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Motor imagery of the unaffected hand in children with spastic hemiplegia.

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Abstract

This study examined the ability of children with hemiplegia to perform motor imagery of their unaffected hand. Children (8-12 years) formed three groups – R-HEMI: right-sided hemiplegia, N = 21; L-HEMI: left-sided hemiplegia, N = 19 and; Comparisons, N = 21. We expected no group differences on a simple imagined grasping task, but the hemiplegia groups to perform atypically on an imagined pointing task. Results showed no group differences on the grasping task, while only the L-HEMI group performed atypically on the pointing task - the functional level of the children played a likely role in this finding. Children with hemiplegia can engage in motor imagery, though task complexity and functional level may have an impact.

Keywords: Motor imagery; Hemiplegia; motor planning

It was recently suggested that motor imagery training may be a useful therapeutic tool for the treatment of children with hemiplegic cerebral palsy (Steenbergen, Crajé, Nilsen, & Gordon, 2009). This proposition was based on several lines of evidence including the positive effects of motor imagery training in post-stroke rehabilitation (see Sharma, Pomeroy, & Baron, 2006 for a review), observations that individuals with hemiplegia display poor motor planning ability when performing prehension tasks (Crajé, Aarts, Nijhuis-van der Sanden, & Steenbergen, 2010; Mutsaarts, Steenbergen, & Bekkering, 2006; Steenbergen, Meulenbroek, & Rosenbaum, 2004) and possible motor imagery deficits in individuals with congenital hemiplegia (Crajé, van Elk et al., 2010; Mutsaarts, Steenbergen, & Bekkering, 2007; Steenbergen, van Nimwegen, & Crajé, 2007; Williams et al., in press). Studies examining the motor imagery ability of hemiplegic individuals, however, have been inconclusive and studies with children with hemiplegia are lacking. Thus, a greater understanding of motor imagery ability in congenital hemiplegia in general, and with children in particular, is required before an adequate evidence base is established and motor imagery training programs can be successfully implemented.

Motor imagery refers to the imagination of a movement, without any overt movement execution (de Lange, Roelofs, & Toni, 2008) and is essentially an internal representation of a movement. According to Johnson’s *imagery as planning theory* (Johnson, 2000), movement planning involves a subconscious unfolding of these representations, which allow the most appropriate motor plan to be selected and implemented. Based on this theory, Mutsaarts and colleagues (2006) suggested that the movement planning deficits they had observed in individuals with hemiplegia might result from a deficit in motor imagery.

A small number of studies have been conducted to examine the motor imagery ability of adolescents and children with hemiplegia, each of which utilized variations of a hand rotation task (Mutsaarts et al., 2007; Steenbergen et al., 2007; Williams et al., in press). This task typically presents participants with rotated images of hands, with a left/right handedness decision required. Such tasks have repeatedly been shown to elicit the use of motor imagery, as individuals imagine moving their own hand into the position of the presented stimulus in order to decide its handedness (de Lange, Hagoort, & Toni, 2005; Parsons, 1987; Parsons & Fox, 1998). Typical task performance results in increasing response times and decreasing accuracy as the angular orientation of the stimulus moves further away from the upright position (de Lange et al., 2005; Kosslyn, Digirolamo, Thompson, & Alpert, 1998). In individuals with hemiplegia, we might expect responses to stimuli representing their affected hand to be slower and perhaps less accurate than to those representing their unaffected hand.

Studies using hand rotation tasks have produced mixed results. Mutsaarts et al. (2007) reported atypical performance patterns in a right hemiplegic group, but not in a left hemiplegic group, and argued that the right hemiplegia group was impaired in their ability to utilize motor imagery. Steenbergen et al. (2007) found that both the left and right hemiplegia groups in their study were slower than the controls, but exhibited a typical response time pattern, with no significant differences in accuracy and no differences in response time to left and right stimuli in either hemiplegia group. This led the authors to suggest that the adolescents with hemiplegia were utilizing visual imagery, in which the hand is treated as an object, rather than a body part, to complete the task. Such a technique is less reliant on motor areas of the brain and may have allowed the groups to overcome any impairment in motor imagery ability to perform the task. In the most recent study from this research group, no direct comparisons were conducted between the hemiplegic (right-side only) and control groups, though the figures show that the hemiplegia group was clearly slower than controls (Crajé, van Elk et al., 2010). Analysis was conducted to determine whether response time patterns conformed to the biomechanical constraints of the movement – i.e. responses to hands rotated medially should be quicker than to those rotated laterally as medial rotation is a more comfortable posture. Although this was the case for the control group (when hands were presented in palm view), it was not statistically true for the hemiplegia group. As such, the authors argued that the hemiplegia group was not engaging in motor imagery to complete the task and that this was indicative of a reduced motor imagery ability.

