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Visual, perceptual functions, and functional vision in children with unilateral cerebral palsy compared to children with neurotypical development

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ABBREVIATIONS

Beery-VMI Beery Buktenica Test of Visuo-Motor Integration

CP Cerebral palsy

CVI Cerebral visual impairment

FCVIQ Flemish cerebral visual impairment questionnaire

FrACT Freiburg Visual Acuity Test

MACS Manual Ability Classification System

MC Motor coordination

NTD Neurotypical development

TVPS-4 Test of Visual Perceptual Skills, Fourth Edition

uCP Unilateral cerebral palsy

VA Visual acuity

VMI Visual-motor integration

VP Visual perception

ABSTRACT

Aim: To investigate visual (perceptual) functions and functional vision in children with unilateral cerebral palsy (uCP) and children with neurotypical development (NTD).

Method: Fifty children with uCP (mean age 11y 11 mo, SD 2y 10 mo, range 7-15 years; 27 males; 26 left-sided uCP; Manual Ability Classification system levels (MACS): I=27, II=16, III=7) and 50 age- and sex-matched children with NTD participated in a cross-sectional study. Visual acuity, stereoacuity, and visual-perceptual functions were measured with standardized clinical tests. Functional vision was assessed in children with uCP with the Flemish cerebral visual impairment questionnaire (FCVIQ). Group differences were investigated with Mann-Whitney *U* tests and Kruskal-Wallis tests and the relative effect sizes (r, η^2, respectively). Correlations between visual assessments and the FCVIQ were investigated with Spearman's rank correlations (r_s).

Results: The total group of children with uCP showed reduced visual acuity compared to children with NTD (p=0.02, r=0.23). Only children with left uCP scored lower than NTD on stereoacuity (p<0.01, r=0.36). Children with right/left uCP scored significantly lower than those with NTD on visual-perceptual functions (p=0.02-0.001) with large effect sizes on visuomotor integration and visual closure (both r=0.57). Children with uCP with MACS level III showed significantly lower scores on visual-perceptual assessments compared to children with MACS level I. Stereoacuity and visual-perceptual functions negatively correlated with the FCVIQ, with the highest association with visual (dis)interest and anxiety-related behaviors.

Interpretations: Multi-level visual profiling is warranted in the clinical intake of children with uCP to detect visual impairments that further compromise their level of functioning.

Short form of title (six words)

Visual impairments in children with uCP

What this paper adds.

- Children with uCP showed reduced visual acuity compared to NTD.
- Differences in stereoacuity were found only in children with left uCP.
- Children with left/right uCP showed reduced visual-perceptual ability compared to NTD.
- Visual-perceptual functions were most impaired in children with the lowest level of manual ability.
- Impaired stereoacuity and visual-perceptual functions affect functional vision.

Although cerebral palsy (CP) is defined as predominantly a motor childhood-onset disability, the impairments extend beyond motor functions.[1] Impairments in visual functions occur in 42.5% to 62% of children with CP[2] with a broad spectrum, including ocular, oculomotor, geniculostriate, and visual-perceptual impairments.[3] Specifically, cerebral visual impairment (CVI), a 'verifiable visual dysfunction not attributed to disorders of the anterior visual pathways or any potentially co-occurring ocular impairment',[4] is reported in 60% to 70% of children with CP.[5] The prevalence of visual impairments varies depending on the CP subtypes.[6] Particularly, in children with spastic unilateral CP (uCP), in whom predominantly one side of the body is affected,[1] previous studies reported on oculomotor impairment, reduction in visual acuity, visual field constrictions and hemianopia, altered stereoacuity and visual-perceptual functions.[3,6–9] Additionally, two studies showed that children with left uCP have worse performance on visual-perceptual tests than children with neurotypical development (NTD) or right uCP.[6,7] Despite the importance of these findings,[3,6–8] sample sizes were relatively small (n<20) and a control group was not included[3,6,8] or not matched.[7] Furthermore, previous studies demonstrated that decreased visual-perceptual abilities impact motor performance[10,11] and quality of life[12] in children with CP, underlining the importance of investigating the use of vision in everyday activities (i.e., functional vision).[13] Nevertheless, the multi-level relation between visual function and functional vision has not been extensively examined in children with uCP with different levels of manual ability.

Hence, the present study aims to (1) describe ocular, oculomotor, geniculostriate, and visual-perceptual impairments in children with uCP; (2) compare geniculostriate and visual-perceptual impairments between children with left uCP, right uCP, and age- and sex-matched children with NTD; (3) investigate potential differences in visual (perceptual) functions and functional vision in children with uCP with different levels of manual ability and (4) investigate the relation between geniculostriate, visual-perceptual impairments, and functional vision in children with uCP.

METHOD

Participants

Children with spastic uCP were recruited from the CP care program of the University Hospitals Leuven, Belgium, according to the following criteria: aged between 7 to 15 and ability to understand the test instructions. Moreover, this study data is part of a larger project which involves upper limb assessments. Therefore, participants were included if they could understand the test instructions and if they were able to actively grasp and stabilize an object (e.g., a small block 3cm x 3cm x 1cm and/or a pencil) with the non-dominant hand (House Functional Classification Score ≥ 4).[14] Participants were excluded when they received upper limb botulinum neurotoxin-A injections six months before testing or when they underwent upper limb surgery two years before assessment. The level of manual ability of children with uCP was categorized according the Manual Ability Classification System (MACS), where a higher level indicates worse manual ability.[15] Age- and sex-matched children with NTD were included when they had no neurological disorder, musculoskeletal problems of the upper limb, or uncorrected visual impairments. This study was approved by the Ethics Committee Research UZ/KU Leuven (no. S62906).

