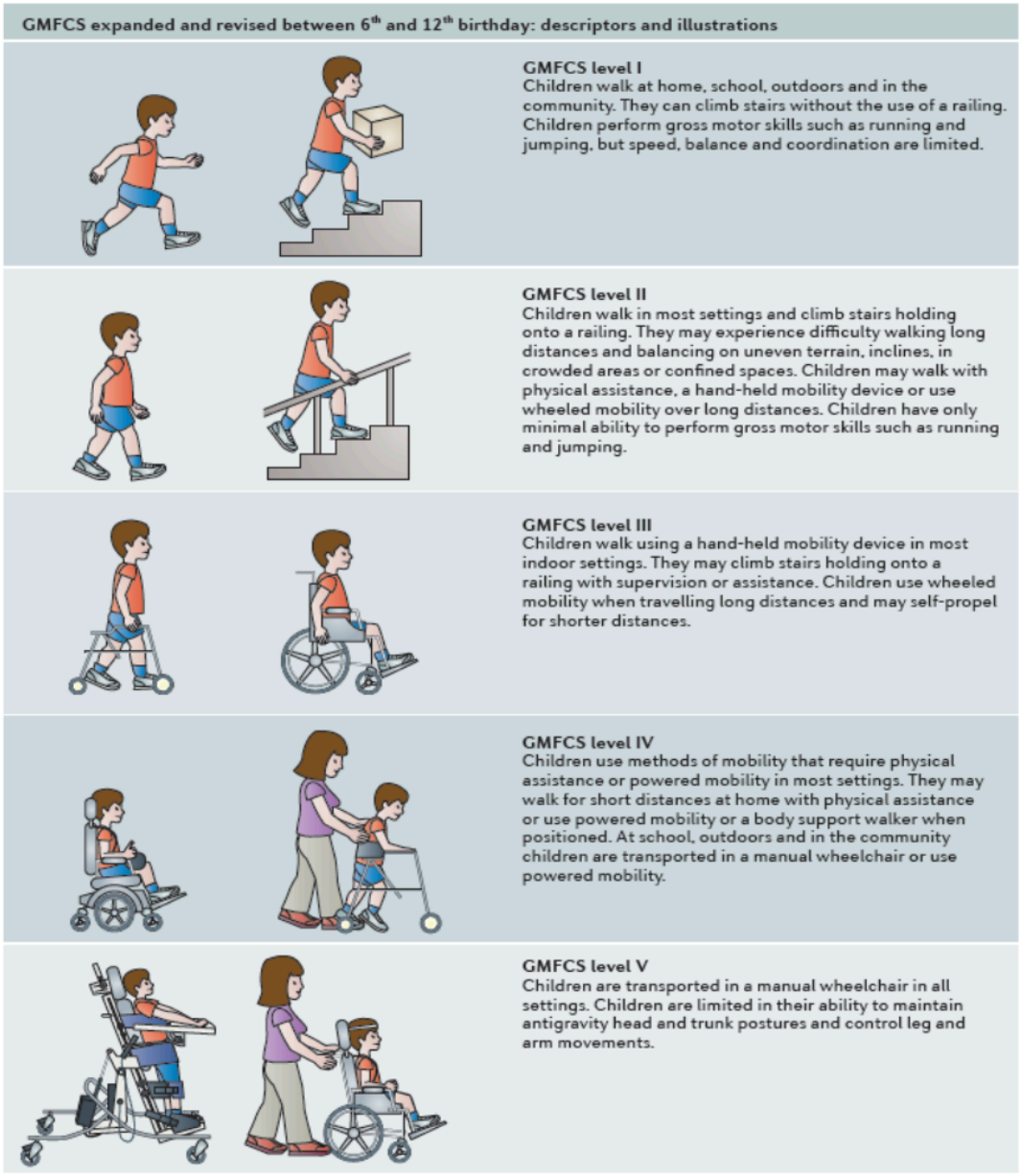
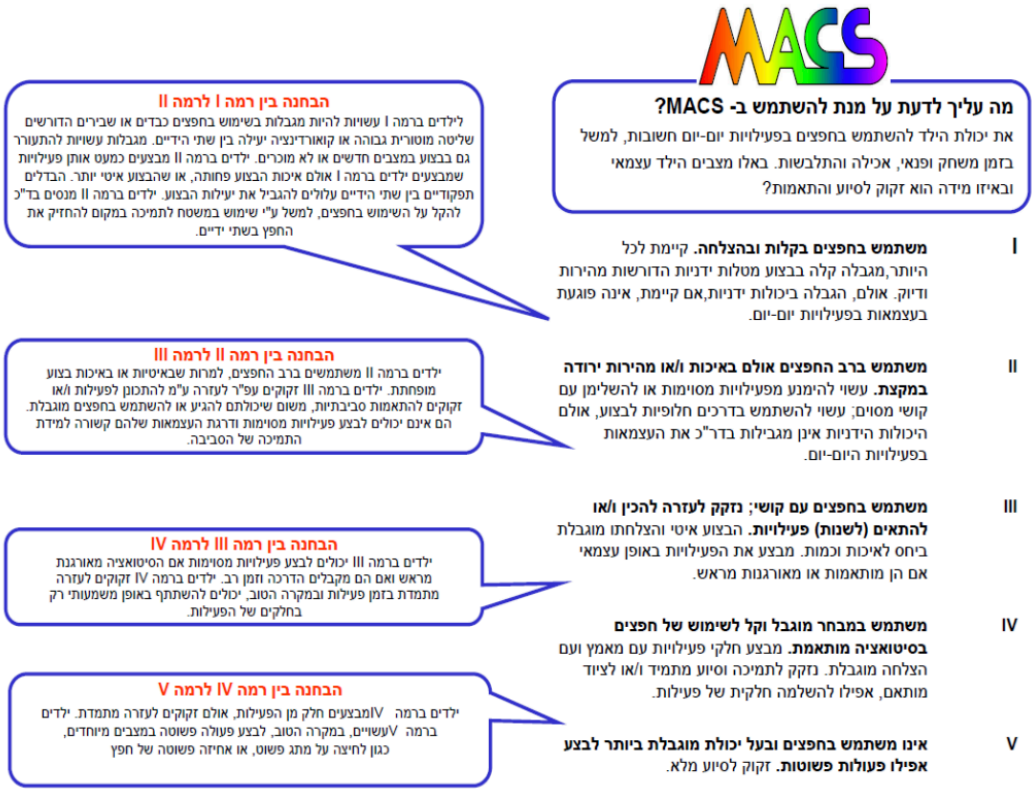