In another study, we found no difference on response time or accuracy between left and right sided hemiplegia groups on the hand rotation task (Williams et al., in press). Like Steenbergen et al. (2007), we found a general slowing in our hemiplegia group, but also found a reduced level of accuracy compared to a comparison group. In contrast to Crajé et al. (2010), our analysis of responses to stimuli rotated clockwise versus counterclockwise supported the use of motor imagery by the hemiplegia group. This led us to argue that children with hemiplegia can perform motor imagery, but are perhaps slower and less accurate when doing so.

These findings highlight the difficulty in utilizing an implicit motor imagery task, such as the hand rotation task, without neuroimaging, in children in general (see Gabbard, 2009 for a review on this) and even more so in a population of children in which the expected pattern of response is unknown. For example, we know that individuals with chronic hemiplegia following stroke are still able to accurately imagine performing motor tasks which they are no longer able to physically perform (Johnson, Sprehn, & Saykin, 2002), but it is unclear if we should expect the same from those with congenital hemiplegia. In line with the movement planning deficits, which are more evident on more complex tasks (Mutsaarts, Steenbergen, & Bekkering, 2005), deficits in motor imagery ability may be limited to more complex tasks.

The aim of this study was to explore motor imagery ability in children with hemiplegia at a basic level, isolating the unimpaired hand and using tasks that are more reliant on motor imagery ability and difficult to complete using visual imagery techniques.

We achieved this by employing two tasks, one which required imagery of a simple grip technique, and another which required the execution and imagery of repetitive tapping movements constrained by speed-accuracy trade-offs. In line with findings that movement planning with the unimpaired hand in hemiplegia is typical when simple movements are performed (Mutsaarts et al., 2006; Steenbergen et al., 2004), we predicted no differences in performance of the imagined grip task between children with left or right hemiplegia and their typically developing peers. On the more complex pointing task, we expected that children with hemiplegia would not be constrained by speed-accuracy trade-offs in their imagined performance of the task while their typically developing peers would. Finally, as we have previously found in children with Developmental Coordination Disorder (DCD) that the severity of motor imagery deficits may be linked to function level, we hypothesized that motor imagery deficits would be more pronounced in children with hemiplegia with low functional levels, compared to those with better function.

Method

Participants

Children with spastic hemiplegia were recruited via the (INFORMATION REMOVED FOR BLIND REVIEW). Ninety-eight children were identified from the XXXX who could be contacted for research purposes and met the following criteria: 1) a Gross Motor Function Classification System score of I or II; 2) aged 8-12 years at the time of searching; and 3) no known intellectual disability.

Of the 98 children, 41 participated in the study. One participant was unable to complete the assessment due to severe language difficulties, leaving 40 participants, 21 with right-sided hemiplegia (R-HEMI; 11 males) and 19 with left-sided hemiplegia (L-HEMI; 11 males). Table 1 includes descriptive information for these groups, including information on the type and likely timing of brain abnormalities from neuroimaging scans, when this information was available from the VCPR.

Twenty-one comparison participants, aged 8-12 years (11 males), were recruited from standard primary schools. Participants were initially identified by teachers as having typical motor coordination for their age, which was confirmed during assessment. They were also required to be free of intellectual impairment and have no known physical or neurological condition affecting motor development.

Measures

Estimated IQ and attention. Measures of IQ and attention were obtained to ensure group equality. The two sub-test version of the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999) was used to obtain an estimate of IQ (M=100; SD=15). Any child with an estimated IQ of less than 70 was excluded from analysis. The Cognitive Problems/Inattention T-score of the Parent Short Form from the Conners' Rating Scale – Revised (Conners, 2001) was used to determine whether levels of attention differed among the groups (M=50, SD=10).

Motor skill assessment. The McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997) includes 10 tasks (5 gross motor, 5 fine motor), with the standard scores for each task summed to provide a Neuromuscular Development Index (NDI; M=100; SD=15). The MAND was used to confirm typical motor development in the comparison group. Further, the beads-in-the-box subtest requires beads to be moved from one box to another using each hand separately. The raw score (number of beads moved in 30s) for the unaffected hand of the children with hemiplegia was used to provide a measure of unaffected hand function.

Everyday functioning. The Adaptive Behavior Composite (ABC) of the Parent/Caregiver Rating Form from the Vineland Adaptive Behavior Scales (2nd ed.) (Sparrow, Cicchetti, & Balla, 2005) was used to provide an indication of the level of everyday functioning for children in each group (M=100; SD=15). Children in the hemiplegia group were categorized as HEMI-LF (low-function: a score of 85 or less) or HEMI-TF (typical-function: a score of 86 or more).

Motor imagery task 1: Grasping task. Participants were presented with a three-dimensional picture, representing a piece of dowel, one half of which was colored pink and the other half tan, which they were required to imagine grasping with their preferred (comparisons) or unaffected (hemiplegia) hand (adapted from Johnson, 1998). Participants were required to decide whether their thumb would be on the pink or tan side if they grasped the dowel using a “power” grip, such as that used to hold a hammer. The examiner demonstrated the required grip using a 3D object similar to the stimulus prior to the task.

