

Bimanual versus unimanual capacity and visuospatial monitoring in children with and without unilateral cerebral palsy

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Title page

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20 **Abstract**

21 Background: Many daily activities require coordinated use of both hands, which is
22 especially challenging for children with unilateral cerebral palsy (uCP), who present a more
23 affected and a less affected arm. Bimanual tasks, and especially asymmetric ones, demand
24 more complex action planning, sustained visuospatial monitoring and divided attention,
25 making them potentially challenging for children with uCP. This study compares relative
26 upper limb motor capacity and visuospatial monitoring strategies during bimanual and
27 unimanual visuomotor tasks in children with and without uCP.

28 Methods: Forty-three children with uCP (mean age=11.5±2.9 years) and 76 typically
29 developing (TD) children (mean age=11.1±2.6 years) performed bimanual and unimanual
30 tasks using a robotic exoskeleton with an integrated eye-tracking system. Motor capacity
31 was quantified using a hit ratio reflecting the relative contribution of each arm. Visuospatial
32 monitoring strategies were characterized by gaze position and variability.

33 Results: Both groups showed a larger asymmetry between arms in the bimanual task
34 compared to the unimanual one, but the difference was larger in children with uCP (group
35 x task interaction, $p = 0.019$). No systematic shift in lateral gaze position was observed
36 across groups or sides, but the variability in gaze lateral location differed between groups
37 during the bimanual task, being lower in children with uCP than TD children ($p = 0.002$).
38 Moreover, children with uCP monitored the space closer to their body during the bimanual
39 task while TD children looked farther away ($p = 0.047$).

40 Conclusion: In children with uCP, bimanual tasks accentuate motor asymmetry, leading to
41 reduced engagement of the more affected arm compared with unimanual tasks. These
42 motor deficits are observed alongside specific gaze patterns, characterized by restricted
43 visual exploration and reduced anticipatory visual of incoming targets. Overall, these
44 results indicate that visuomotor control in children with uCP is shaped by the specific
45 demands of bimanual tasks.

46 **Keywords:** Neurodevelopmental disorders, Youth, Oculomotor behaviour, Sensorimotor
47 integration, Gaze, Bilateral motor control

48 Introduction

49 Most everyday activities require to use both upper limbs (UL) in a concerted
50 manner, each UL contributing either simultaneously or sequentially to achieve the
51 behavioral goal (1,2). The complexity of bimanual tasks exceeds that of unimanual ones,
52 given that dual-limb synchronisation requires increased neural and cognitive efforts (3–
53 5). This impacts motor capacity, with longer reaction time, reduced movement velocity,
54 delayed target-force attainment as well as greater variability in force or movement
55 accuracy during bimanual compared to unimanual tasks (3–5). The reduced capacity
56 during bimanual tasks is thought to arise from the additional interhemispheric
57 communication demands (4), and is prominent when both ULs have to produce
58 asymmetric movements (6). Bimanual asymmetric tasks demand more complex action
59 planning, sustained visuospatial monitoring and divided attention, given that each hand
60 may have a different subtask (7,8). This requires the brain to decide when and where to
61 look to optimize the capacity of both effectors (9). Indeed, the eyes serve both hands but
62 can fixate only one location at a time, and peripheral vision is less precise (10,11).
63 Previous studies have reported asymmetries in the level of visuospatial monitoring of the
64 two hands that can be influenced by the hand dominance, task requirements
65 (symmetric/asymmetric, target characteristics) and age, and that the visuomotor strategy
66 can influence UL motor behavior (12–16).

67 Taken together, the heightened demands of bimanual actions make them
68 particularly challenging for children with neuromotor impairments such as unilateral
69 cerebral palsy (uCP) compared to typically developing (TD) children (17). uCP is defined
70 as a non-progressive motor and postural disorder resulting from early brain lesion, leading
71 to asymmetric motor and sensory impairments affecting corticospinal tract and

multisensory pathways on one side of the body (18,19). As a result, children with uCP often present developmental disregard, a phenomenon characterized by reduced spontaneous use of the more affected UL due to limited awareness of its functional capacity (20). Over time, such underuse reduces opportunities to practice and refine control of this UL and reinforces asymmetrical motor habits (21), which amplifies the challenges associated to the realization of bimanual tasks (20,22,23). This highlights the need to study the capacity of the more affected limb in the context of bimanual tasks compared to comparable unimanual tasks. Existing work has primarily examined the association between unimanual capacity and overall bimanual capacity in different tests (e.g. Jebsen-Taylor Hand Function Test vs. Assisting Hand Assessment), without assessing how each limb contributes across task contexts (24–27).

The higher demands on visuospatial monitoring during bimanual task adds an additional layer of complexity given that children with neurodevelopmental disorders, including uCP, frequently have trouble processing and combining visual information and exhibit alterations in eye-hand coordination (28–30). In TD children, gaze tends to anticipate hand movements, allowing them to rely more on feedforward control during rapid visuomotor actions (31). In contrast, children with uCP rely more heavily on visual information and show reduced anticipatory control during UL actions, especially as task complexity increases (30,32–34). Their increased dependence on visual input may represent a compensatory strategy to offset sensory deficits, enabling them to monitor movement execution more closely when internal sensory cues are insufficient (30,34,35). This may cause children to increase their visual monitoring of the workspace corresponding to the affected limb. According to a recent systematic review, no conclusive evidence exists regarding how the oculomotor and manual systems coordinate during bimanual tasks under varying visuomotor demands in individuals with uCP (30).

Examining visuospatial monitoring in bimanual versus unimanual tasks in children with uCP is crucial as it could provide deeper insight into the specific challenges, they experience in performing everyday activities.

Therefore, the general objective of this study was to compare the motor capacity of each UL as well as visuospatial monitoring in bimanual versus unimanual tasks in children with and without uCP.

Objective #1 was to determine whether the relative capacity of each UL (the more affected vs. the less affected) differs between bimanual and unimanual tasks in children with uCP and in TD children. It was hypothesized that children with uCP would demonstrate greater asymmetry in arm capacity during the bimanual task than during the unimanual task, reflecting developmental disregard. TD children were expected to show a similar directional pattern, reflecting a dominance effect. However, the difference between tasks was expected to be smaller than in children with uCP.

Objective #2 was to explore whether there are differences in visuospatial monitoring strategies between children with uCP and TD children during bimanual and unimanual tasks and between sides (non-dominant (or more affected) versus dominant (or less affected) UL). It was hypothesised that children with uCP would show a bias in visuospatial monitoring, i.e. that their gaze would shift toward the side of the workspace corresponding to their more affected UL and would stay closer to their body compared to TD children. It was also expected that children with uCP would explore the workspace to a lesser extent, resulting in less variability in gaze location.

Methods

Participants

Children with uCP and TD children were recruited as part of a multicenter cross-sectional study conducted in the provinces of Quebec and Alberta (Canada). Participants with uCP were identified through institutional mailing lists and clinical databases of the Centre intégré universitaire de santé et de services sociaux de la Capitale-Nationale (CIUSSS-CN, Quebec City) and through the Alberta Perinatal Stroke Project. TD participants were recruited through institutional mailing lists in Quebec City and through the Healthy Infants and Children Clinical Research Program in Calgary, which recruits healthy children via hospital-based advertisements, word of mouth, and online research platforms (36). Children with uCP were eligible if they: (1) were between 7 and 19 years old; (2) had a confirmed diagnosis of uCP; and (3) presented mild to moderate UL impairments, operationalized as levels I to III on the Manual Ability Classification System (37). The exclusion criteria were: (1) uncorrected visual severe impairments and/or cognitive limitations preventing task comprehension and behavioural problems preventing cooperation. No formal clinical evaluation of these criteria was conducted. Eligibility was based on parent report or available medical records. TD participants were included if they were 7 to 19 years old and had no history of neurological, developmental, or musculoskeletal conditions affecting UL function or vision. No specific inclusion criteria were applied regarding handedness. In children with uCP, the more and less affected sides were determined based on clinical diagnosis, whereas hand dominance in TD children was determined by self-report. Written informed consent was obtained from each participant or, for those under 18 years of age, from their legal guardian. Ethical approval for the study was granted by the CIUSSS-CN Research Ethics Board (RIS:

#2020-1961, #2023-2684) and by the University of Calgary Conjoint Health Research Ethics Board (CHREB: REB22-0303).