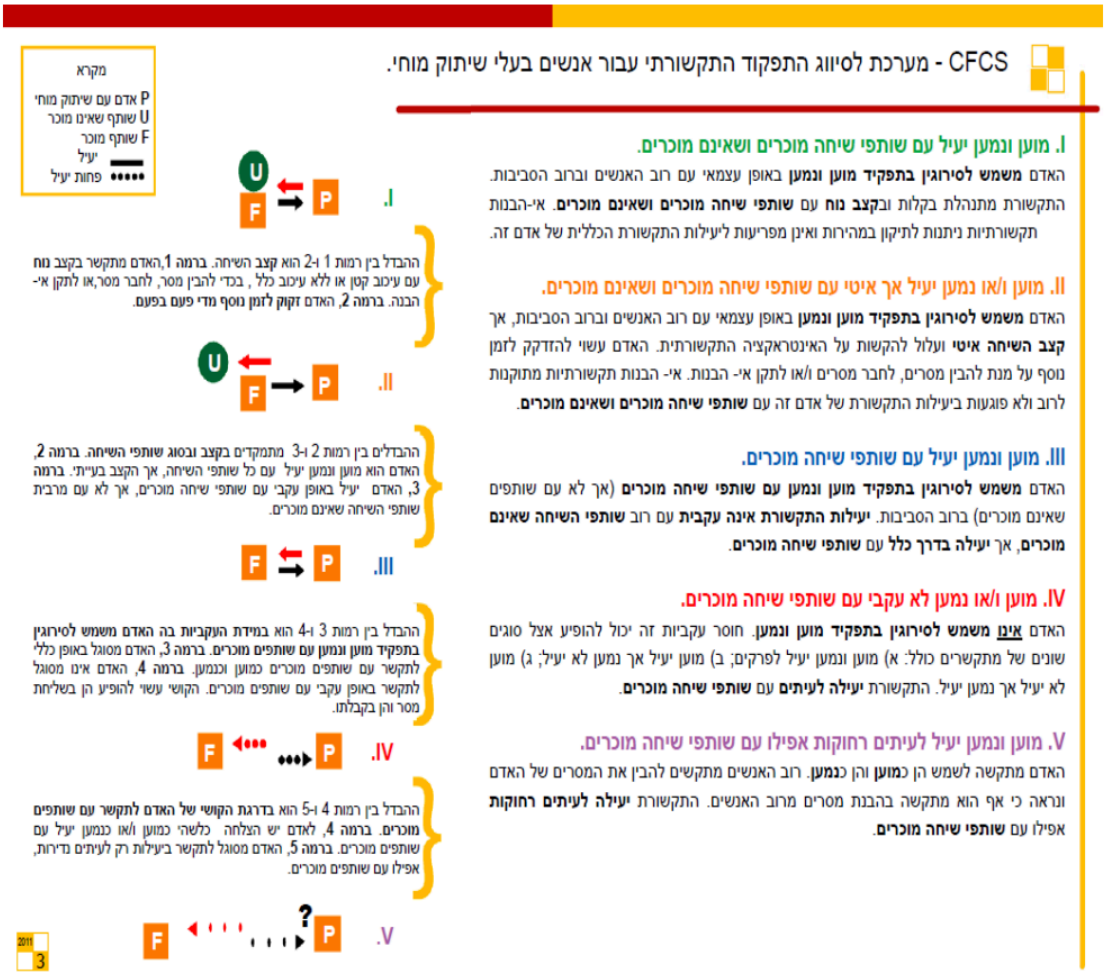