The stimulus pictures were presented in one of eight different orientations (0-315°, 45° increments) on a laptop computer screen, which was placed on the table in front of participants. Four trials were presented at each angle using E-Prime™ (Psychology Software Tools). Each stimulus was presented following a random delay of 2-3s and remained on the screen until a response was recorded or until 10s had elapsed. Participants responded by pressing one of two response buttons, designated ‘pink’ or ‘tan’. If participants did not respond within 10s, the next trial began. The software recorded the end chosen (pink or tan).

Motor imagery task 2: Visually guided pointing task (VGPT). The VGPT was used to examine the relationship between participants’ real and imagined movements and has been used previously in a number of healthy and motor impaired samples, including children (Caeyenberghs, Tsoupas, Wilson, & Smits-Engelsman, 2009; Lewis, Vance, Maruff, Wilson, & Cairney, 2008; Sirigu et al., 1996). Real movements in the task are typically constrained by a speed-accuracy trade-off, best described by the logarithmic relationship of Fitts' law (Fitts, 1954). In typically developing populations, imagined movements are also similarly constrained, but in some motor impaired populations, such as children with Developmental Coordination Disorder, they are not (Maruff, Wilson, Trebilcock, & Currie, 1999; Wilson, Maruff, Ives, & Currie, 2001).

Participants were presented with five individual sheets of laminated paper. Each sheet had an 80mm vertical line, as well as a target box with its closest edge 30mm from the vertical line (see Figure 1). The width of the target box varied on each of the five plastic sheets (1.9, 3.7, 7.5, 14.9, or 30mm). Participants were asked to make pointing movements between the vertical line and the target box five times, as quickly and accurately possible. One pointing movement was defined as a hand motion beginning from the far side of the vertical line to touch the inside of the target box and back to the far side of the vertical line. Participants made five of these back and forth movements for each trial (2 trials per target size) of each width using their preferred or unaffected hand.

Participants were required to complete this task under two movement conditions: 'real' and 'imagined' conditions. The 'real' condition involved making actual hand movements between the line and target box using a pen. The 'imagined' condition required participants to imagine they were performing the same movements as in the 'real' condition, but without making any overt hand movements. The 'imagined' trials always followed the 'real' trials, and the order of the targets presented was counterbalanced across participants.

A stop watch was used to record the duration of participants' hand movements for each trial. Timing of each trial began when then examiner said "Go" and ended when the participant said "Stop" once they completed the actual or imagined movements. If the participant lost count of the number of movements completed or lost concentration during a trial, it was repeated immediately by the examiner.

Procedure

The study had ethical approval from the Human Research Ethics Committee of the (INFORMATION REMOVED FOR BLIND REVIEW), and all participants' parents gave informed consent prior to their child's assessment. All assessments were conducted on an individual basis, either at the hospital or the child's school. All of the measures were administered in a randomised order across participants, with the MAND tasks inter-dispersed among the other activities.

Statistical Analysis

All statistical analyses were conducted using SPSS, v.17. Group means for age and descriptive measures (IQ, NDI, ABC and Cognitive Problems/Inattention) were submitted to individual univariate analysis of variance (ANOVA) to isolate group effects. The critical value for significance was adjusted using the Bonferroni method and set at p = .013. Post-hoc tests were conducted using Tukey's HSD procedure and partial eta squared (η^2) was calculated to determine effect size.

Grasping task. Initially, we calculated the probability of choosing the tan end of the dowel at each angle for each participant (e.g. choosing tan at 0º on 3 of 4 trials would amount to a probability of .75). We then calculated group mean probability at each angle. As all participants in the comparison group were right-handed, we were able to compare directly the probability at each angle directly with the L-HEMI group using a repeated measures ANOVA. As we did not have a left-handed comparison group, we elected to swap the probabilities of the comparison group at the following angles – 45 and 315º, 90 and 270º, 135 and 225º – while keeping the probabilities at the remaining angles the same. This created a second set of comparison data, similar to what we would have expected to find had we assessed a comparison group of left-handed children, and enabled us to compare directly the performance of the R-HEMI group.

Two repeated-measures ANOVAs were conducted to compare the response probabilities of the hemiplegic and comparison groups at each angle. The multivariate approach to repeated-measures ANOVA was used throughout the analysis to protect against violations to sphericity. The first compared the L-HEMI and comparison groups, and the second compared R-HEMI group and our “left comparison” group data. Effect size was calculated using partial eta squared (η^2). The performance of the hemiplegia subgroups (low and typically functioning) was compared using a third ANOVA. The critical value for significance was again adjusted using the Bonferroni method and set at $p = .017$

Visually guided pointing task. Participants’ mean movement duration was calculated for each target width in each movement condition. To determine whether a speed-accuracy trade-off existed in real and imagined movements for each group, group means for movement duration were calculated and plotted against target width for “real” and “imagined” conditions. Logarithmic curves were then fitted to the data points and goodness of fit was determined using a least squares regression. Regression estimates, fit (R^2) and significance are reported for each group individually. These curves were also fitted to the movements of the low and typically functioning hemiplegia subgroups.