Experimental setup

All participants completed a robotic assessment using the Kinarm Exoskeleton Lab (Kinarm, Kingston, Ontario, Canada) (Further details can be found at the following link: <https://kinarm.com/solutions/exoskeleton-lab/>). The system supports the arms in the horizontal plane and allows free shoulder and elbow movements. Participants were seated in an adjustable chair, with both arms placed in padded troughs that were individually adjusted to ensure a comfortable posture and unrestricted planar motion. Visual stimuli were projected into the workspace through a semi-reflective mirror, while an opaque cover prevented direct vision of the UL. Standard anthropometric adjustments and system calibration were performed at the start of each session as per manufacturer instructions. Eye movements were recorded using an integrated EyeLink 1000 system (SR Research Ltd., Ottawa, Canada). Participants stabilized their head against a padded forehead rest, and monocular gaze position was sampled at 500 Hz within a $\sim 50 \times 50$ cm usable tracking area. Calibration of gaze to the augmented-reality workspace was performed using the manufacturer's procedures (Further details can be found at the following link: https://kinarm.com/wp-content/uploads/2023/07/EL1000Plus_UserManual_1.0.20_GOP.pdf). Calibration failure was defined as the inability to obtain a valid calibration solution (e.g., unsuccessful completion of the calibration procedure or unstable tracking). In such cases, eye-tracking data were excluded from further analyses. For successful calibrations, calibration quality was classified as Good when mean calibration error was $< 1.0^\circ$ and maximum calibration error was $< 1.5^\circ$, and as Fair when mean calibration error was between 1.0° and 1.5° and maximum calibration error was between 1.5° and 2.0° . Calibrations that did not meet

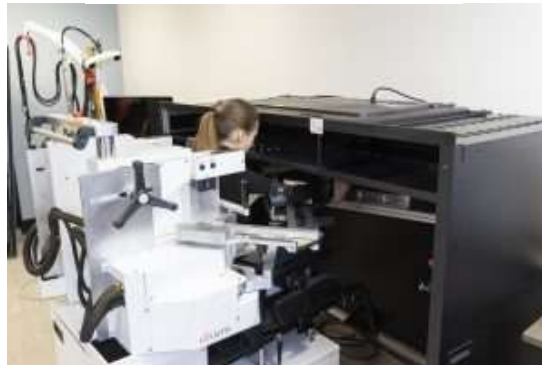
these criteria (i.e., Poor calibrations; calibration completed but accuracy outside acceptable limits) were repeated up to three times, depending on the child's level of cooperation. When acceptable eye-tracking calibration could not be achieved, the assessment proceeded with the manual task, and participants were still included in the study. If calibration remained Poor after repeated attempts, the corresponding eye-tracking data were excluded from further analyses. In addition to calibration quality, eye-tracking data were screened for signal quality. Datasets were excluded if more than 50% of gaze samples were missing or if the signal was excessively noisy and deemed non-exploitable after preprocessing. Final inclusion in eye-tracking analyses required at least Fair calibration accuracy and usable gaze signal quality. Calibration was performed using an 80% tracking area for most participants; however, in a few cases, the usable tracking area was reduced to 70% to achieve acceptable calibration. All kinematic data were exported in comma-separated values (CSV) format for subsequent processing and analysis.

Experimental tasks

Participants performed the Object Hit (OH) task using the Kinarm Exoskeleton Lab (Fig. 1A). The bimanual version of the task corresponds to the standard Kinarm OH task (Fig. 1B), whereas the unimanual version is a custom adaptation of the task developed to assess each arm separately (Fig. 1C). In both tasks, virtual paddles were displayed at the fingertips, and balls fell from the top of the workspace equally spaced horizontal locations (bins). Participants were instructed to intercept as many balls as possible before they reached the bottom of the screen. Direct vision of the arms was occluded, and a brief haptic pulse signaled paddle-ball contact. In the standard bimanual condition, participants were free to use both of their hands. A total of 300 balls were presented in 10 horizontal

bins over approximately 2 minutes, with ball speed and presentation frequency increasing progressively. In the custom unimanual condition, the task was performed separately with the dominant/less-affected arm and the non-dominant/more-affected arm while the other arm was maintained by the robot on the side of the workspace. Each unimanual trial consisted of 180 balls, presented with the same progressive speed increase as in the bimanual task. The spatial distribution was adjusted, corresponding to the 6 central bins of the 10 bins used in the bimanual tasks. That was done as it is impossible to reach the bins located completely to the opposite side of the workspace. Bins were removed on both sides so that the bins are similar between the unimanual task performed with each arm.

(A) Kinarm Exoskeleton Lab



(C) Bimanual task

(B) Unimanual task

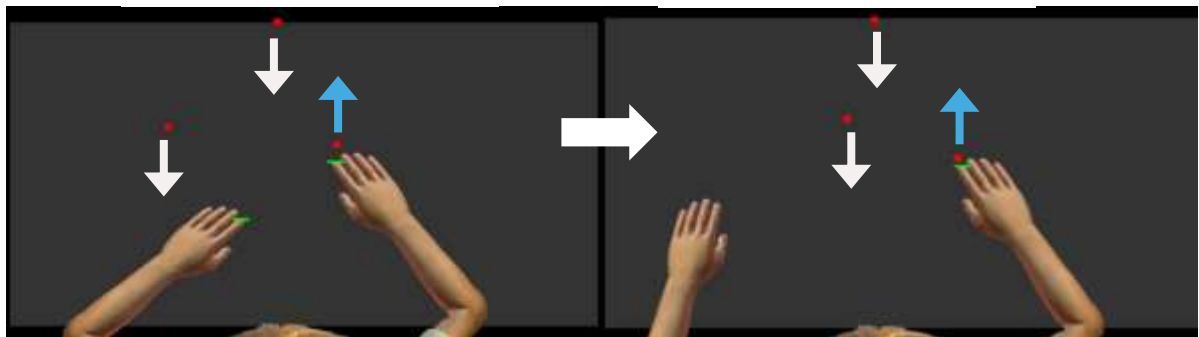


Figure 1. Kinarm setup and experimental conditions for the Object Hit visuomotor task. (A) Participant seated and installed in the Kinarm Exoskeleton Lab, with arms supported in the horizontal plane and visual stimuli projected into the workspace while direct vision of the arms is occluded. (B) Standard bimanual Object Hit task in which participants use both arms to intercept the falling balls across the workspace. (C) Custom unimanual version of the task performed separately with the dominant/less-affected and non-dominant/more-affected arm while the other arm remains stationary.