Procedure

A cross-sectional study was conducted between 2021 and 2023. Parents signed the informed consent and children from 12 years also provided their assent to participate. In children with uCP, information about clinical history (gestational age, birth weight) and comorbidities (epilepsy, ASD, ADHD, cognitive and hearing impairments) were retrieved through questionnaires filled by caregivers and through medical records.

Measures

To assess visual functions, standardized and age-appropriate tests were used. Specifically, the Freiburg Visual Acuity Test (FrACT) for far binocular visual acuity, the Titmus Stereo Fly test for binocular stereoacuity, the Test of Visual Perceptual Skills, Fourth Edition (TVPS-4) for motor-free visual-perceptual abilities, the Beery Buktenica Test of Visuo-Motor Integration (Beery-VMI) for motor-dependent visual-perceptual abilities, and the Flemish cerebral visual impairment questionnaire (FCVIQ) for functional vision were selected based on previous studies in CP.[6,16,17] All assessments were performed with both eyes open with best-corrected vision (i.e., wearing glasses).[18]

Ophthalmological characteristics

For children with uCP, ophthalmological information was obtained from caregiver questionnaires. Missing information was completed using data retrieved from medical records from the appointment that was closest to the date of the other visual assessments performed in our study. Ophthalmological data included the presence of ocular impairments (myopia, hypermetropia, and astigmatism), oculomotor impairment (strabismus), and geniculostriate impairments (amblyopia and nystagmus). In children with NTD, ophthalmological information was provided by caregivers.

Geniculostriate visual function

Visual acuity (VA). The Freiburg Visual Acuity Test (FrACT) software[19] was used to assess far binocular VA. Eighteen trials of Landolt C rings were displayed on a computer screen at 3m distance. The FrACT result was presented on the computer screen as a continuous variable in LogMAR (LogMAR = - $\log_{10}$(decimal acuity)[20]. VA in LogMAR was further categorized according to the World Health Organization as normal ($\leq$0.3), mild (0.3<to<0.5), moderately (0.5$\leq$to$\leq$1), or severely (>1) impaired.

Stereoacuity. To assess binocular stereoacuity, the Titmus Stereo Fly test was administered, wearing 3D glasses.[21] In the fly test, the child has to pinch the wings of a fly displayed in a 3D perspective. The circle test includes nine trials with a disparity ranging from 800 to 40 arc seconds where the subject had to look at four circles and choose the one that appeared to come out closer. The last correctly identified circle was recorded as the child's stereoacuity, with scores ranging between 1 and 9 (ordinal values). If the participant failed to identify the first circle, information from the fly test was retrieved and scored as 0 if failed and 0.5 if successful. Failure to identify the circle number 5 (100 seconds of arc) or lower was categorized as impaired stereoacuity.[22]

Results of VA (FrACT) and stereoacuity (Titmus Stereo Fly) were not adjusted for age since children were aged between 7 and 15, and according to literature, VA and stereoacuity are fully developed by the third year of life.[23]

Visual-perceptual function

The Test of Visual Perceptual Skills, Fourth Edition (TVPS-4)[24] was administered to assess motor-free visual-perceptual abilities. In our study, the visual memory and sequential memory subtests were not administered since we did not focus on memory-related deficits.

The Beery Buktenica Test of Visuo-Motor Integration (Beery-VMI) was administered to assess motor-dependent visual-perceptual abilities with the visual-motor integration (VMI) and the motor coordination (MC) subtests and, motor-free visual-perceptual abilities with the visual

perception (VP) subtest.[25] TVPS-4 raw scores were translated into scaled scores (mean=10, SD=3) and Beery-VMI raw scores into standard scores (mean=100, SD=15) according to the (chronologically) age-equivalent scores reported in the manuals. The scaled scores of the TVPS-4 and the standard scores of Beery-VMI were transformed into standardized z-scores (mean=0, SD=1) for between and within group analyses and categorized as normal (>-1), impaired (-2<to≤-1), and severely impaired (≤-2). TVPS-4 and VP results are grouped under motor-free visual-perception.

Functional vision

CVI was defined according to Sakki et al.[4] and diagnosis of CVI was retrieved from the medical records and reported as present, suspected, not present, or unknown. CVI diagnosis was performed in accordance with recommendations of Ortibus et al.[26] and carried out by a multidisciplinary team at the Center for Developmental Disabilities of Leuven (Belgium). Several assessments including neuropsychological tests measuring visual (perceptual) functions as well as neurological examination were used in combination with history-taking and caregiver and teacher interviews. Furthermore, the Flemish cerebral visual impairment questionnaire (FCVIQ),[27] a 46-item binary-response screening tool filled by the caregivers, was used to measure functional vision. Responses were calculated according to the sum of the 'yes' items (1: the child presents the characteristic described in the item; 0: characteristic not present) and grouped into five factors: object and face processing impairments, visual (dis)interest, clutter and distance viewing impairments, moving in space impairments, and anxiety-related behaviours.[28] The five factors are an average score, ranging between 0 and 1, calculated using the following formula:

$$\text{Score on factor} = \frac{\text{Sum of respective items for a specific factor}}{\text{Total number of items for a specific factor}}$$

For each of the five FCVIQ factors, we calculated medians and interquartile ranges. As a supplementary analysis, results were descriptively compared to the mean scores of children with and without CVI but suspected for visual-perceptual problems reported in the literature.[28] Higher averages (medians or means ranging from 0-1) reflect a higher level of visual function impairments.