Figure 1 | **Gross Motor Function Classification System expanded and revised for children with cerebral palsy, 6–12 years of age.** The Gross Motor Function Classification System (GMFCS) has become the gold standard to classify motor function in children with cerebral palsy. The GMFCS is an ordinal classification in which different descriptors are used according to the age of the child. The descriptors for children 6–12 years of age are shown. GMFCS has been shown to be valid, reliable, stable and predictive of long-term gross motor function. The descriptors were devised by Palisano *et al.*[284,285]. Images are courtesy of B. Reid, A. Harvey and H.K.G., The Royal Children's Hospital, Melbourne, Victoria, Australia.

Appendix C3: Manual Ability Classification System (MACS; Eliasson et al., 2006)



Appendix C4: Communication Function Classification System (CFCS; Hidecker et al., 2011)



Appendix C5: Eating and Drinking Classification System (EDACS; Sellers, 2014)

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EDACS
EATING AND DRINKING ABILITY CLASSIFICATION SYSTEM

Eating and Drinking Ability Classification System

GENERAL HEADINGS

Level I	Eats and drinks safely and efficiently.
Level II	Eats and drinks safely but with some limitations to efficiency.
Level III	Eats and drinks with some limitations to safety; there may be limitations to efficiency.
Level IV	Eats and drinks with significant limitations to safety.
Level V	Unable to eat or drink safely – tube feeding may be considered to provide nutrition.

Fuller descriptions of the levels are given below along with distinctions between the levels. These are to assist in determining the level that most closely resembles an individual's current eating and drinking ability.