Outcome Measures

1. Relative Motor Capacity Measures

Hit Ratio (bimanual and unimanual tasks)

To quantify the relative motor capacity of each UL, a hit ratio was calculated as:

$$\text{Hit Ratio} = \frac{\text{Number of balls hit by the non-dominant / more affected arm}}{\text{Number of balls hit by the dominant / less affected arm}}$$

A ratio < 1 indicates reduced contribution of the non-dominant (or more affected) arm relative to the dominant (or less affected) arm. Note that during the bimanual task, the ratio represents the number of balls hit by each arm during the same trial, while in the unimanual arm it represents the ratio between the number of balls hit by each arm during distinct trials (i.e., one performed with each arm).

2. Visuospatial Monitoring Measures

Visuospatial monitoring behavior was characterized using measures extracted from the eye-tracking signal recorded during each condition. An example of the spatial distribution of gaze data and the derived measures is shown in Figure 2 for representative participants with uCP and TD.

Center of Mass of Gaze (x and y)

The center of mass of gaze position was computed as the mean gaze location in the x and y (38):

- Center of mass in x-axis: A positive value reflects a gaze bias toward the dominant / less affected side of the participant; negative values indicate a shift toward the non-dominant / more affected side.
- Center of mass in y-axis: Higher values correspond to gaze directed farther from the body, a behavior associated with more anticipatory visuomotor control in similar interception tasks (38).

Values are expressed in centimeters.

Gaze Variability (x and y)

Gaze variability was quantified as the range of the 95% confidence interval of gaze position along x-axis and y-axis. Larger values indicate greater dispersion of gaze across the workspace, respectively, whereas smaller values reflect more spatially constrained gaze behavior. All values are expressed in centimeters.

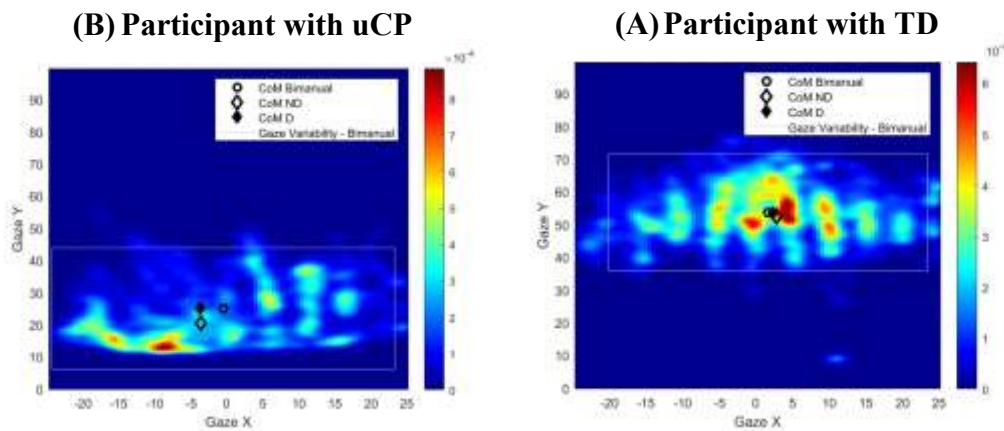


Figure 2. Heat maps representing the spatial distribution of gaze positions during the bimanual task for representative participants. (A) Example from a child with uCP. (B) Example from a child with TD. In the x-axis, a positive value reflects a gaze bias toward the dominant / less affected side. In the y-axis, higher values correspond to gaze directed farther from the body. The circle indicates the center of mass of gaze during the bimanual task. Diamonds represent the center of mass during unimanual conditions (filled diamond: dominant/less affected arm; empty diamond: non-dominant/more affected arm). The white rectangle represents gaze variability during the bimanual task.

Statistical Analyses

All statistical analyses were carried out with SPSS Statistics version 30.0 (IBM, Armonk, NY, USA). Demographic and clinical characteristics were summarized using descriptive statistics. Between-group comparisons were conducted using Chi-square test for categorical variables and Student's t-tests test for continuous variables. For the object hit task, the number of balls hit by each side (dominant/less affected and non-dominant/more

affected) during bimanual and unimanual tasks was reported. Within-group comparisons between sides were performed using paired t-tests.

To address Objective #1, a two-way analysis of variance (ANOVA) was conducted with group (uCP vs. TD) and task (unimanual vs. bimanual) as between- and within-subject factors, respectively, to examine differences in hit ratio. Assumptions of normality, homogeneity of variance, and independence of observations were verified to ensure the validity of the analyses. Post hoc comparisons were conducted to examine between-group differences for each side, as well as between-side differences within each group. Effect sizes were estimated using partial eta squared (η^2) and interpreted as small (0.01–0.059), medium (0.06–0.13), and large (≥ 0.14) (39). To address Objective #2, analyses were performed separately for bimanual and unimanual tasks, and comparisons were conducted between groups (uCP vs. TD) and between sides (non-dominant or more affected vs. dominant or less affected arm). For the bimanual task, between-group comparisons of gaze center of mass and gaze variability on both axes were conducted using independent-samples Student's t-tests or Mann–Whitney U test when normality assumptions were violated. For the unimanual task, within-group comparisons between sides were performed using paired-samples Student's t-tests or Wilcoxon signed-rank tests, as appropriate. When applicable, outliers were identified based on visual inspection and statistical criteria and were excluded from specific analyses when justified. Descriptive statistics are reported as mean $\pm$ standard deviation for normally distributed data and as median (interquartile range (IQR)) for non-normally distributed variables. Statistical significance was set at $p < 0.05$.

Results

Sample description

The demographic and clinical characteristics of both groups are presented in Table 1. The groups did not differ in age or sex distribution. In the uCP group, 25 children had a more affected left arm, and 18 had a more affected right arm. Table 1 also reports the number of balls hit by each upper limb during the bimanual and unimanual object hit tasks. Significant between-group differences were observed for both sides in both tasks.

The total sample included 43 children with uCP, with 21 recruited in Quebec City and 22 in Calgary, and 76 TD children, with 53 from Quebec City and 23 from Calgary. No significant differences across sites were observed between sites in age or sex distribution ($p = 0.362$ and $p = 0.887$, respectively). In children with uCP, significant differences between sites were observed in the number of balls hit for both tasks and both limbs, suggesting slightly greater motor impairment in the clinical subsample from Quebec City. Importantly, no significant differences were found between sites in TD children, suggesting that the differences observed in children with uCP are not due to methodological differences across sites.

Table 1. Demographic and Clinical Characteristics

		uCP	TD	p
N		43	76	
Age (means years $\pm$ SD)		11.5 (2.9)	11.1 (2.6)	0.444
Female/Male		20/23	30/46	0.562
Less affected arm (Dominance)		25 R/ 18 L	66 R/ 10L	<0.001
Number of balls hit in bimanual task (means$\pm$ SD)	ND side	56.4 (21)	81.6 (19.1)	<0.001
	D side	89.6 (20.7)	98.8 (19.1)	0.017
Number of balls hit in unimanual task (means$\pm$ SD)	ND side	90.6 (26.5)	114.9 (21.4)	<0.001
	D side	109 (22)	123.3 (20.2)	<0.001

uCP: children with unilateral cerebral palsy, TD: typically developing children, ND: non-dominant, D: dominant

Main results

- Relative capacity of each UL across tasks and groups

To address Objective #1, relative UL capacity was assessed using the hit ratio (more affected/non-dominant vs. less affected/dominant arm) across bimanual and unimanual tasks and groups.