Statistical analysis

Results of the visual assessments were reported as categorical variables for descriptive statistics and as ordinal values ranging between 0 and 9 (Titmus Stereo Fly) and numerical continuous variables (FrACT, TVPS-4, Beery-VMI, and FCVIQ) to assess normality and for between and

within group analysis. Specifically, results were reported in LogMAR for visual acuity, as ordinal values ranging between 0 and 9 for stereoacuity, as standardized *z* scores for the TVPS-4 and Beery-VMI, and as numerical continuous values ranging between 0 and 1 for the FCVIQ factors. Normality was assessed with the Shapiro-Wilk test and histograms were used to inspect data skewness. Since results of the visual and functional vision assessments were not normally distributed, between groups analysis was performed with Mann-Whitney U tests and Kruskal-Wallis tests and within group analysis with Spearman's Rank correlations. Data was analysed using SPSS v28 (IBM Corp., Armonk, NY, USA).

Between group analysis

Kruskal–Wallis tests with post-hoc comparison were used to investigate differences between children with left uCP, right uCP, and NTD. Kruskal–Wallis test effect sizes were calculated using eta squared (η^2)[29] and interpreted as small (0.010–0.059), medium (0.060–0.139), or large (≥0.140).[30]

If Kruskal-Wallis tests were not significant, Mann–Whitney *U* tests were performed to compare the total group of children with uCP and NTD. Mann–Whitney *U* test effect sizes were calculated using correlation coefficients (r)[29] and interpreted as small (<0.3), medium (0.3-0.5), or large (≥0.5).[31]

Kruskal–Wallis tests with post-hoc comparison and effect sizes (η^2)[29] calculation were performed to investigate potential differences in visual (perceptual) functions and functional vision between children with uCP with MACS level I (n = 27), level II (n = 16), and level III (n = 7).

Within group analysis

In children with uCP, Spearman's rank correlations (r_s) were performed to investigate the relation between geniculostriate function (stereoacuity), visual-perceptual function (TVPS-4 and Beery-VMI) and functional vision (FCVIQ). Results were interpreted as no or negligible correlation (<0.30), low (0.30-0.49), moderate (0.50-0.69), high (0.70-0.89), or very high (≥0.90).[31]

RESULTS

Participants

Fifty children with uCP (mean age 11y 11 mo, SD 2y 10 mo, range 7-15 years; 27 males; 26 left-sided uCP) and 50 individually age- and sex-matched children with NTD (42 right-handed) were included in the analyses. Participant characteristics and comorbidities are presented in

Table 1. One child was unable to complete any of the visual assessments due to severe comorbidities. Children with missing data (and their match) were excluded from the statistical analysis of that specific test but included for assessments where data was present (**Figure-online-only S1**).

Descriptive visual function measures

Table 2 shows the neuro-ophthalmological results for children with uCP and NTD.

Ophthalmological characteristics. Ophthalmological impairments ranged between 2% and 24% in children with uCP and between 0% and 14% in those with NTD. Hypermetropia (24%) and strabismus (20%) were the most prevalent ophthalmological impairments in children with uCP. Concurrent impairments were present in eight children with uCP: four children had hypermetropia and strabismus, one child myopia and strabismus, one child myopia and astigmatism, one child nystagmus and strabismus, and one child hypermetropia, astigmatism, and amblyopia.

Geniculostriate visual function. Geniculostriate impairments ranged between 12% and 39% in children with uCP and between 6% and 12% in those with NTD. Five (10%) children with uCP had both reduced VA and impaired stereoacuity.

Visual-perceptual function. Motor-free visual-perceptual impairments ranged between 29% and 44% in children with uCP and between 4% and 10% in those with NTD. The most impairment was found in the TVPS-4 visual closure for children with uCP (44%) and in form constancy for children with NTD (10%). Five to six (10-12%) children with uCP showed severe impairments, depending on the TVPS-4 subtests, while no severe impairments were found in children with NTD. In the Beery-VMI, the most impairment was found in the MC for both groups (uCP: 65%; NTD: 31%).

Co-occurring impairments. Impairments for more than three tests were found in one (2%) child with NTD and in 26 (53%) children with uCP. Four (8%) children with uCP showed impairments in all visual assessments. Furthermore, all these four children had cognitive impairments, two had CVI, two ASD, two epilepsy, one amblyopia, one strabismus, and one child had both strabismus and nystagmus. Additionally, in the uCP group, all the 10 (20%) children with strabismus showed impaired stereopsis.