LEVEL OF ASSISTANCE REQUIRED

An individual's eating and drinking ability will be expressed as a level I-V followed by an indication of the degree of help needed at mealtimes. For example, a child who is able to eat safely with some limitations to efficiency and requires assistance in loading the spoon or steadying a cup would be **EDACS Level II Requires Assistance (RA)**; a child who has an unsafe swallow and is able to bring food and drink to the mouth would be **EDACS Level V Independent (Ind)**.

Independent (Ind) indicates that individuals are able to bring food and drink to their own mouth without any assistance. It does not indicate that individuals are able to modify food to the required texture for safe and / or efficient eating and drinking. It also does not indicate that individuals are able to sit independently.

Requires Assistance (RA) indicates that an individual needs help to bring food or drink to the mouth, either from another person or through the use of adapted equipment. Help may be needed loading the spoon, placing food in the hand or guiding the individual's hand to the mouth, holding a cup steadily, providing close supervision or verbal prompts.

Totally Dependent (TD) indicates that an individual is totally dependent upon another to bring food or drink to the mouth.

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Appendix D: The CP-CVI Group: Each Child's Neurologic and Optometric Information

	Age Yr	Gender	Type CP	Gestage (W)	Neuro	VFCS	CVI diag	cvir1	cvir2	Refr Rt	Refr Lt	VArt	Field	Pursuit	Eye move
1	7 1/3	F	Lt Hemi	29	IVH	2	Yes	8.5	9	2.5+	2.5+	-0.57	v	v	v
2	8 1/6	F	Lt Hemi	40	MCA	1	Susp	9.5	10	4.5+	3.25+	-0.30	v	v	v
3	5 1/6	F	Lt Hemi	28	IVH	2	Yes	9	9.25	1	0.75+	-0.54	v	(-)	v
4	16 2/3	M	Diplegia	30	PVL	2	Yes	8.75	9	1.0+	1.25+	-0.30	(-)	v	v
5	11 7/12	F	Tetraplegia	32	HIE	3	Yes	7.5	7	0.75-	0.75+	-0.48	(-)	v	v
6	7	M	Quad	40	HIE	1	Susp	9.5	10	0.25-	0.50-	-0.18	v	v	v
7	4 1/2	M	Diplegia	40	Corpus calosum	1	Susp	9.5	9.25	2.25+	2.25+	0.00	v	v	v
8	8 5/12	M	Quad	28	PVL, IVH	3	Yes	8	8.5	0.5+	0.5+	-0.60	v	v	v
9	10 4//12	F	Hemi	40	MCA	2	Yes	8.5	9	2+	1+	-0.60	(-)	v	v
10	14 1/2	M	Quad	34	PVL	3	Yes	8	8	0	0	-0.18	(-)	v	v
11	9 5/12	F	Quad	28	PVL	3	Yes	6.5	7	4.25+	4.5+	0.00	v	v	v
12	5 2/3	F	Hemi	40	Tumor	2	Yes	8.5	9	2+	2.2+	-0.54	v	(-)	v
13	14 5/6	M	Quad	28	PVL	3	Yes	6	6.25	0.25+	0.25+	0.18-	(-)	v	(-)
14	17	F	Diplegia	31	PVL	3	Yes	10	9.5	1+	1.25+	-0.54	v	v	v
15	7 3/4	M	Quad	40	Infraction	4	Yes	8	8	0	0	-1.30	v	v	v
16	15 2/3	F	Diplegia	27	PVL	3	Yes	8	9	4-	10.5-	-0.48	v	v	v
17	9 1/6	F	Diplegia	29	IVH	3	Yes	7	6.75	0	0	-0.60	v	v	v
18	9 1/12	M	Diplegia	25	IVH	2	Yes	9	9	3.5-	0.25-	-0.30	v	v	v
19	14 3/4	M	Quad	25	IVH	3	Yes	8	7	1.5+	1.5+	-0.18	(-)	v	v
20	15 3/4	F	Quad	40	N/A	2	Yes	8	8.5	4.5+	4.5+	0.00	v	v	v
21	10 1/4	F	Quad	25	IVH	3	Yes	9	8.5	4.5-	1.5-	-1.30	v	v	(-)
22	15 5/6	M	Quad	29	PVL	3	Yes	8	8.5	2.50+	1.75+	N/A	v	v	v
23	12 1/6	F	Quad	26	HIE	2	Susp	9.5	9	1.5+	1.5+	N/A	(-)	v	(-)
24	11 11/12	F	Quad	24	PVL	4	Susp	8.75	9	4-	0.5-	N/A	v	v	v
25	7 1/2	M	Quad	24	PVL	3	Susp	7	7	1.5+	1.5+	N/A	(-)	v	v
26	13 1/2	F	Diplegia	29	PVL	3	Susp	9	9	N/A	N/A	-0.48	v	v	v
27	17	F	Tetraplegia	26	IVH	3	Yes	8	9	N/A	N/A	-0.60	N/A	v	N/A
28	13 1/4	F	Diplegia	32	HIE	3	Yes	10	9	0.75+	1.5+	N/A	v	v	v
29	8 3/4	F	Quad	31	HIE	3	Yes	8	7	0.75+	1.00+	0.00	v	v	v
30	10 1/4	M	Diplegia	40	N/A	2	Yes	9	10	1.5+	1.5+	0.00	v	v	(-)
31	4 1/3	F	Hemi	27	IVH	2	Yes	9	9.25	4+	4.25+	-0.30	(-)	v	v
32	7	M	Diplegia	31	IVH	2	Yes	9	10	2.25-	1.75	0.00	v	(-)	(-)