To determine how similar real and imagined movement times were, and to allow comparisons across groups, the absolute difference between real and imagined movements was calculated for each participant at each target width. Group means for each target width were then calculated and submitted to a group (comparison, R-HEMI, L-HEMI) x target width (5 levels) ANOVA, with repeated measures on the target width factor. Partial eta squared (η^2) was calculated to determine effect size. A second ANOVA was conducted to explore differences between the low and typically functioning hemiplegia subgroups. A Bonferroni adjustment was again made to critical value for significance, with p set at .025.

Finally, we determined the mean difference between real and imagined movement times, across target width, for the hemiplegia groups. We then conducted a correlation analysis to determine the relationship between the mean difference in movement time and scores for the beads-in-the-box task (unaffected hand). As this score was not scaled for age, a partial correlation was conducted, controlling for age and used Cohen's (1988) guidelines, where > 0.5 is large, 0.5-0.3 is moderate, < 0.3 is small.

Results

Five participants were excluded from data analysis as a result of an estimated IQ < 70 on the WASI. Three children were from the L-HEMI group and two were from the R-HEMI group. The group means for age and IQ, NDI, ABC and Cognitive Problems/Inattention can be viewed in Table 1. There were no significant differences between the groups on age, $F(2,53) = 2.11$, $p = .13$, $\eta^2 = .07$, or the Cognitive Problems/Inattention t-score, $F(2,44) = 1.02$, $p = .37$, $\eta^2 = .04$. Group differences were identified however for IQ, $F(2,48) = 7.21$, $p = .002$, $\eta^2 = .98$, NDI, $F(2,52) = 37.06$, $p < .001$, $\eta^2 = .59$, and ABC, $F(2,37) = 9.67$, $p < .001$, $\eta^2 = .34$. For each of these, the hemiplegia groups scored significantly lower than the comparison group (see Table 1 for p values).

Grasping Task

Repeated-measures ANOVA comparing the response probabilities of the L-HEMI and comparison groups found a significant effect of angle, Wilks' $\Lambda = .038$, $F(7,27) = 97.39$, $p < .001$, $\eta^2 = .96$, but no effect for group, $F(1,33) = 0.13$, $p = .73$, $\eta^2 = .004$, nor a significant interaction between angle and group, Wilks' $\Lambda = .84$, $F(7,27) = 0.73$, $p = .65$, $\eta^2 = .16$.

Bonferroni adjusted pairwise comparisons revealed a significant difference between the majority of angles, as evident in Figure 2.

A second repeated measures ANOVA comparing the response probabilities of the R-HEMI and “left comparison” groups found a significant effect of angle, Wilks’ Λ = .086, $F(7,28) = 42.68$, $p < .001$, $\eta^2 = .914$. There was neither a significant main effect of group, $F(1,34) = 0.24$, $p = .63$, $\eta^2 = .007$, nor a significant interaction between angle and group, Wilks’ Λ = .864, $F(7,28) = .63$, $p = .73$, $\eta^2 = .14$. Bonferroni adjusted pairwise comparisons revealed a significant difference between the majority of angles, as evident in Figure 2.

The final repeated measures ANOVA, to determine whether there were any differences between low and typically functioning children with hemiplegia involved only those in the L-HEMI group as there was an insufficient number of low function children in the R-HEMI group and groups could not be collapsed for this task. No effect of function was found, $F(1,11) = 0.88$, $p = .37$, $\eta^2 = .074$, nor was there an interaction involving function, Wilks’ Λ = .539, $F(7,5) = .611$, $p = .73$, $\eta^2 = .46$.

Visually Guided Pointing Task.

The relationship between movement duration and target width conformed to a logarithmic model for both real and imagined movements in comparison and R-HEMI groups, as shown in Table 2. Similarly, the logarithmic model described the relationship between movement duration and target width for real movements in the L-HEMI group. However, the imagined movements of the L-HEMI group did not conform to a logarithmic model.

Figure 3 shows the mean difference between real and imagined movements for each group at each target width. Repeated measures ANOVA indicated a significant effect of target width on the mean difference in movement time, Wilks’ Λ = .602, $F(4,44) = 7.29$, $p <$

.001, $\eta^2 = .40$, but there was no significant effect of group, $F(2,47) = 0.86$, $p = .43$, $\eta^2 = .04$. The interaction between target width and group did not reach significance, Wilks' $\Lambda = .728$, $F(8,88) = 1.90$, $p = .071$, $\eta^2 = .15$. Comparisons of estimated marginal means indicated that the effect for angle was the result of the large mean difference between real and imagined movements at the smallest target a width.