Figure 3 shows the comparison of hit ratio between groups and tasks. One outlier was identified in the TD group and excluded from the analyses ($N = 75$). The ANOVA shows a significant interaction between group and task ($F = 5.7$, $p = 0.019$, $\eta_p^2 = 0.047$). Additionally, a significant main effect of group was observed ($F = 36.26$, $p < 0.001$, $\eta_p^2 = 0.238$). Multiple comparison analyses showed a significant difference between groups for the bimanual task (95% CI $[-0.256, -0.117]$, $F = 28.066$, $p < 0.001$, $\eta_p^2 = 0.195$) as well as for the unimanual task (95% CI $[-0.149, -0.057]$, $F = 20.02$, $p < 0.001$, $\eta_p^2 = 0.147$). A significant difference between tasks was found for the uCP group (95% CI $[-0.24, -0.13]$, $F = 44.11$, $p < 0.001$, $\eta_p^2 = 0.276$), and for TD group (95% CI $[-0.143, -0.06]$, $F = 23.221$, $p < 0.001$, $\eta_p^2 = 0.167$). Effect sizes were large for all significant comparisons, except for group and task interaction, which was small. The interaction effect reflects the fact that although a difference between tasks was observed in both groups, this difference was larger in the uCP group.

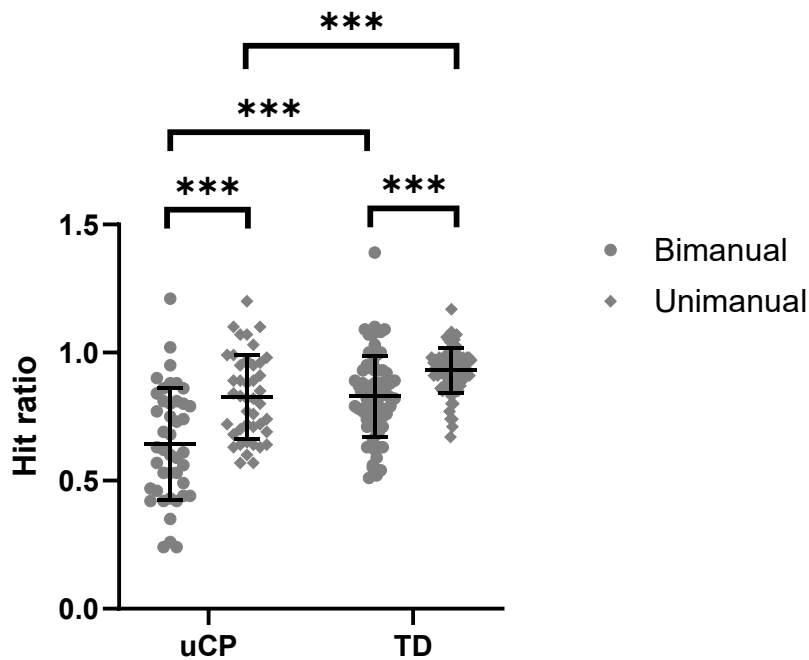


Figure 3. Mean (SD) relative hit ratio for each task across the two groups
uCP: children with unilateral cerebral palsy; TD: typically developed children ***: $p < 0.001$; Error bars: mean and SD. Circles represent the hit ratio in bimanual task and diamonds represent the hit ratio in unimanual task.

- Visuospatial monitoring strategies across tasks and sides

Visuospatial monitoring analyses were conducted on participants whose eye-tracking data met the predefined quality criteria (i.e., successful calibration with at least Fair accuracy and usable gaze signal quality) (23 uCP and 45 TD). Outliers were identified for some of the analyses. For the bias in the center of mass of gaze on the y-axis, one outlier was identified in the uCP group for the bimanual task ($N=22$). For the variability in the center of mass of gaze on the y-axis, one outlier was identified in the TD group for bimanual task ($N = 44$).

• Visuospatial monitoring bias

To address Objective #2, visuospatial monitoring bias was assessed using the center of mass of gaze along the x and y axes. Values indicate in the x axis reflect the lateral gaze bias (positive toward the dominant/less affected side), while values in the y-axis

reflect the distance of gaze relative to the body, with higher values indicating more forward-looking gaze.

During the bimanual task, no significant group effect was observed in the x-axis between children with uCP (mean $\pm$ standard deviation: -0.5 ± 4.1 cm) and TD children (0.6 ± 2.6 cm; $p = 0.186$). For the y-axis, a significant difference between groups was found, with children with uCP exhibiting lower values than TD children (35.8 ± 5.1 cm vs. 38.9 ± 6.2 cm; $p = 0.047$), meaning that they monitored the space closer to their body (see Figure 4).

During the unimanual task, no side difference (non-dominant/more affected vs. dominant/less affected) was observed in x-axis in either group (uCP group: -1.4 ± 4.7 cm vs. -0.7 ± 3.9 cm; $p = 0.203$; TD group: 0.001 ± 2.5 cm vs. 0.1 ± 2.5 cm; $p = 0.488$). For y-axis, no side effect was found in children with uCP (35.8 ± 7.7 cm vs. 35.8 ± 7.2 cm; $p = 0.975$), whereas TD children showed lower values (they monitored the space closer to their body) when using the non-dominant arm compared to the dominant arm (35.8 ± 7 cm vs. 36.8 ± 6 cm; $p = 0.013$) (see Figure 4).

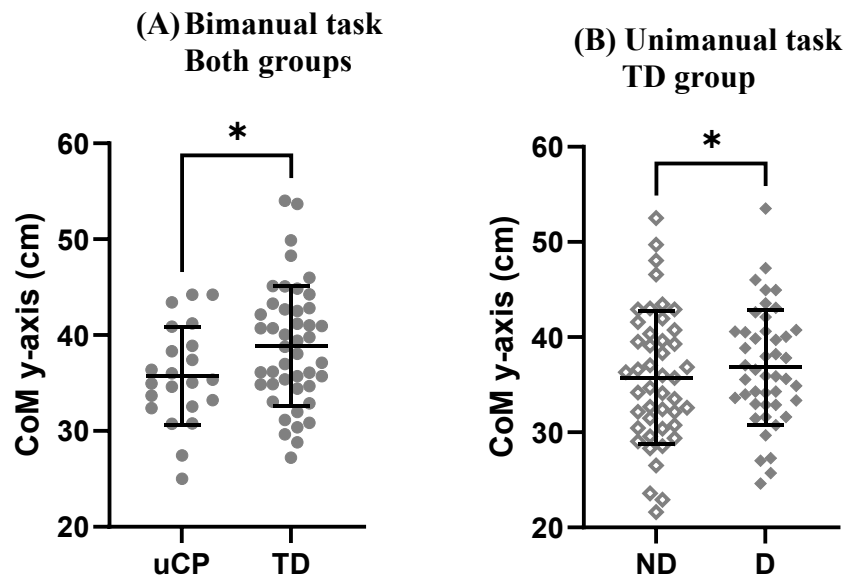


Figure 4. Mean (SD) location of center of mass of gaze in the y-axis. (A) Comparison across the two groups. (B) Comparison across the two sides for TD group. uCP: children with unilateral cerebral palsy; TD: typically developed children; D: dominant side; ND: non-dominant side; *: $p < 0.05$; **: $p < 0.01$; Error bars (A) and (B): mean and SD. Circles represent the center of mass on the y-axis in the bimanual task, and diamonds represent the center of mass on the y-axis in the unimanual task. Filled diamonds indicate the dominant-side data, while empty diamonds indicate the non-dominant-side data.