	Age Yr	Gender	Type CP	Gestage (W)	Neuro	VFCS	CVI diag	cvir1	cvir2	Refr Rt	Refr Lt	VArt	Field	Pursuit	Eye move
33	14 1/2	M	Quad	28	PVL	3	Yes	7	6.75	N/A	N/A	-1.26	v	(-)	(-)
34	7 1/3	F	Quad	28	IVH	2	Yes	8.5	8.5	2+	2+	-0.60	(-)	v	v
35	11 1/6	M	Hemi	32	PVL	3	Yes	7	7.25	1.75	1.75	N/A	v	(-)	v
36	4 3/4	M	Quad	31	IVH	3	Susp	9	8.25	-	-	-	(-)	v	v
37	4 1/6	M	Diplegia	31	Micro cephalus	2	Susp	8	7.75	-4.5	1	N/A	v	v	v
38	7 7/12	M	Quad	29	IVH	3	Yes	8.5	8	3.25	2	N/A	(-)	(-)	(-)
39	17 1/2	M	Diplegia	34	PVL	3	Yes	7.75	8	1.5+	1.5+	-0.48	(-)	(-)	(-)
40	17	M	Quad	30	PVL	3	Susp	7.5	7.5	N/A	N/A	0.00	(-)	(-)	(-)
41	10 1/3	F	Quad	33	PVL	3	Yes	9	8.75	4.5-	5.75-	-0.48	(-)	(-)	(-)
42	8 1/2	M	Diplegia	40	PVL	2	Yes	9	9	0.75+	0.75+	-0.88	v	(-)	(-)
43	10 7/12	M	Lt Hemi	36	PVL	2	Yes	10	9.5	0.75+	1.5+	-0.70	v	v	v
44	4 1/3	M	Rt Hemi	26	IVH	2	Yes	9	8.75	1.5+	1.5+	0.00	(-)	v	v
45	9 2/3	F	Quad	34	PVL	3	Yes	9	9	2.5+	2.5+	0.00	v	v	v
46	10 ½	F	Rt Hemi	36	HIE	2	Susp	9	8.75	7.5	7.5	0.00	v	v	v
47	12 3/4	M	Quad	26	PVL	3	Susp	7.5.	7.5.	2.75+	4.75+	-0.62	v	(-)	(-)
48	8 11/12	M	Quad	35	HIE	3	Yes	9	9	1.25+	1.25+	0.00	(-)	(-)	(-)
49	12 1/3	M	Quad	33	PVL	2	Yes	9	8.5	3.25+	3.25+	-0.40	v	(-)	v
50	10 7/12	M	Quad	40	Infraction	3	Susp	7.5	7.25	1+	1.5+	-1.18	v	v	v
51	11	M	Diplegia	29	PVL	3	Susp	8.5	8.25	0.5+	0.5+	-0.48	(-)	(-)	(-)