Functional vision. **Table 3** shows functional vision descriptive results in the total group of children with uCP, further divided in suspected/diagnosed CVI, and no CVI. Visual (dis)interest was most frequently reported as impaired in the total group of uCP. Except for object and face processing impairments, children with uCP and CVI had equal or higher means compared to those with CVI reported in the literature.[28] Children with uCP without CVI showed lower means on all the factors of the FCVIQ compared to children with and without CVI (**Table-online-only S1)**.[28]

Between groups analysis

Table 4 shows the results of visual function assessments comparing children with left uCP, right uCP, and NTD. Differences between the three groups were found with moderate to large effect sizes for the Titmus Stereo Fly (p=0.007, η^2=0.08), the TVPS-4 (all p<0.01, 0.12<η^2<0.31), and the Beery-VMI (all p<0.001, 0.14<η^2<0.31). Post-hoc analysis (**Table-online-only S2**) showed that only children with left uCP scored significantly lower than children with NTD on the Titmus Stereo Fly (p=0.005, r=0.36) while both children with left and right uCP scored significantly lower than NTD on the TVPS-4 and Beery-VMI (r=0.29-0.58). No significant differences were found for the FrACT (p=0.064, η^2=0.04), however on the Mann-Whitney U test, the total group of uCP scored significantly lower than NTD (p=0.02; r=0.23. **Table-online-only S3**). The comparison of visual function and functional vision assessments between children with uCP with different levels of manual ability (MACS levels I-III) is presented in **Table-online-only S4**. Our results showed no significant difference in children with uCP with different levels of manual ability on visual acuity (FrACT), stereoacuity (Titmus Stereo Fly), and functional vision (FCVIQ). A significant difference was found for the visual figure-ground subtest of the TVPS-4 (p = 0.02, η^2 = 0.14) and the subtests of the Beery-VMI, namely visuomotor integration (p = 0.04, η^2 = 0.10), visual perception (p = 0.03, $\eta 2$ = 0.11), and motor coordination (p = 0.03, η^2 = 0.11). Post-hoc analysis showed that only children with MACS level III scored significantly lower on visual-perceptual assessments compared to children with MACS level I.

Within group analysis

Table 5 shows the Spearman's rank correlations between stereoacuity, motor-free visual-perception, VMI, MC, and functional vision in children with uCP. Low to moderate positive correlations were found between stereoacuity and (1) motor-free visual-perception (r_s=0.29-0.40), (2) VMI (r_s=0.50), and (3) MC (r_s=0.47). Low negative correlations were found between

impaired functional vision and (1) stereoacuity (r_s=-0.34 to -0.46), (2) motor-free visual-perception (r_s=-0.29 to -0.57), (3) VMI (r_s=-0.31), and (4) MC (r_s=-0.31).

DISCUSSION

In our study, we first described the visual profile of 49 children with uCP, reporting a wide spectrum of visual impairments in ophthalmological characteristics (2-24%), visual acuity (12%), stereoacuity (14%), motor-free visual-perception (44%), and visuomotor integration (62%). Only six children (12%) with uCP did not present with any impairment. Secondly, the total uCP group showed reduced VA compared to children with NTD. Only children with left uCP showed reduced stereoacuity compared to children with NTD, while both children with left and right uCP scored significantly lower than those with NTD on visual-perceptual assessments. No difference was found between children with right and left uCP. Lastly, we showed that impaired stereoacuity and visual-perceptual functions are related to functional vision in children with uCP.

Our results confirmed the presence of heterogeneous visual impairments in children with uCP (2-62%), further showing the frequency of co-occurring impairments on multi-level visual functions. Strabismus (20%) was present in all the children with impaired stereoacuity. This in line with previous studies showing that reduced stereoacuity and strabismus frequently co-occur in uCP.[3] Furthermore, 53% of children with uCP had impairments in more than three tests, highlighting the necessity of integrating visual function testing into routine CP assessment.

We found that children with uCP scored significantly lower than those with NTD on all visual assessments. This is in accordance with previous findings,[7,8] however, in our study children with uCP were individually compared to a control group matched for age and sex. Remarkably, differences in VA (with a small effect size) were only found when comparing children with NTD and the total uCP group. These results are in line with previous findings reporting that children with CP can have normal or mildly affected VA in the presence of more severe visual-perceptual impairments.[12,32] Only children with left uCP had lower performance than those with NTD on the Titmus Stereo Fly, in line with the hypothesis that the right parietal posterior cortex is responsible for stereoacuity.[33] To the best of the authors' knowledge, we are the first reporting that impairments in stereoacuity are found in children with only left uCP. Both children with left and right uCP showed reduced visual-perceptual functions compared to those with NTD. In the TVPS-4, the most discriminative differences were found for visual figure-ground and visual closure. Large effect sizes were also found for the Beery VMI and MC subtests that

require fine motor ability to draw. Previous studies showed that motor performance of the dominant hand of children with uCP are lower than those with NTD.[34] Beery VP, TVPS-4 visual discrimination and form constancy subtests were less discriminative between groups. These subtests require to identify two similar objects within a series, suggesting that, in children with uCP, this ability is less impaired compared to more complex skills involving filtering (visual figure-ground) and recognizing partially occluded information (visual closure). Overall, our results suggest that visual-perceptual impairments are more discriminative between groups than geniculostriate ones. VA and stereoacuity are subserved by the primary visual cortex and develop by the third year, while visual-perceptual functions improve up to 7-9 years with the development of parietal and temporal lobes.[23] This could result in different critical periods and early neuroplasticity processes which might compensate for impairments in (stereo)acuity.