• Visuospatial monitoring variability

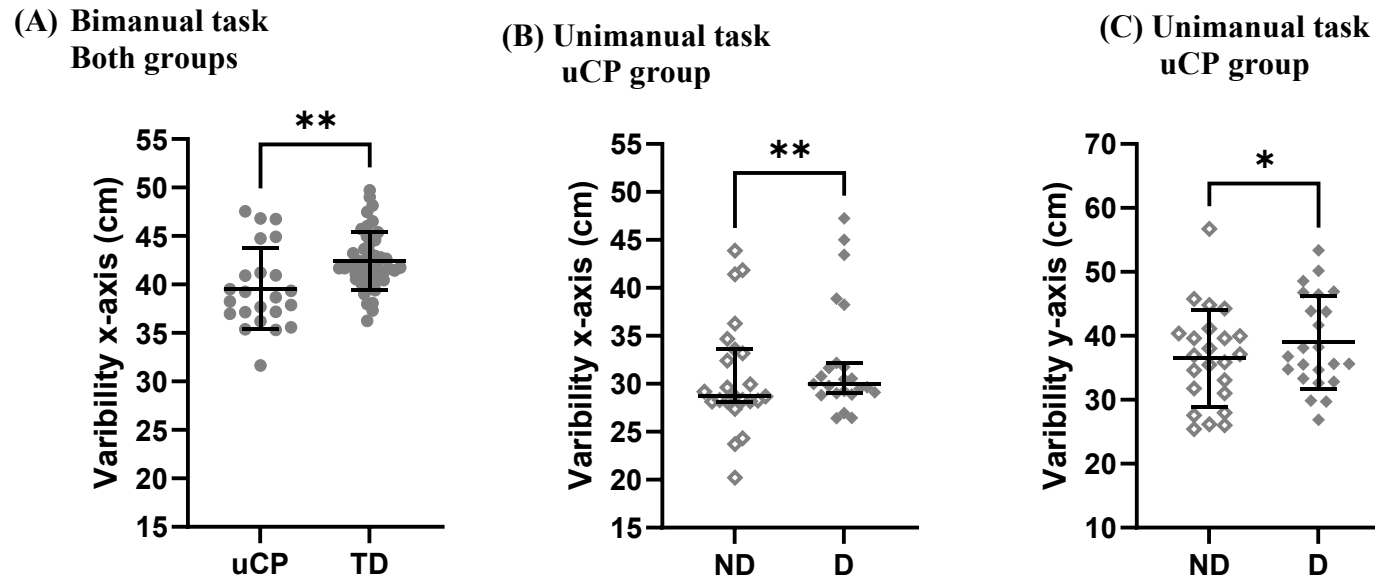
To further address Objective #2, visuospatial exploration was characterized using gaze position variability along the x and y axes.

During the bimanual task, a significant difference between groups was observed in x-axis, with children with uCP showing lower variability than TD children (39.6 ± 4.2 cm vs. 42.4 ± 3 cm; $p = 0.002$) (see Figure 5). In y-axis, no significant group effect was found (median [IQR]: uCP: 36.9 [30.4-42.2] cm; TD: 31.7 [28.2-37.3] cm; $p = 0.087$).

During the unimanual task, a significant difference between sides in x-axis was observed in children with uCP, with lower variability when using the non-dominant/more affected side compared to the dominant/less affected one (28.7 [28.2-33.6] cm vs. 30 [29-32.2] cm; $p = 0.007$) (see Figure 5). No such side effect was observed in TD children

393 (29.4 $\pm$ 2.2 cm vs. 29.7 $\pm$ 2.5 cm; $p = 0.411$). For y-axis, a significant side effect was
394 observed in children with uCP (36.5 $\pm$ 7.6 cm vs. 39 $\pm$ 7.3 cm; $p = 0.03$), however, no
395 significant effect was found for TD children (37.2 $\pm$ 7.5 cm vs. 37.1 $\pm$ 7 cm; $p = 0.737$).
396

397



398

399 **Figure 5. Variability of the center of mass across the groups and the sides. (A) Mean (SD) and comparison between the two groups. (B) Median (IQR) and comparison between the two**
 400 **sides for uCP group. (C) Mean (SD) and comparison between the two sides for uCP group.**
 401 uCP: children with unilateral cerebral palsy; TD: typically developed children; D: dominant side; ND: non-dominant side; *: < 0.05 ; p **: $p <$
 402 0.01 ; Error bars (A) and (C): mean and SD; Error bars(B): median and IQR: interval inter-quartile. Circles represent the variability of the center
 403 of mass on the x-axis in the bimanual task, and diamonds represent the variability of the center of mass on the x-axis in the unimanual task. Filled
 404 diamonds indicate the dominant-side data, while empty diamonds indicate the non-dominant-side data.

405

406

407 Discussion

408 This study was the first to concurrently investigate manual capacity and
409 visuomotor monitoring strategies during both bimanual and unimanual tasks in children
410 with uCP compared to their TD peers. Consistent with our hypothesis, our results show
411 that performing a bimanual task amplifies motor asymmetry in children with uCP, with a
412 reduced involvement of the more affected UL compared to a comparable unimanual task.
413 TD children show a similar effect related to UL dominance, but to a lesser extent.
414 Contrary to our hypothesis, children with uCP did not display a lateral gaze bias toward
415 the more affected side. However, they did show more constrained visual exploration than
416 TD children, as reflected by reduced gaze variability in the x (left-right) axis. Finally,
417 group differences in gaze position in the y-axis indicate reduced anticipatory visual
418 monitoring in children with uCP compared to TD children.

419 The fact that the motor capacity of the most affected UL in children with uCP that
420 was observed during the bimanual task was significantly lower than during the unimanual
421 task suggests that bimanual coordination imposes additional constraints that
422 disproportionately disadvantage the more affected arm (40,41). Studies demonstrating
423 increased attentional demand and learned underuse of the affected hand during dual-hand
424 and complex tasks in children with uCP suggest that when task demands increase, the
425 motor system may minimize the cost by relying more heavily on the limb that provides
426 more reliable control, reinforcing developmental disregard (20,21). The increased need
427 for efficient communication between hemispheres, largely mediated by the corpus
428 callosum, during tasks involving bimanual coordination (42,43) may also pose an
429 additional challenge. Indeed, reduced callosal integrity (especially in posterior segments)

has been shown to be associated with poorer temporal bimanual coordination (e.g., goal synchrony, movement time) in children with uCP (44,45). Altogether, these mechanisms may help to explain why everyday bimanual activities such as opening containers or tying shoelaces remain difficult, even when unimanual capacity appears relatively preserved. To the best of our knowledge our study was the first to specifically address that question using comparable unimanual and bimanual tasks. Results in the TD group showing a predominant effect of dominance in the bimanual task (i.e., increased asymmetry) are consistent with those of a study measuring laterality index and performance in a bimanual crank-rotation task in young TD children, which showed that the less right-handed the children were, the better their bimanual coordination was (46). Overall, these results show that unimanual testing is insufficient to accurately represent UL bimanual motor capacity. Therefore, rehabilitation interventions should integrate bimanual tasks and promote active engagement of the two limbs.

The absence of difference between groups (or between limbs in the uCP group) in lateral (left-right) gaze position challenges the notion that children with uCP rely on visual monitoring of the more affected arm as a compensatory strategy, a hypothesis that was supported by prior work suggesting increased weighting of visual feedback when somatosensory processing of the more affected UL is impaired (30,32,34,47). However, children with uCP showed significantly lower gaze variability than TD children, suggesting that their gaze remained more tightly centered within the workspace. Taken together, these findings indicate that children with uCP tended to maintain their gaze closer to the center of the workspace with less dispersion than TD children. One potential explanation is that gaze strategies are strongly shaped by task demands (30). In tasks that involve precise motor planning or object manipulation, increased visual monitoring of the acting hand has been observed in uCP (34). In contrast, tasks requiring multiple object

tracking, like the one employed in the present study, show that observers rarely fixate individual targets; instead, gaze is pulled toward a central location among the targets, a center-looking strategy that supports simultaneous monitoring of several moving items (48–50). This center-looking strategy allows the use of peripheral vision to track several moving objects simultaneously (48). Looking at or near the centroid of the target array improves tracking performance and is interpreted as optimizing overall visual monitoring and balancing attentional resolution across hemifields (48–50). In this context, the more stable central gaze observed in children with uCP may reflect an adaptive strategy rather than a deficit. However, because our analysis captures only the overall distribution of gaze and not specific fixations, this explanation should be considered with caution.