*Note***.** M = male; F = female; CP = cerebral palsy; Lt = left; Rt = right; Hemi = hemiplegia; Diplegia = bilateral lower limb involvement; Quad = quadriplegia; Tetraplegia = involvement of all four limbs; Gest age = gestational age (in weeks); Neuro = neurological diagnosis; IVH = intraventricular hemorrhage; PVL = periventricular leukomalacia; MCA = middle cerebral artery infarct; HIE = hypoxic-ischemic encephalopathy; CVI = cerebral visual impairment; CVI diag = CVI diagnosis (Yes/Susp = suspected); VFCS = Visual Function Classification System (Levels 1–5); Refr = refraction (diopters); VA Rt/Lt = visual acuity (right/left eye); VArt/VAlt = visual acuity (right/left); VArt = visual acuity, right eye; VAlt = visual acuity, left eye; Field = visual field response (v = visual field detected; (-) = not detected); Pursuit = visual pursuit (v = present; (-) = absent); Eye move = voluntary eye movements (v = present; (-) = absent); / - = hyperopia (+) / myopia (-); .25, .5, etc. = diopter increments of refractive error.

קשיים בעיבוד חזותי וחושי בילדים עם שיתוק מוחין ולקות ראייה צרברלית

השלכות על השתתפות, נגישות סביבתית ואיכות חיים

נאוה גלקופ

תקציר

רקע : שיתוק מוחין (CP), הינו הפרעה נוירו־התפתחותית בתחום המוטורי, המלווה לעיתים קרובות בלקות ראייה צרברלית על רקע הפגיעה המוחית (CVI) ובקשיי עיבוד חושי. שילובם של גורמים אלה מגביל תפקוד יומיומי, השתתפות ואיכות חיים (QOL). עם זאת, המנגנונים המקשרים בין קשיים בעיבוד חושי, עיבוד ראייתי על מדרגי ופגיעה אוקולומוטורית לבין תפקוד והשתתפות, עדיין מובנים חלקית בלבד, במיוחד בקרב ילדים עם שיתוק מוחי ולקות ראיה מוחית, בעלי יכולות ראיה בסיסיות ויכולות קוגניטיביות שמורות יחסית, אך עם ליקויי עיבוד דורסלי והפרעה באינטגרציה התפיסתית. בהתבסס על סיווג ICF (WHO, 2001) ועל מודל PEOP, עבודה זו בחנה כיצד קשיי עיבוד חזותי וחושי פועלים במשותף ומשפיעים על השתתפות ואיכות חיים.

מטרות: (1) לבחון את שכיחות קשיי העיבוד החזותי וקשיי העיבוד החושי (SPD) בקרב ילדים עם CP-CVI בהשוואה לקבוצת ילדים נוירו-טיפוסיים; (2) לאמת כלי סינון פסיכו-פיזיקאלי חדש לזיהוי מרכיבי CVI; (3) להשוות בין הקבוצות בנוגע להשתתפות, נגישות סביבתית ואיכות חיים, ולבחון קשרים אלו בתוך קבוצת CP-CVI ; (4) לזהות מנבאים חזותיים, חושיים, תפקודיים וסביבתיים להשתתפות ולאיכות חיים.