In regard to function, it was found that both the real and imagined movements of the HEMI-TF group conformed to a logarithmic model (Table 2). In contrast, only the real movements of the HEMI-LF group conformed to a logarithmic model. Figure 3 indicates that at four of the five target widths, the difference between real and imagined movement times appears greater for the HEMI-LF group than the HEMI-TF group, though this failed to reach significance when analysed with a repeated measures ANOVA. There was no interaction between width and group, Wilks' $\Lambda = .694$, $F(4,22) = 2.42$, $p = .079$, $\eta^2 = .31$, and no significant effect of group, $F(1,25) = 3.34$, $p = .079$, $\eta^2 = .12$. There was a strong correlation between scores on the beads-in-the-box task (unaffected hand) and the mean difference between real and imagined movements, after partialling out the effect of age, $r = -.62$, $p < .001$.

Discussion

Our aim was to determine whether children with spastic hemiplegia were capable of accurately performing motor imagery with their unaffected hand. The results of the power grip task supported our hypothesis, that children with hemiplegia would not be impaired in their ability to perform a simple motor imagery task with their unaffected hand. As seen in Figure 2, the probability of grasping the cylinder in a manner that would place the thumb on the tan end was very similar between comparisons and each hemiplegia group. There was also no difference in grip preference between high and low functioning hemiplegia. These grip preference patterns were also similar to that seen in the past in healthy young adults (Johnson, 1998). Previously, it has been demonstrated that adolescents with hemiplegia tend to grasp an object with their unaffected hand in a similar way to typically developing children if their only task is to grasp it (Mutsaarts et al., 2006; Steenbergen et al., 2004). Only in circumstances when the adolescents had to grasp the object and then turn it did their initial grasping pattern became less than optimal. Thus, our results for the power grip task supported previous results examining simple movement planning in hemiplegia.

The more complex VGPT, which constrains movements with a speed-accuracy trade-off, proved interesting. As expected, both the real and imagined movements of our comparison group conformed to a logarithmic relationship. Interestingly, so too did the movements of our R-HEMI group. In contrast, though the real movements of the L-HEMI group conformed to a logarithmic relationship, their imagined movements did not. This is in line with children with DCD (Wilson et al., 2001) and brain injury (Caeyenberghs, van Roon, Swinnen, & Smits-Engelsman, 2009) and adults with damage to the parietal cortex (Sirigu et al., 1996).

The results are in contrast to the suggestions of Steenbergen and colleagues that motor imagery deficits are likely to be more common in individuals with right hemiplegia (Crajé, van Elk et al., 2010; Steenbergen et al., 2009). This suggestion is based on findings that motor planning deficits are more pronounced in adolescents with right, compared to left, hemiplegia (Crajé, van der Kamp, & Steenbergen, 2009; Steenbergen et al., 2004) and the atypical performance of the right hemiplegia group in the motor imagery study of Steenbergen et al. (2007). However, it is unclear whether motor planning and imagery are as lateralized in children with congenital hemiplegia compared with healthy populations or adults who acquire hemiplegia. As the brain insult causing the hemiplegia has occurred early in development, cortical reorganization may result in the lateralization of such functions becoming less clear. It has been demonstrated, for example, that cortical projection patterns in children with hemiplegia may reorganize and run in an ipsilateral or mixed pattern, rather than the typical contralateral pattern (Carr, Harrison, Evans, & Stephens, 1993). Further, research has shown that there can be a mismatch between the hemisphere sending motor commands and receiving sensory information as the movement unfolds – i.e. though the ipsilateral hemisphere may send the motor command, the afferent projection may still be directed to the contralateral hemisphere (Thickbroom, Byrnes, Archer, Nagarajan, & Mastaglia, 2001).

Although there were no deficits in motor imagery identified in the R-HEMI group in this study, we would not conclude that such deficits are not present in children with right hemiplegia. Our analysis of function level indicates that there was a link between function level and motor imagery performance (discussed below). However, we identified only one child in the R-HEMI group that was considered to have poor everyday functioning based on Vineland scores. Hence, the outcome of our R-HEMI group may have been different had more children in this group had lower levels of function.

The results of our analysis of function level were intriguing. As with children with DCD, the results here showed that children with low function were impaired in their ability to imagine complex movements with high spatio-temporal constraints. This suggests that the function level of a child with hemiplegia is an important factor to consider when examining motor imagery ability and may play a more significant role than side of hemiplegia alone. Why might a low level of function be related to poor motor imagery performance? Children with low function could have greater limitations in movement execution and these limitations may lead to a failure to properly develop internal representations of movement. That is, representing movements internally may be difficult for an individual who has always had great difficulty in executing movements. This possibility was dismissed as unlikely by

Mutsaarts, Steenbergen and Bekkering (2006), as the execution difficulties of children with hemiplegia are primarily on one side of the body and their motor planning difficulties exist on both sides. However, we found a strong and significant correlation between unaffected hand function and performance on the VGPT in this study and as motor deficits also reported in the unaffected hand in some children (e.g. Dellatolas, Filho, Souza, Nunes, & Braga, 2005; Rönnqvist & Rösblad, 2007), this cannot be ruled out. An alternative possibility is that those classified as low function by their parents using the Vineland have suffered a greater level of neural damage, which has affected their functional abilities across a range of domains. In turn, this increased level of neural damage may have impacted upon their ability to form or maintain internal representations of movement. Unfortunately in this study, we did not have access to information about the severity or precise location of neural damage in our hemiplegia groups and our sample was not large enough to study the effect of patterns of brain abnormality on MI performance.