Our results showing that children with uCP maintained their gaze closer to their body, whereas TD children looked farther ahead along the trajectory of the incoming targets, suggest a less predictive visuomotor strategy. Rather than anticipating the future position of the target, children with uCP may rely on visual information closer to the ongoing interaction, possibly because predicting the target trajectory and planning the movement in advance is more challenging. It was shown that children with CP have difficulty using predictive, time-based information to guide interception compared to their TD peers (51). This dependence on online sensory information reflects a limitation in internal model formation and predictive planning (52). Studies assessing interception tasks show that predictive fixations and smooth pursuit lead to the target, allowing the visual system to sample motion information earlier, improving estimation of target speed and time-to-contact and thus supporting feedforward control (53,54). In line with this interpretation, previous research has shown that anticipatory gaze behaviour during interception tasks was associated with successful performance in children with uCP, highlighting the importance of predictive visual sampling during action (55). Only TD

children showed gaze positions farther away from the body when using the dominant arm during the unimanual task, consistent with the literature indicating that the dominant limb relies more on predictive control (56). The absence of this pattern in children with uCP suggests a more global alteration of predictive visuomotor control across both limbs. Overall, these findings emphasize the need to examine oculomotor behavior across diverse task contexts and demands instead of presuming a single compensatory strategy.

Limitations: A first limitation of this study is the fact that the unimanual task was a custom adaptation of the standardized bimanual Object Hit task. Despite our efforts to match task demands, it has been necessary to use a narrower workspace for the unilateral task to make sure that it was feasible to reach all the balls. The number of balls for each vertical bin and their speed was maintained identical, but the average distance between two successive balls and the total number of balls differed. As a result, the two tasks were not directly comparable, which is why our analyses focused on relative comparisons. However, we cannot exclude the possibility that the motor capacity and gaze results may have been impacted by these differences. A second limitation is that visual, cognitive, and behavioral eligibility criteria were not formally assessed using standardized clinical measures and were instead based on parent report or available medical records. Another limitation is lesion heterogeneity in children with uCP (e.g., pure unilateral versus mixed or bilateral lesions), which may influence visuomotor outcomes. In addition, visual impairments, including cerebral visual impairment, were not formally assessed. Only a subset of subjects (23 uCP and 45 TD) had sufficient valid eye-tracking data, primarily because of signal loss and calibration issues. Eye-tracking studies involving rapid visuomotor tasks and paediatric populations, especially those with motor deficits, often face such issues (57,58). Calibration challenges may be influenced by several factors, including some unrelated to clinical conditions such as eye characteristics (e.g., eye color)

and the use of corrective lenses. In the present study, head movements were not constrained in order to avoid interfering with motor capacity, which may have increased calibration challenges and data loss. However, this choice was made to preserve the ecological validity of the task.

Conclusion

This study provides new insights into how children with uCP coordinate their hands and gaze behavior during unimanual and bimanual tasks. Our results indicate that tasks requiring bimanual control accentuates motor asymmetry in children with uCP, with a disproportionately reduced contribution of the more affected UL. In addition, children with uCP showed reduced visual exploration (i.e., variability) in the left-right axis and reduced anticipatory visual sampling of incoming targets, while maintaining a similar lateral gaze distribution as TD children. Rehabilitation programs should move beyond unimanual training and place greater emphasis on bimanual activities that actively engage the more affected arm across different task contexts varying in difficulty. They should also consider the visual demands of the task and incorporate training that promotes effective visuomotor strategies.

Declarations

Ethics approval and consent to participate

Ethical approval for this study was obtained from the Research Ethics Board of the Centre intégré universitaire de santé et de services sociaux de la Capitale-Nationale (CIUSSS-CN, Quebec City; RIS: #2020-1961 and #2023-2684) and from the University of Calgary Conjoint Health Research Ethics Board (CHREB: REB22-0303). Written

informed consent was obtained from each participant or, for those under 18 years of age, from their legal guardian.

Consent for publication

Not applicable.

Availability of data and materials

Not applicable.

Competing interests

Not applicable.

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Author Contributions

Conceptualization, C.M., M.A. and C.S.B.; methodology, C.M., M.A., I.P., M.M., C.R., A.K. and C.S.B.; validation, C.M., M.A., I.P., C.R., M.M., A.K., and C.S.B.; formal analysis, C.M., M.A., I.P., C.R., M.M., A.K., and C.S.B.; investigation, M.A., I.P., M.M. and C.R.; data curation, M.A., I.P., M.M. and C.R.; writing—original draft preparation, M.A.; writing—review and editing, C.M., M.A., I.P., C.R., M.M., A.K., and C.S.B.; supervision, C.M., C.S.B. and A.K.; project administration, C.M. and A.K; funding

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References

1. Nemanich S, Schindler-Ivens S. Age-Related Development of Bilateral Coordination of the Upper Limbs in Children and Adolescents. *J Mot Behav.* 2025;57(1):12-20. doi:10.1080/00222895.2024.2396114
2. Wang J, Bi L, Fei W, Xu X, Liu A, Mo L, et al. Neural Correlate and Movement Decoding of Simultaneous-and-Sequential Bimanual Movements Using EEG Signals. *IEEE Trans Neural Syst Rehabil Eng.* 2024;32:2087-95. doi:10.1109/TNSRE.2024.3406371
3. Wenderoth N, Debaere F, Sunaert S, Swinnen SP. The role of anterior cingulate cortex and precuneus in the coordination of motor behaviour. *Eur J Neurosci.* 2005;22(1):235-46. doi:10.1111/j.1460-9568.2005.04176.x
4. Westenberg Y, Smits-Engelsman BCM, Duysens J. Development of unimanual versus bimanual task performance in an isometric task. *Hum Mov Sci.* 2004;23(3-4):461-74. doi:10.1016/j.humov.2004.08.018
5. Mickevičienė D, Skurvydas A, Karanauskienė D. Is Intraindividual Variability Different between Unimanual and Bimanual Speed-Accuracy Movements? *Percept Mot Skills.* 2015;120(1):125-38. doi:10.2466/25.PMS.120v14x3
6. Fling BW, Seidler RD. Task-dependent effects of interhemispheric inhibition on motor control. *Behav Brain Res.* 2012;226(1):211-7. doi:10.1016/j.bbr.2011.09.018
7. Baldauf D, Deubel H. Visual attention during the preparation of bimanual movements. *Vision Res.* 2008;48(4):549-63. doi:10.1016/j.visres.2007.11.023
8. Hoyer EH, Bastian AJ. The effects of task demands on bimanual skill acquisition. *Exp Brain Res.* 2013;226(2):193-208. doi:10.1007/s00221-013-3425-4
9. Foulsham T. Eye movements and their functions in everyday tasks. *Eye.* 2015;29(2):196-9. doi:10.1038/eye.2014.275