שיטות : המחקר שילב שאלונים קליניים סטנדרטיים עם מטלות פסיכו-פיזיקאליות ורישום עיניים (eye tracking), להערכת רמות שונות של עיבוד חזותי ואוקולומוטורי. במדגם השתתפו 99 ילדים בגילאי 17–4 שנים (51 עם CP-CVI ו-48 נוירו-טיפוסיים). המשתתפים מילאו את שאלוני Insight Inventory Questionnaire (IIQ) להערכת עיבוד חזותי ומאפייני CVI, את שאלון Sensory Profile (SP) להערכת רישום וויסות חושי, את שאלון PEM-CY להערכת השתתפות וסביבה; ואת שאלון PedsQL למדידת איכות חיים. בנוסף, כל הילדים ביצעו שלוש מטלות ניסוי: (1) מטלת עקיבה חלקה (smooth pursuit) בתנאים גלויים ומוסתרים לבחינת תשואה (gain) והלטנטיות, שונות בראייה דו-עינית ויציבות פיקסציה;

(2) מטלת oddball מותאמת (McKyton et al., 2015) לבדיקת דיוק ומהירות תגובה ברמות מורכבות

שונות; (3) צפייה חופשית בסרטון קצר מצויר למדידת דפוסי מבט.

הניתוחים הסטטיסטיים בוצעו בתוכנה IBM SPSS 27 ובתוכנה MATLAB R2022a- וכללו מבחנים לא־פרמטריים, מתאמי ספירמן ורגרסיות לינאריות מדרגות.

ממצאים : נמצאו דפוסים עקביים של תפקוד חזותי ואוקולומוטורי חריג בקרב ילדים עם CP-CVI למרות חדות ראייה קרוב לתקינה או מתוקנת. השאלונים הצביעו על קשיי קשב חזותי, חיפוש חזותי ותפישת תנועה, לצד ליקויים משמעותיים בעיבוד ובוויסות החושי. מדדים חזותיים וחושיים נמצאו בקורלציה עם ירידה בהשתתפות, עלייה בחסמים סביבתיים וירידה באיכות החיים הפיזית, החברתית והרגשית. במטלת העקיבה, ילדים עם CP-CVI הראו שגיאות פיקסציה מוגברות, שונות גבוהה בראייה דו-עינית ותנועות ראש מודגשות, בעיקר בתחילת הגירוי. בתנאי הסתרה, מסלולי העקיבה סטו באופן מובהק מהתנאי הגלוי, עדות לפגיעה במנגנוני חיזוי ושליטה סגורה. מדדים אלו נמצאו קשורים להערכת תפקוד ראיה- CVI-Range ולסיווג הראייתי - VFCS ולציוני קשב חזותי ב-IIQ.

במטלת הבחנה חזותית ה- oddball, נצפו זמני תגובה איטיים יותר ופחות דיוקים בתנאים מורכבים, המעידים על ליקויי אינטגרציה חזותית ועל קשיי סינון. בצפייה בסרטון, דפוסי המבט של קבוצת CP-CVI סטו במידה ניכרת מאלה של ילדים נוירו-טיפוסיים (קורלציה ממוצעת $R\approx0.4$ לעומת 0.8, $p<0.0005$), כולל מעבר איטי יותר בין מיקומים ועלייה בסקאדות ובאקראיות בזמן. דמיון המבט לקבוצת הביקורת חזה במובהק את רמת הסיווג ב- VFCS , ואת החלק של קשב ראייתי ב-IIQ ($R\approx0.7$) , מה שמאשר את התוקף האקולוגי של המדד כמדד סקר לסיווג CVI.

קשיי עיבוד חושי היו נפוצים יותר בקבוצת CP-CVI בעיקר בתחומי ראייה, ווסטיבולרי ושמיעה, וכן במודולציה של טונוס, תנועה ותגובתיות התנהגותית. רישום חושי היה התחום הפגום ביותר, כאשר 98% מהילדים עם CP-CVI, הראו ליקויים בתחום. תחומי ה-SP נמצאו בקשר למדרגי תפקוד, לתחומי ה-IIQ ולביצועים הפסיכו-פיזיקאליים.