It should be noted that although we found no differences between our R-HEMI group and “left comparison” group on the grasping task, this analysis was limited by the fact that the comparison data was not a genuine left-hand group and was instead our right-hand comparison group data switched at critical angles to match the pattern expected of children using their left hand. Though the patterns of the two groups were closely matched, the results of this analysis should be treated with some caution.

Unlike the hand rotation tasks used previously, the tasks used here were more explicit measures of motor imagery and are not confounded by the possible use of a visual strategy. Our findings indicated that children with hemiplegia appear capable of performing simple motor imagery tasks at an age-appropriate level. However, when imagined movements become more complex, the motor imagery ability of some children with hemiplegia appears compromised. In the current study, it was children with left hemiplegia who were unable to accurately imagine complex movements. However, more detailed analysis showed that motor imagery ability was more likely linked to function level than side of hemiplegia. These results are promising for those interested in implementing motor imagery training programs to improve motor planning in children with hemiplegia, as they indicate that children with hemiplegia can in fact engage in (simple) motor imagery tasks. Still, the complexity of training tasks used may need to be tailored to the individual child based on function level, and possibly side of hemiplegia, to ensure engagement and appropriate training. Further research examining motor imagery of the affected hand in children with hemiplegia will allow a more thorough picture of motor imagery ability in this group to be formed.

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Table 1.

Group descriptions.

	R-HEMI	L-HEMI	Comparison
Mean age in years (SD)	10.6 (1.4)	9.7 (1.2)	9.8 (1.0)
Gender (% males)	52.4	57.9	52.4
Preterm birth (%)	57.9	37.5	-
Likely pathology (%)			
- PWMI	38.1	26.3	-
- Focal vascular	28.6	21.1	-
- Malformation	0	10.5	-
- Other	0	5.3	-
- Unknown	33.3	36.8	-
Estimated timing of insult (%)			
- 1st trimester	0	10.5	-
- Late 2nd / early 3rd trimester	52.4	36.8	-
- Term / Perinatal	23.8	15.9	-
- Postneonatal	0	10.5	-
- Unknown	23.8	26.3	-

Note: *R-HEMI* = Right hemiplegia group; *L-HEMI* = Left hemiplegia group

Table 2.

Group means (SD) for descriptive measures

	R-HEMI (N = 19)	*L-HEMI* (N=16)	*Comparison* (N = 21)	*Post-hoc Comparison*
Age	10y 6mn (1y 5mn)	9y10mn (1y 4mn)	9y 9mn (1y 1mn)	
Estimated IQ	94.50 (14.06)	96.64 (14.84)	110.37 (12.37)	a. *p* = .003. b. *p* = .017
NDI	60.63 (22.80)	61.87 (17.31)	105.10 (13.31)	a. *p* < .001. b. *p* < .001
ABC	98.64 (14.26)	94.60 (19.29)	120.36 (10.15)	a. *p* = .004. b. *p* < .001
Low function (n)	1	6	0	
Cognitive Problems/ Inattention	50.81 (7.87)	51.81 (7.31)	48.13 (6.92)	

Note: *R-HEMI* = Right hemiplegia group; *L-HEMI* = Left hemiplegia group; NDI = MAND Neuromuscular Development Index; ABC = Vineland Adaptive Behavior Composite. a = R-HEMI v Comparison, b = L-HEMI v Comparison.

Table 3.

Logarithmic model summary for the relationship between target width and movement duration

Group	*Condition*	*Logarithmic Equation*	*R^2*	*p*
Comparison	Real	$y = -0.88x + 6.1$	.99	.001
	Imagined	$y = -0.64x + 6.1$	.95	.004
R-HEMI	Real	$y = -0.79x + 7.2$	.97	.003
	Imagined	$y = -0.27x + 5.4$	.89	.017
L-HEMI	Real	$y = -1.08x + 7.6$	.85	.025
	Imagined	$y = -0.44x + 5.8$	.73	.064
HEMI-TF	Real	$y = -0.81x + 7.1$	.89	.016
	Imagined	$y = -0.35x + 5.5$	.87	.021
HEMI-LF	Real	$y = -1.12x + 8.2$	.88	.018
	Imagined	$y = -0.35x + 6.0$	.49	.19

Note: R-HEMI = Right hemiplegia group; L-HEMI = Left hemiplegia group; HEMI-TF = Typically functioning hemiplegia; HEMI-LF = Low functioning hemiplegia.