- 586 10. Vater C, Wolfe B, Rosenholtz R. Peripheral vision in real-world tasks: A
587 systematic review. *Psychon Bull Rev.* oct 2022;29(5):1531-57.
588 doi:10.3758/s13423-022-02117-w
- 589 11. Mooshagian E, Wang C, Ferdoash A, Snyder LH. Movement order and saccade
590 direction affect a common measure of eye-hand coordination in bimanual
591 reaching. *J Neurophysiol.* 1 août 2014;112(3):730-9. doi:10.1152/jn.00234.2014
- 592 12. Srinivasan D, Martin BJ. Eye–hand coordination of symmetric bimanual reaching
593 tasks: temporal aspects. *Exp Brain Res.* juin 2010;203(2):391-405.
594 doi:10.1007/s00221-010-2241-3
- 595 13. Kiani K, Patel M, Fu Q. Effect of aging on the visuomotor control during
596 continuous bimanual movement. *Front Aging Neurosci.* 6 août 2025;17:1525535.
597 doi:10.3389/fnagi.2025.1525535
- 598 14. Coudiere A, Morin M, Bernier PM, Danion FR. Hand Dominance Increases
599 During Concurrent Bimanual Tracking: The Role of Gaze Contingencies and
600 Visual Display. *Hum Factors J Hum Factors Ergon Soc.* janv 2026;68(1):92-108.
601 doi:10.1177/00187208251358637
- 602 15. Kokubu M, Ando S, Oda S. The order of gaze shifts affects spatial and temporal
603 aspects of discrete bimanual pointing movements. *Exp Brain Res.* oct
604 2009;198(4):501-11. doi:10.1007/s00221-009-1950-y
- 605 16. Sardar SD, Yeo SH, Allsop JE, Punt TD. Overt visual attention and between-limb
606 asynchrony for bimanual reaching movements. *Exp Brain Res.* fevr
607 2023;241(2):649-60. doi:10.1007/s00221-023-06552-6
- 608 17. Decraene L, Orban De Xivry JJ, Kleeren L, Crotti M, Verheyden G, Ortibus E, et
609 al. In-depth quantification of bimanual coordination using the Kinarm
610 exoskeleton robot in children with unilateral cerebral palsy. *J NeuroEngineering*
611 *Rehabil.* 11 nov 2023;20(1):154. doi:10.1186/s12984-023-01278-6
- 612 18. Dan B, Rosenbaum P, Carr L, Gough M, Coughlan J, Nweke N. Proposed
613 updated description of cerebral palsy. *Dev Med Child Neurol.* 11 avr
614 2025;dmcn.16274. doi:10.1111/dmcn.16274
- 615 19. Jaspers E, Byblow WD, Feys H, Wenderoth N. The Corticospinal Tract: A
616 Biomarker to Categorize Upper Limb Functional Potential in Unilateral Cerebral
617 Palsy. *Front Pediatr.* 6 janv 2016;3. doi:10.3389/fped.2015.00112
- 618 20. Zielinski IM, Jongsma ML, Baas CM, Aarts PB, Steenbergen B. Unravelling
619 developmental disregard in children with unilateral cerebral palsy by measuring
620 event-related potentials during a simple and complex task. *BMC Neurol.* déc
621 2014;14(1). doi:10.1186/1471-2377-14-6
- 622 21. Houwink A, Aarts PBM, Geurts ACH, Steenbergen B. A neurocognitive
623 perspective on developmental disregard in children with hemiplegic cerebral
624 palsy. *Res Dev Disabil.* nov 2011;32(6):2157-63. doi:10.1016/j.ridd.2011.07.012

- 625 22. Hung YC, Meredith GS. Influence of dual task constraints on gait performance
626 and bimanual coordination during walking in children with unilateral Cerebral
627 Palsy. *Res Dev Disabil.* avr 2014;35(4):755-60. doi:10.1016/j.ridd.2014.01.024
- 628 23. Mutalib SA, Mace M, Ong HT, Burdet E. Influence of visual-coupling on
629 bimanual coordination in unilateral spastic cerebral palsy. In: 2019 IEEE 16th
630 International Conference on Rehabilitation Robotics (ICORR) [Internet].
631 Toronto, ON, Canada: IEEE; 2019 [cité 11 déc 2024]. p. 1013-8. Disponible sur:
632 <https://ieeexplore.ieee.org/document/8779390/>
633 doi:10.1109/ICORR.2019.8779390
- 634 24. Chaleat-Valayer E, Bard-Pondarre R, Ganne C, Roumenoff F, Combey A,
635 Bernard JC. Relation between unimanual capacities and bimanual performance in
636 hemiplegic cerebral-palsied children: Impact of synkinesis. *Eur J Paediatr Neurol.*
637 mars 2015;19(2):193-201. doi:10.1016/j.ejpn.2014.12.002
- 638 25. Sakzewski L, Ziviani J, Boyd R. The relationship between unimanual capacity
639 and bimanual performance in children with congenital hemiplegia. *Dev Med*
640 *Child Neurol.* sept 2010;52(9):811-6. doi:10.1111/j.1469-8749.2009.03588.x
- 641 26. Gaillard F, Cretual A, Cordillet S, Le Cornec C, Gonthier C, Bouvier B, et al.
642 Kinematic motion abnormalities and bimanual performance in children with
643 unilateral cerebral palsy. *Dev Med Child Neurol.* août 2018;60(8):839-45.
644 doi:10.1111/dmcn.13774
- 645 27. Klingels K, Demeyere I, Jaspers E, De Cock P, Molenaers G, Boyd R, et al.
646 Upper limb impairments and their impact on activity measures in children with
647 unilateral cerebral palsy. *Eur J Paediatr Neurol.* sept 2012;16(5):475-84.
648 doi:10.1016/j.ejpn.2011.12.008
- 649 28. Baglio F, Cabinio M, Ricci C, Baglio G, Lipari S, Griffanti L, et al. Abnormal
650 development of sensory-motor, visual temporal and parahippocampal cortex in
651 children with learning disabilities and borderline intellectual functioning. *Front*
652 *Hum Neurosci.* 15 oct 2014;8. doi:10.3389/fnhum.2014.00806
- 653 29. McClelland VM, Lin JP. Sensorimotor Integration in Childhood Dystonia and
654 Dystonic Cerebral Palsy—A Developmental Perspective. *Front Neurol.* 23 juill
655 2021;12:668081. doi:10.3389/fneur.2021.668081
- 656 30. Abid M, Poitras I, Gagnon M, Mercier C. Eye-hand coordination during upper
657 limb motor tasks in individuals with or without a neurodevelopmental disorder: a
658 systematic review. *Front Neurol.* 25 juin 2025;16:1569438.
659 doi:10.3389/fneur.2025.1569438
- 660 31. Wilmot K, Wann JP, Brown JH. Problems in the coupling of eye and hand in the
661 sequential movements of children with Developmental Coordination Disorder.
662 *Child Care Health Dev.* nov 2006;32(6):665-78. doi:10.1111/j.1365-
663 2214.2006.00678.x
- 664 32. Surkar SM, Hoffman RM, Davies B, Harbourne R, Kurz MJ. Impaired
665 anticipatory vision and visuomotor coordination affects action planning and