ילדים עם CP-CVI השתתפו בפחות פעילויות והתמודדו עם חסמים סביבתיים רבים יותר בכל ההקשרים. קשרים משמעותיים נמצאו בין יכולות חזותיות וחושיות לבין השתתפות בבית, בבית הספר ובקהילה. לדוגמה, בבית נמצא קשר בין מספר ותדירות השתתפות לבין קשב חזותי ב-IIQ (r=.28–.34) ולזמני תגובה.

בבית הספר, מעורבות וחסמים נמצאו קשורים לתגובתיות התנהגותית ב-SP, בקהילה נמצא קשר בין תמיכה וחסמים לבין זיהוי חזותי ומורכבות חזותית.

מבחני רגרסיה הראו כי השתתפות בבית נבעה בעיקר מקשב חזותי (R^2=.14), והשתתפות בבית הספר הוסברה על ידי תפיסת תנועה, זיהוי חזותי וניידות חזותית, וכן דרגות הסיווג- VFCS (R^2=.37). איכות החיים הייתה נמוכה באופן מובהק בכל התחומים בקבוצת CP-CVI. איכות חיים חברתית ופסיכו־חברתית הייתה קשורה לתחומי SP, בעוד שאיכות חיים פיזית הייתה קשורה לכל מדרגי התפקוד. רגרסיות הצביעו על כך שאיכות חיים פיזית הוסברה על ידי סיווג ה-GMFCS, תחומי IIQ וגורמי השתתפות וסביבה (R^2=.71). איכות חיים חברתית הוסברה על ידי וויסות חושי, קשב חזותי ותמיכה סביבתית בקהילה; ואיכות חיים רגשית על ידי תמיכה בקהילה, הכוונת תנועה חזותית ותגובתיות התנהגותית-חושית.

מסקנות: תוצאות המחקר מצביעות על חתימה ויזו־מוטורית ייחודית לילדים עם CP-CVI המאופיינת במעברים איטיים ובלתי יציבים של המבט, תיאום דו-עיני לקוי ושליטת חיזויי פגומה. ליקויים אלה שזורים בקשיי פיענוח וויסות חושית ומתקשרים להגבלות בהשתתפות ואיכות חיים , עדות לפגיעות דו מערכתית המשולבת של תחום הראייה ותחום העיבוד החושי.

בנוסף, פרופיל העיבוד החושי בקבוצה זו היה מובחן והטרוגני, מה שמדגיש את הצורך בהערכה רב-ממדית ומעמיקה של עיבוד חושי וחזותי, מעבר לסיווגי תפקוד חזותי מקובלים, לשם איתור שונות תפקודית בעלת משמעות. ממצאי המחקר תומכים בגישה אינטגרטיבית המבוססת על מודלים של- ICF ו- PEOP, כוללת הערכה משולבת של מרכיבים חושיים, אוקולו-מוטוריים ותפיסתיים לצורך הבנה טובה יותר של השתתפות ואיכות חיים. רישום עיניים בצפייה מהווה כלי מבטיח לאיתור פגיעה בראייה תפקודית. התערבויות המשלבות חיזוק אינטגרציה חושית ומנגנוני חיזוי ויזו מוטוריים עשויות לשפר מעורבות, למידה ותפקוד יומיומי, ולתרום לשיפור השתתפות ואיכות חיים בקרב ילדים עם CP-CVI. שיתוף פעולה בין אנשי מקצוע מתחומי הבריאות, הראייה והחינוך הוא חיוני לקידום תפקוד אקולוגי ולקידום רצף טיפולי איכותי ועקבי.

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השלכות על השתתפות, נגישות סביבתית ואיכות חיים

נאוה גלקופ

בהנחיית : פרופ' בתיה אנגל יגר

פרופ' יורם בונה

חיבור לשם קבלת התואר

"דוקטור לפילוסופיה"

מונוגרפיה

אוניברסיטת חיפה

הפקולטה למדעי הרווחה והבריאות

החוג לריפוי בעיסוק

נובמבר 2025

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