We did not find differences between children with left and right uCP on the visual-perceptual assessments. This is in contrast with previous studies reporting that children with left uCP showed lower performance compared to right uCP or NTD.[6,7] This was explained by the fact that the right hemisphere of the brain processes visuospatial functions. Differences with our findings could be explained by more widespread (bilateral) lesions in our cohort. Specifically, children are divided into right/left uCP based on their clinical motor performance, which is not always reflected by lesions restricted to only one hemisphere of the brain. The presence of widespread (i.e., bilateral) lesions might lead to more severe impairments in visual functions. Previous studies showed that children with spastic bilateral CP present with more impairments in VA than children with uCP,[8] while no significant difference in visual-perceptual impairments has been reported between children with different spastic subtypes of CP.[8,35–37] Our findings on VA impairments in children with uCP (12%) are in line with the study of Stiers et al.,[8] showing that children with uCP (9%) present with less VA impairments compared to children with bilateral CP (54%).[8] In relation to visual-perceptual impairments, our results (ranging between 44-62% depending on the TVPS-4 and Beery-VMI subtests) are comparable with studies in children with bilateral CP (39-69% differing per study),[8,35–37] suggesting that the location rather than the extent of the brain lesion might affect visual-perceptual function development.

For functional vision, we found that visual (dis)interest was the factor most frequently reported as impaired in the total group of uCP. Furthermore, children with uCP and CVI descriptively had higher means on all the FCVIQ factors, except for object and face processing impairments (factor 1).[28] Previous findings showed that factor 1 is not associated with CP but is the most discriminative between children with and without CVI.[28] This was not replicated in our findings

in which the largest difference was found for moving in space impairments. Our results are explorative due to the small sample of children with (suspected) CVI (*n*=6). Nevertheless, a previous retrospective study found that CP explained additional variance in visual (dis)interest which was the factor that was most frequently reported as impaired in our study.[28] While the FCVIQ has good predictive value, it is still only considered a screening tool.[27] Hence, a diagnosis of CVI cannot be based exclusively on the FCVIQ results.

Differences in visual function in children with different levels of manual ability were only found between children with MACS levels I and III for all the subtests of the Beery-VMI and the figure-ground subtest of the TVPS-4. Only seven children with uCP had a MACS level III, while 27 children had a MACS level I. Hence, significant findings should be treated cautiously. According to previous studies, the motor performance of the dominant-hand in children with uCP is impaired compared to those of children with NTD and the accuracy of the movement is related to the extent of their brain lesion.[34,38] Hence, we could hypothesize that children with worse manual function in their non-dominant hand also have lower manual ability in their dominant hand. Furthermore, children with worse manual ability could present with more severe brain lesions which could potentially impact their visual (perceptual) functions and functional vision. Our results on the VMI and MC subtests of the Beery-VMI are in line with this hypothesis, showing that children with uCP and a MACS level III present with lower scores compared to those with MACS level I. A previous study, including children with uCP aged between 5 to 18 years, reported that visual-perceptual functions (measured according to the TVPS-3) did not differ between children with different levels of manual ability (measured according to the MACS).[6] In contrary, we found a significant difference in visual-perceptual functions (visual figure-ground subtest of the TVPS-4 and the VP subtest of the Beery-VMI) between children with MACS levels I and III. The study of Berelowitz and Franzsen[6] included different subtypes of CP, a different age range, and a different version of the TVPS, which might account for the differences from our results. No significant differences were found for functional vision (i.e., FCVIQ) in contrast to previous findings[39] which reported a moderate correlation between MACS level and functional vision measured with the Visual Classification Scale.[40] Differences in results could potentially be due to population characteristics since Gore et al.[39] included different types of CP (uCP: 21%) and the majority of children had a MACS level V (58%). Furthermore, they used the Visual Classification Scale, a five-level system designed for describing functional vision in children with CP, while the FCVIQ is a more

specific screening tool targeting CVI characteristics, which might explain the lack of relation to the MACS level in our participants.

In the relation between visual impairments and functional vision, impaired stereoacuity was correlated with impaired visual-perceptual functions and functional vision, with the strongest correlations with MC and VMI. This is line with previous studies showing that stereoacuity impairments impact the later development of movement planning and execution.[41] Additionally, children with more visual (dis)interest showed more impairments in VMI and in all the TVPS-4 subtests, while children presenting with higher anxiety-related behaviours had more impairments in the TVPS visual discrimination, spatial relationships, and form constancy subtests. Lastly, clutter and distance viewing impairments were associated with impaired VMI and MC. Previous studies showed that impaired visual-perceptual abilities are associated with a poorer quality of life in children with CP, particularly in recognition, attention, emotion and social components.[12] Our results further highlight which specific factors of functional vision are associated with impaired stereoacuity and visual-perceptual impairments.