- 666 execution in children with hemiplegic cerebral palsy. *Res Dev Disabil.* sept
667 2018;80:64-73. doi:10.1016/j.ridd.2018.06.009
- 668 33. Payne AR, Plimmer B, McDaid A, Davies TC. Eye movements show similar
669 adaptations in temporal coordination to movement planning conditions in both
670 people with and without cerebral palsy. *Exp Brain Res.* mai
671 2017;235(5):1375-85. doi:10.1007/s00221-017-4891-x
- 672 34. Verrel J, Bekkering H, Steenbergen B. Eye–hand coordination during manual
673 object transport with the affected and less affected hand in adolescents with
674 hemiparetic cerebral palsy. *Exp Brain Res.* mai 2008;187(1):107-16.
675 doi:10.1007/s00221-008-1287-y
- 676 35. Savelsbergh GJP, Ledebt A, Smorenburg ARP, Deconinck F. Upper limb activity
677 in children with unilateral spastic cerebral palsy: the role of vision in movement
678 strategies. *Dev Med Child Neurol.* nov 2013;55(s4):38-42.
679 doi:10.1111/dmcn.12305
- 680 36. Ruest N, Floer A, Chugh A, Kirton A. Public participation in child health: the
681 Healthy Infants and Children Clinical Research Program (HICCUP). *Pediatr Res.*
682 12 mars 2026. doi:10.1038/s41390-026-04882-z
- 683 37. Eliasson AC, Krumlinde-Sundholm L, Rösblad B, Beckung E, Arner M, Öhrvall
684 AM, et al. The Manual Ability Classification System (MACS) for children with
685 cerebral palsy: scale development and evidence of validity and reliability. *Dev*
686 *Med Child Neurol.* juill 2006;48(07):549. doi:10.1017/s0012162206001162
- 687 38. Perry CM, Singh T, Springer KG, Harrison AT, McLain AC, Herter TM.
688 Multiple processes independently predict motor learning. *J NeuroEngineering*
689 *Rehabil.* déc 2020;17(1):151. doi:10.1186/s12984-020-00766-3
- 690 39. Richardson JTE. Eta squared and partial eta squared as measures of effect size in
691 educational research. *Educ Res Rev.* janv 2011;6(2):135-47.
692 doi:10.1016/j.edurev.2010.12.001
- 693 40. Smits-Engelsman BCM, Klingels K, Feys H. Bimanual force coordination in
694 children with spastic unilateral cerebral palsy. *Res Dev Disabil.* sept
695 2011;32(5):2011-9. doi:10.1016/j.ridd.2011.04.007
- 696 41. Nemanich ST, Rich TL, Gordon AM, Friel KM, Gillick BT. Bimanual Skill
697 Learning after Transcranial Direct Current Stimulation in Children with
698 Unilateral Cerebral Palsy: A Brief Report. *Dev Neurorehabilitation.* 3 oct
699 2019;22(7):504-8. doi:10.1080/17518423.2019.1600065
- 700 42. Cacioppo M, Loos A, Lempereur M, Brochard S. Bimanual movements in
701 children with cerebral palsy: a systematic review of instrumented assessments. *J*
702 *NeuroEngineering Rehabil.* 27 févr 2023;20(1):26. doi:10.1186/s12984-023-
703 01150-7
- 704 43. Derakhshan I. Bimanual simultaneous movements and hemispheric dominance:
705 Timing of events reveals hard-wired circuitry for action, speech, and imagination.
706 *Psychol Res Behav Manag.* sept 2008;1. doi:10.2147/PRBM.S4132

- 707 44. Hung YC, Robert MT, Friel KM, Gordon AM. Relationship Between Integrity of
708 the Corpus Callosum and Bimanual Coordination in Children With Unilateral
709 Spastic Cerebral Palsy. *Front Hum Neurosci.* 24 sept 2019;13:334.
710 doi:10.3389/fnhum.2019.00334
- 711 45. Mailleux L, Decraene L, Kalkantzi A, Kleeren L, Crotti M, Campenhout AV, et
712 al. Spatiotemporal coordination in children with unilateral cerebral palsy: Insights
713 from a bimanual goal-directed task. *Eur J Paediatr Neurol.* nov 2024;53:73-87.
714 doi:10.1016/j.ejpn.2024.10.003
- 715 46. Fagard J, Corroyer D. Using a continuous index of laterality to determine how
716 laterality is related to interhemispheric transfer and bimanual coordination in
717 children. *Dev Psychobiol.* juin 2003;43(1):44-56. doi:10.1002/dev.10117
- 718 47. Sansare A, Arcodia M, Lee SCK, Jeka J, Reimann H. Individuals with cerebral
719 palsy show altered responses to visual perturbations during walking. *Front Hum*
720 *Neurosci.* 8 sept 2022;16:977032. doi:10.3389/fnhum.2022.977032
- 721 48. Fehd HM. Looking at the center of the targets helps multiple object tracking. *J*
722 *Vis.* 2010;10(4):1-13. doi:10.1167/10.4.19
- 723 49. Fehd HM, Seiffert AE. Eye movements during multiple object tracking: Where
724 do participants look? *Cognition.* juill 2008;108(1):201-9.
725 doi:10.1016/j.cognition.2007.11.008
- 726 50. Hyönä J, Li J, Oksama L. Eye Behavior During Multiple Object Tracking and
727 Multiple Identity Tracking. *Vision.* 31 juill 2019;3(3):37.
728 doi:10.3390/vision3030037
- 729 51. Van Kampen PM, Ledebt A, Deconinck FJA, Savelsbergh GJP. Visual guidance
730 of interceptive actions in children with spastic unilateral cerebral palsy is
731 influenced by the side of the lesion. *Disabil Rehabil.* janv 2010;32(18):1527-37.
732 doi:10.3109/09638288.2010.497043
- 733 52. Martinie O, Mercier C, Gordon AM, Robert MT. Upper Limb Motor Planning in
734 Individuals with Cerebral Palsy Aged between 3 and 21 Years Old: A Systematic
735 Review. *Brain Sci.* 12 juill 2021;11(7):920. doi:10.3390/brainsci11070920
- 736 53. Sinha O, Madarshahian S, Gómez-Granados A, Paine ML, Kurtzer I, Singh T.
737 Smooth pursuit eye movements contribute to anticipatory force control during
738 mechanical stopping of moving objects. *J Neurophysiol.* 1 juin
739 2023;129(6):1293-309. doi:10.1152/jn.00075.2023
- 740 54. Arthur T, Vine S, Wilson M, Harris D. The role of prediction and visual tracking
741 strategies during manual interception: An exploration of individual differences. *J*
742 *Vis.* 6 juin 2024;24(6):4. doi:10.1167/jov.24.6.4
- 743 55. Van Kampen PM, Ledebt A, Smorenburg ARP, Vermeulen RJ, Kelder ME, Van
744 Der Kamp J, et al. Gaze behaviour during interception in children with Spastic
745 Unilateral Cerebral Palsy. *Res Dev Disabil.* janv 2012;33(1):45-53.
746 doi:10.1016/j.ridd.2011.08.008

- 747 56. Yadav V, Sainburg RL. Limb Dominance Results from Asymmetries in
748 Predictive and Impedance Control Mechanisms. Holmes NP, éditeur. PLoS ONE.
749 2 avr 2014;9(4):e93892. doi:10.1371/journal.pone.0093892
- 750 57. Boethun A, Von Holstein SL, Mathiasen R, Kolko M, Cornelissen FW, Goossens
751 J, et al. Pediatric eye movement-based perimetry: progress, pitfalls, and
752 prospects. Front Ophthalmol. 4 nov 2025;5:1681070.
753 doi:10.3389/fopht.2025.1681070
- 754 58. Warlop G, Vansteenkiste P, Lenoir M, Deconinck FJA. An exploratory study of
755 gaze behaviour in young adults with developmental coordination disorder. Hum
756 Mov Sci. oct 2020;73:102656. doi:10.1016/j.humov.2020.102656
- 757