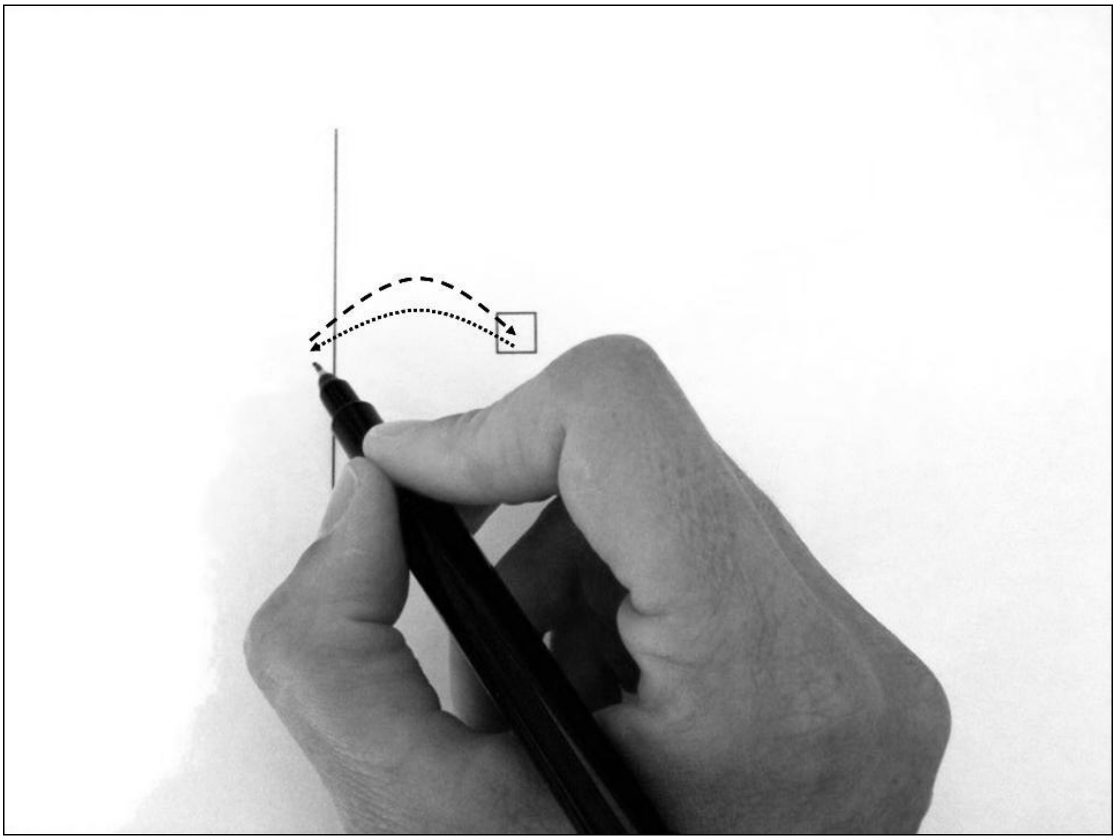

Figure 1. Visually Guided Pointing Task (VGPT) example.