Some limitations of our study should be noted. First, the ocular and oculomotor impairments in children with uCP were retrieved retrospectively from medical files in combination with caregiver reporting, and not always evaluated at the same time as the other visual assessments which could lead to "structural missingness". Nevertheless, reviewing of retrospective records gave us the advantage of attaining clinical data which otherwise would not have been available. Secondly, in the present paper we did not include visual field assessment results although visual field impairments can significantly affect visual-perceptual function and functional vision. Contradictory literature exists, as on the one hand, visual field function may normalize during childhood as a consequence of reorganization of the visual system,[42] but, on the other hand, studies in children with uCP report a presence of visual field impairments.[3,9] Therefore, visual field assessment should be addressed in future studies and included in the routine intake of children with CP. Lastly, functional vision was not assessed in children with NTD which limited the possibility to perform a between-group comparison. Nevertheless, in the authors experience, children with NTD rarely show impairments on the FCVIQ.

In conclusion, in contrast to motor impairments, visual difficulties are "not directly visible" and despite their negative impact on daily life functioning, they are understudied in children with uCP. We provided a comprehensive description of visual (perceptual) and functional vision impairments in children with uCP compared to age- and sex-matched children with NTD. We

found that both children with left and right uCP show more impairments than those with NTD in visual-perceptual functions. Furthermore, our results suggest that differences in stereoacuity are only present in children with left uCP and that visual-perceptual functions were more impaired in children with uCP with MACS level III compared to MACS level I. Lastly, stereoacuity and visual-perceptual impairments were associated with functional vision impairments, especially with visual (dis)interest and anxiety-related behaviours.

Our study highlights the need to include multi-level visual function assessments into the CP intake procedure. Future research could focus on profiling the child's performance at different levels of the visual hierarchy to understand what to prioritise in therapy, further supporting functional vision and quality of life of children with uCP.

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TABLES

Table 1. Clinical characteristics of children with unilateral cerebral palsy and children with neurotypical development.

General characteristics	**Category**	**uCP** ***n*** **(%)**	**NTD** ***n*** **(%)**
Mean age (SD)		11y 11mo (2y 10mo)	11y 11mo (2y 10mo)
Sex	Male	27 (54)	27 (54)
	Female	23 (46)	23 (46)
Handedness	Right-handed	26 (52)	42 (84)
	Left-handed	24 (48)	8 (16)
Side of cerebral palsy	Right-sided	24 (48)	
	Left-sided	26 (52)	
MRICS	A	2 (5)	
	B	28 (68)	
	C	8 (20)	
	D	1 (2)	
	E	2 (5)	
MACS	I	27 (54)	
	II	16 (32)	
	III	7 (14)	
[a]Gestational age	Term	26 (52)	
	Preterm	15 (30)	
	Very preterm	7 (14)	
	[c]Unknown	2 (4)	50 (100)
[b]Birth weight	Normal birth weight	30 (60)	
	Low birth weight	16 (32)	
	[c]Unknown	4 (8)	50 (100)
[e]Comorbidities	**Category**	**uCP** ***n*** **(%)**	
Epilepsy	No epilepsy	33 (66)	
	Epilepsy	17 (34)	
Autism spectrum disorder	No ASD	37 (70)	
	ASD	13 (26)	
Attention deficit hyperactivity disorder	No ADHD	47 (94)	
	ADHD	3 (6)	
Cognitive impairments	No	45 (90)	
	Yes	5 (10)	
Hearing impairments	No	50 (100)	
	Yes	0 (0)	
Cerebral visual impairment	No	37 (74)	
	Yes	4 (8)	
	[d]Suspected	4 (8)	
	[c]Unknown	5 (10)	

uCP: unilateral cerebral palsy. NTD: neurotypical development. SD: standard deviation. y: years. mo: months. MRICS: Magnetic Resonance Imaging Classification Scale.[43] Results available only in 41 children. A:

Maldevelopments; B: Predominant white matter injury; C: Predominant grey matter injury; D: Miscellaneous; E: Normal. MACS: Manual Ability Classification System.[15] [a]Gestational age refers to completed weeks of pregnancy: term ≥ 37–< 42 weeks, preterm ≥ 32–<37 weeks, very preterm < 32 weeks. [b]Birth weight: normal birth weight ≥ 2500 g, low birth weight < 2500 g. [c]Unknown reflects no reported data or missing data, which exists due to the retrospective data retrieval. [d]Suspected reflects screened for cerebral visual impairment with clear signs but no diagnosis. [e]Retrieved from medical records. Percentages are calculated out of the total sample of children with uCP (N=50) and with NTD (N=50).

Table 2. Visual function (ophthalmological, geniculostriate, and visual-perceptual) characteristics of children with unilateral cerebral palsy and children with neurotypical development.

Ophthalmological characteristics			**uCP N =49, *n* (%)**	**NTD N =49, *n* (%)**
Myopia		No	41 (84)	42 (86)
		Yes	8 (16)	7 (14)
Hypermetropia		No	37 (76)	46 (94)
		Yes	12 (24)	3 (6)
Astigmatism		No	47 (96)	49 (100)
		Yes	2 (4)	0 (0)
Strabismus		No	39 (80)	49 (100)
		Yes	10 (20)	0 (0)
Nystagmus		No	48 (98)	49 (100)
		Yes	1 (2)	0 (0)
Amblyopia		No	48 (98)	49 (100)
		Yes	1 (2)	0 (0)
Geniculostriate visual assessments		**Category**	**uCP N =49, *n* (%)**	**NTD N =49, *n* (%)**
Far visual acuity (FrACT)		Normal (VA ≤ 0.3 LogMAR)	43 (88)	46 (94)
		Mild (0.3 < VA < 0.5 LogMAR)	5 (10)	3 (6)
		Moderate (0.5 ≤ VA ≤ 1 LogMAR)	0 (0)	0 (0)
		Severe (VA > 1 LogMAR)	1 (2)	0 (0)
Stereoacuity (Titmus Stereo Fly)		Normal (≤ 100 sec per arc)	30 (61)	43 (88)
		Impaired (>100 sec per arc)	19 (39)	6 (12)
[a]Visual-perceptual function assessments	**Subtests**	**Category**	**uCP *n* (%)**	**NTD *n* (%)**
[b]Test of Visual Perceptual Skills, Fourth Edition (TVPS-4)	Visual Discrimination	Normal (z > -1)	32 (67)	44 (92)
		Impaired (-2 < z ≤ -1)	11 (23)	4 (8)
		Severely impaired (z ≤ -2)	5 (10)	0 (0)
	Spatial Relationships	Normal (z > -1)	34 (71)	46 (96)
		Impaired (-2 < z ≤ -1)	8 (17)	2 (4)
		Severely impaired (z ≤ -2)	6 (12)	0 (0)
	Form Constancy	Normal (z > -1)	32 (67)	43 (90)
		Impaired (-2 < z ≤ -1)	11 (23)	5 (10)
		Severely impaired (z ≤ -2)	5 (10)	0 (0)
		Normal (z > -1)	31 (65)	48 (100)

	Visual Figure-Ground	Impaired (-2 < *z* ≤ -1)	11 (23)	0 (0)
		Severely impaired (*z* ≤ -2)	6 (12)	0 (0)
	Visual Closure	Normal (*z* > -1)	27 (56)	44 (92)
		Impaired (-2 < *z* ≤ -1)	15 (31)	4 (8)
		Severely impaired (*z* ≤ -2)	6 (13)	0 (0)
Beery Buktenica Test of Visuo-Motor Integration (Beery-VMI)	Visuomotor Integration	Normal (*z* > -1)	18 (38)	40 (82)
		Impaired (-2 < *z* ≤ -1)	15 (31)	5 (10)
		Severely impaired (*z* ≤ -2)	15 (31)	4 (8)
	[b]Visual Perception	Normal (*z* > -1)	31 (63)	45 (92)
		Impaired (-2 < *z* ≤ -1)	11 (23)	4 (8)
		Severely impaired (*z* ≤ -2)	7 (14)	0 (0)
	Motor Coordination	Normal (*z* > -1)	17 (35)	39 (80)
		Impaired (-2 < *z* ≤ -1)	17 (35)	8 (16)
		Severely impaired (*z* ≤ -2)	15 (30)	2 (4)

uCP: unilateral cerebral palsy. NTD: neurotypical development. FrACT: Freiburg Visual Acuity Test. VA: Visual acuity. TVPS-4: Test of Visual Perceptual Skills, Fourth Edition. Beery-VMI: Beery Buktenica Test of Visuo-Motor Integration. One child was unable to complete any of the visual assessments due to severe autism. [a]Two children did not complete the TVPS-4 and one child the VMI subtest. [b]Motor-free visual-perceptual assessments.

Table 3. Medians and interquartile ranges of the five Flemish cerebral visual impairment questionnaire (FCVIQ) factors in children with unilateral cerebral palsy with and without cerebral visual impairment.

FCVIQ factors	**uCP Median (IQR) N=48**	**uCP with CVI Median (IQR) N=6**	**uCP without CVI Median (IQR) N=42**
[a]F1-FCVIQ	0.00 (0.00-0.10)	0.17 (0.08-0.32)	0.00 (0.00-0.06)
[a]F2-FCVIQ	0.13 (0.00-0.34)	0.38 (0.25-0.38)	0.13 (0.00-0.25)
[a]F3-FCVIQ	0.00 (0.00-0.25)	0.63 (0.00-1.00)	0.00 (0.00-0.25)
[a]F4-FCVIQ	0.00 (0.00-0.33)	0.67 (0.25-1.00)	0.00 (0.00-0.33)
[a]F5-FCVIQ	0.00 (0.00-0.20)	0.30 (0.20-0.60)	0.00 (0.00-0.20)

[a]Results are reported as numerical continuous values ranging between 0 and 1. FCVIQ: Flemish cerebral visual impairment questionnaire; F1: Object and face processing impairments; F2: Visual (dis)interest; F3: Clutter and distance viewing impairments; F4: Moving in space impairments; F5: Anxiety-related behaviours. uCP: unilateral cerebral palsy. IQR: interquartile range CVI: Cerebral Visual Impairment. Without CVI: Children screened with no diagnosis of CVI. Caregivers of one child did not filled the FCVIQ.

Table 4. Comparison between children with left unilateral cerebral palsy, right unilateral cerebral palsy, and children with neurotypical development on the visual assessments.