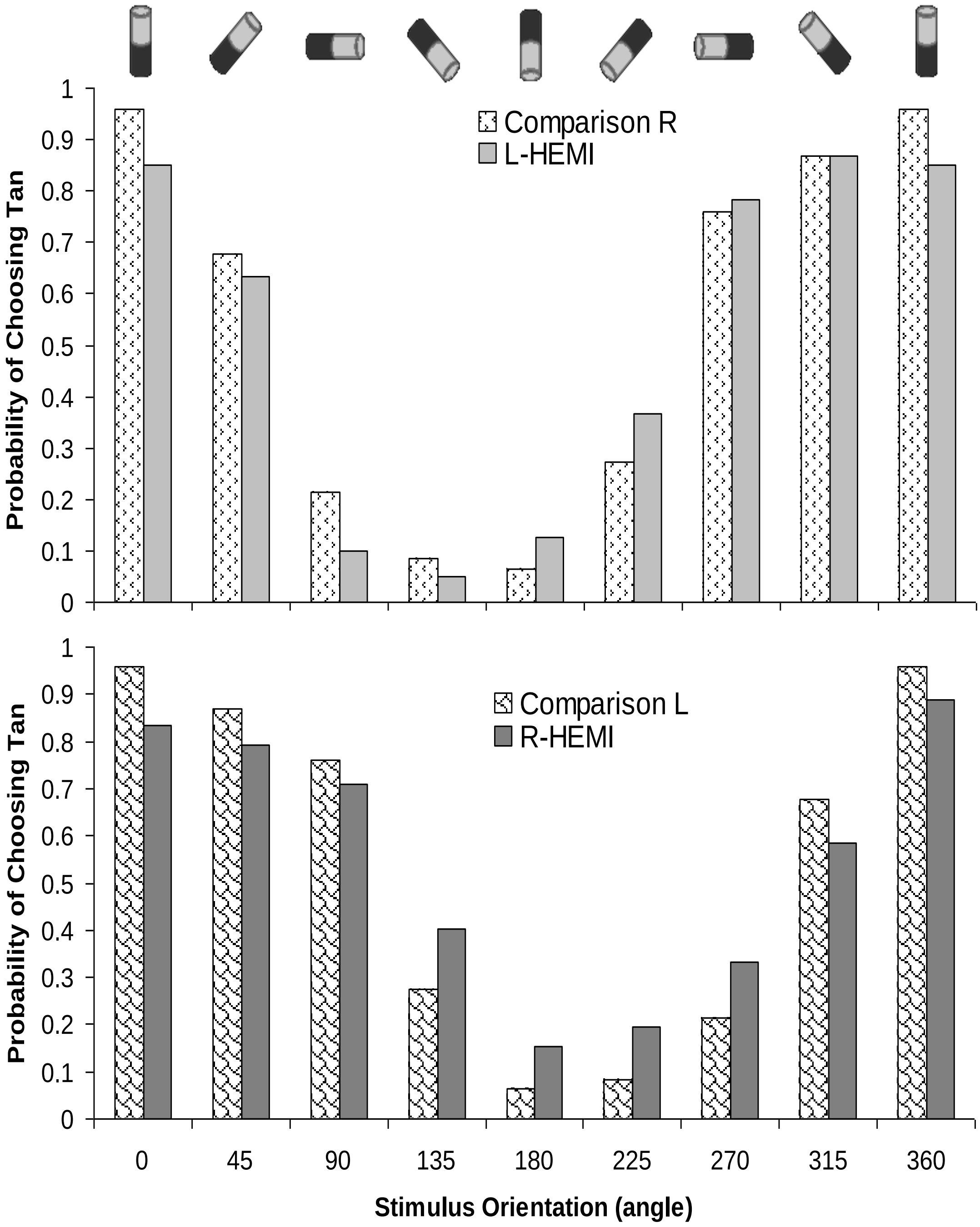

Figure 2. Probability of grasping the object with thumb on the tan end.

Note: Lighter color end = tan end.

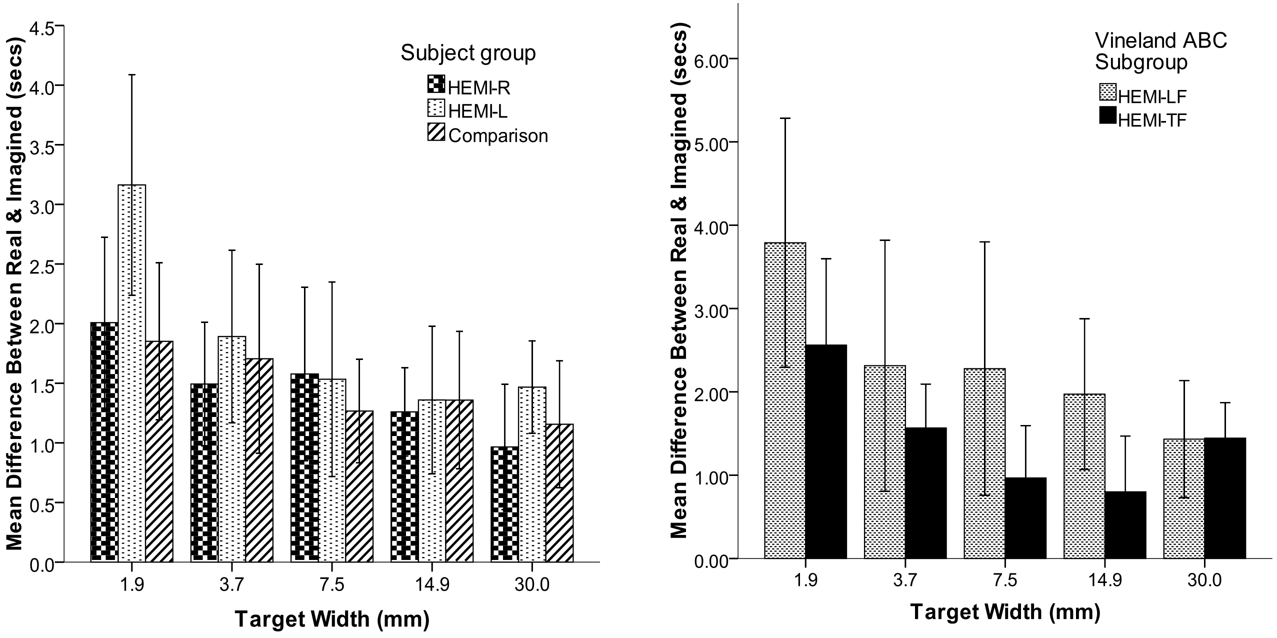

Figure 3. Mean absolute difference between real and imagined movements at each target width.

Note: R-HEMI: right hemiplegia; L-HEMI: left hemiplegia; HEMI-LF: hemiplegia low function; HEMI-TF: hemiplegia typical function.