Visual assessment	Left uCP Median (IQR)	Right uCP Median (IQR)	NTD Median (IQR)	p-value	Effect size (η^2)
[a]FrACT	-0.12 (-0.19-0.15)	-0.09 (-0.22-0.21)	-0.18 (-0.25 to -0.05)	0.064	0.04
[b]Titmus Stereo Fly	4.00 (2.0-9.0)	9.00 (4.75-9.00)	9.0 (7.5-9.0)	**0.007**[**d]	0.08
[c]TVPS-Visual Discrimination	-0.33 (-1.67-0.25)	-0.33 (-1.00-0.33)	0.33 (0.00-0.67)	**0.001**[**** d,e]	0.12
[c]TVPS-Spatial Relationships	0.00 (-1.25-0.67)	0.00 (-1.00-0.67)	1.00 (0.33-1.00)	< **0.001**[*** d,e]	0.21
[c]TVPS-Form Constancy	-0.67 (-1.25-0.33)	-0.33 (-1.00-0.67)	0.33 (0.00-1.00)	**0.001**[*** d,e]	0.14
[c]TVPS-Visual Figure-Ground	-0.67 (-1.33-0.00)	-0.33 (-1.33-0.33)	0.33 (0.00-1.00)	< **0.001**[*** d,e]	0.30
[c]TVPS-Visual Closure	-0.67 (-1.58-0.33)	-0.67 (-1.33-0.00)	0.33 (0.33-1.00)	< **0.001**[*** d,e]	0.31
[c]Beery-Visuomotor Integration	-1.30 (-2.57 to -0.55)	-1.10 (-1.98to -0.73)	-0.17 (-0.67-0.43)	< **0.001**[*** d,e]	0.31
[c]Beery-Visual Perception	-0.47 (-1.73-0.13)	-0.47 (-1.32-0.07)	0.13 (-0.20-0.67)	< **0.001**[*** d,e]	0.14
[c]Beery-Motor Coordination	-1.53 (-2.53 to -0.83)	-1.20 (-1.85 to -0.47)	-0.27 (-0.83-0.33)	< **0.001**[*** d,e]	0.28

Cases were excluded pairwise. [a]Results are reported in LogMAR. [b]Results report the last circle identified or the fly test. [c]Results are reported in *z* scores. uCP: unilateral cerebral palsy. NTD: neurotypical development. IQR: interquartile range. FrACT: Freiburg Visual Acuity Test. TVPS: Test of Visual Perceptual Skills. Beery: Beery Buktenica Test of Visuo-Motor Integration. Significant results are shown in bold. Significance *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001. [d]Significant difference between children with left uCP and NTD. [e]Significant difference between children with right uCP and NTD; η^2: eta squared ($\eta^2 = \frac{H-k+1}{n-k}$, where H is the Kruskal-Wallis H-test statistic, k is the number of groups and n is the total number of observations). Effect sizes were interpreted as small (0.010–0.059), medium (0.06–0.139), and large (≥0.140).[30]

Table 5. Spearman correlations between the Flemish cerebral visual impairment questionnaire, the Titmus Stereo Fly, the Test of Visual Perceptual Skills, and the Beery Buktenica Test of Visuo-Motor Integration in children with unilateral cerebral palsy.

		TVPS-4					**Beery-VMI**			**Titmus**
		Visual Discrimination	*Spatial Relationships*	*Form Constancy*	*Visual Figure-Ground*	*Visual Closure*	*Visuomotor Integration*	*Visual Perception*	*Motor Coordination*	
Titmus	r_s	0.23	**0.29***	**0.40****	**0.31***	0.26	**0.50*****	**0.37****	**0.47*****	1.0
	p	0.12	0.05	0.01	0.04	0.07	< 0.001	0.01	< 0.001	.
F1-FCVIQ	r_s	-0.29	-0.20	-0.22	-0.08	-0.21	-0.26	-0.09	-0.08	**-0.34***
	p	0.05	0.18	0.13	0.59	0.16	0.08	0.55	0.59	0.02
F2-FCVIQ	r_s	**-0.46*****	**-0.45*****	**-0.46*****	**-0.30***	**-0.43****	**-0.30***	-0.27	-0.24	**-0.46*****
	p	0.001	0.001	0.001	0.04	0.003	0.04	0.06	0.10	0.001
F3-FCVIQ	r_s	-0.18	-0.10	-0.06	-0.10	-0.14	**-0.31***	-0.12	**-0.31***	**-0.43****
	p	0.24	0.51	0.67	0.53	0.37	0.04	0.42	0.03	0.002
F4-FCVIQ	r_s	0.00	-0.10	-0.11	-0.23	-0.19	-0.10	-0.08	-0.11	-0.25
	p	0.98	0.49	0.48	0.12	0.20	0.49	0.60	0.45	0.08
F5-FCVIQ	r_s	**-0.57*****	**-0.29***	**-0.32***	-0.23	-0.22	-0.03	-0.21	-0.18	-0.22
	p	< 0.001	0.05	0.03	0.11	0.14	0.82	0.15	0.21	0.13

Titmus: Titmus Stereo Fly. TVPS-4: Test of Visual Perceptual Skills, Fourth Edition. Beery-VMI: Beery Buktenica Test of Visuo-Motor Integration. FCVIQ: Flemish cerebral visual impairment questionnaire; F1: Object and face processing impairments; F2: Visual (dis)interest; F3: Clutter and distance viewing impairments; F4: Moving in space impairments; F5: Anxiety-related behaviours. r_s: Spearman correlation interpreted as no or negligible correlation (<0.30), low (0.30-0.49), moderate (0.50-0.69), high (0.70-0.89), and very high (≥0.90).[31] *p* :*p*-value. Significance *p ≤ 0.05, **p ≤ 0.01, ***p ≤ 0.001.