Motor imagery ability in children with congenital hemiplegia: Effect of lesion side and functional level

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Motor imagery ability in children with congenital hemiplegia: effect of lesion side and

functional level.

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Abstract

In addition to motor execution problems, children with hemiplegia have motor planning deficits, which may stem from poor motor imagery ability. This study aimed to provide a greater understanding of motor imagery ability in children with hemiplegia using the hand rotation task. Three groups of children, aged 8-12 years, participated: right hemiplegia (R-HEMI; N=21), left hemiplegia (L-HEMI; N=19) and comparisons (N=21). All groups conformed to biomechanical limitations of the task, supporting the use of motor imagery, and all showed the expected response-time trade-off for angle. The general slowing of responses in the HEMI groups did not reach significance compared to their peers. The L-HEMI group were less accurate than the comparison group while the R-HEMI group were more variable in their performance. These results appeared to be linked to functional level. Using the Vineland Adaptive Behavior Composite, children were classified as low or normal functioning – of the seven classified as low function, six were in the L-HEMI group. Accuracy was lower in the low function subgroup, but this failed to reach significance with an adjusted critical value. However, there was a strong correlation between function level and mean accuracy. This indicates that motor imagery performance may be more closely linked to function level than to the neural hemisphere that has been damaged in cases of congenital hemiplegia. Function level may be linked to the site or extent of neural damage or the level of cortical reorganisation experienced and more attention should be paid to neural factors in future research.

Key words: Motor imagery, hemiplegia, motor planning, mental rotation

1.0 Introduction

Computational neuroscience has provided an important theoretical concept for motor control research – that of internal models (see, for example, Wolpert, 1997; Wolpert, Ghahramani, & Jordan, 1995; Wolpert, Miall, & Kawato, 1998). Forward internal models predict the outcome of a motor command, allowing individuals to select the most appropriate motor plan for a particular movement (Wolpert, 1997). Forward models require an internal representation of movement to be formed, to allow motor prediction to take place. Deficits in the ability to represent movements internally would interfere with the ability to predict the outcome of a particular motor command and thereby affect motor planning abilities.

Internal simulations of movement occur in a variety of contexts, at varying degrees of conscious awareness (Jeannerod, 2001). These include the observation of others performing a movement, when an internal simulation maps the movement onto the observer's motor network for later replication, and motor imagery. Motor imagery refers to the imagination of a movement (from a kinesthetic or first-person perspective) without any overt movement taking place. Internal simulations of movement have been shown to activate similar neural networks to those activated during actual movement (Grézes & Decety, 2001) and motor imagery has repeatedly been shown to be constrained by the same biomechanical (e.g. Kosslyn, Digirolamo, Thompson, & Alpert, 1998; Parsons, 1987) and timing (e.g. Choudhury, 2007; Sirigu, et al., 1996) constraints as actual movement in healthy individuals. These findings have supported the role of internal simulations of movement in movement planning.

Utilizing these theories, a line of research has been conducted that examined the movement planning and motor imagery abilities of children and adolescents with hemiplegic cerebral palsy (Crajé, Aarts, Nijhuis-van der Sanden, & Steenbergen,

2010; Crajé, van Elk, et al., 2010; Mutsaarts, Steenbergen, & Bekkering, 2005, 2006, 2007; Steenbergen & Gordon, 2006; Steenbergen, van Nimwegen, & Crajé, 2007; Williams, et al., in press). Hemiplegia affects motor execution on one side of the body, most commonly as the result of muscle spasticity and results from damage to the opposite cerebral hemisphere (i.e. right-sided hemiplegia indicates left hemisphere damage) (Miller, 2005). Although the motor execution difficulties of children with hemiplegia have long been recognized, deficits in movement planning abilities are a more recent discovery. In a series of studies that required participants to either grasp or pick up an object and perform some form of rotation, Steenbergen and colleagues have demonstrated that adolescents and children with hemiplegia do not plan their movements in the same way as typically developing peers (Crajé, Aarts, et al., 2010; Mutsaarts, et al., 2005, 2006; Steenbergen, Meulenbroek, & Rosenbaum, 2004). It has generally been found that, when a simple movement was required, the grasping pattern of children with hemiplegia matched their peers. When a complex rotation was required, typically developing children showed a tendency to adopt an uncomfortable initial grasping posture that allowed them to complete the movement and end in a comfortable grasping position. In contrast, children with hemiplegia planned their grasp for initial comfort, at the expense of end-state comfort, indicating that they were not planning for the second phase of the movement. One study suggested that these planning deficits may be more prominent in those with right-sided hemiplegia (Steenbergen, et al., 2004).

In line with theories that suggest motor imagery plays a role in movement planning (Johnson, 2000), Mutsaarts, Steenbergen and Bekkering (2006) speculated that the planning deficits observed in hemiplegia could be the result of a reduced ability to utilize motor imagery. Following this suggestion, a small number of studies

testing the motor imagery ability of adolescents (Crajé, van Elk, et al., 2010; Mutsaarts, et al., 2007; Steenbergen, et al., 2007) and children (Williams, et al., in press) with hemiplegia using variations of the commonly used hand rotation task. Traditionally, this task involves the presentation of pictures of hands at varying angular rotations and requires the individual to make a laterality judgment. Neuroimaging studies have shown that such a task involves motor imagery, as individuals imagine their own hand rotated into the position of the hand on the screen prior to making the laterality decision (Kosslyn, et al., 1998; Parsons & Fox, 1998). Typically, response times (RTs) increase and accuracy decreases as the angular orientation of the stimulus moves away from 0° (e.g. Kosslyn, et al., 1998).

The studies conducted so far have produced mixed results. Mutsaarts et al. (2007) found that adolescents with right hemiplegia performed atypically on the task, but that those with left hemiplegia did not differ from controls. This was in line with the earlier finding that planning deficits were more severe in those with right hemiplegia (Steenbergen, et al., 2004). In another study, designed to facilitate the use of motor imagery, Steenbergen et al. (2007) found that both left and right hemiplegia groups were significantly slower to respond than controls, but that all three groups conformed to the typical RT pattern. There were also no group differences for accuracy, leading the authors to argue that the hemiplegia groups were using an alternative technique to complete the task, which took longer, but enabled accurate responses to be made. For example, they may have treated the hands as objects and used a form of visual rotation, which is less reliant on motor networks in the brain. They argued that using such a technique, instead of engaging in motor imagery, reflected a deficit in motor imagery ability.

Based on findings that hands presented in the palm view may be more likely to elucidate motor imagery than those in the back view (Ter Horst, Van Lier, & Steenbergen, 2010), a more recent study with adolescents with right hemiplegia only presented hand stimuli in both the palm and back view and analyzed responses to the two views separately (Crajé, van Elk, et al., 2010). It was suggested that responses to hands rotated medially should be faster than to those rotated laterally, as medial rotation is more comfortable biomechanically, and that this effect would be stronger when hands were presented in palm view. Direct group comparisons were not reported, but only the control group showed the expected effect (responses took longer when hands were rotated laterally). The authors argued that the right hemiplegia group were not engaging in motor imagery due to deficits in motor imagery ability.

In contrast, the most recent study involved younger children (8-13 years of age) with both left and right hemiplegia, with hands presented in the back view only (Williams, et al., in press). No differences were reported between children with left and right hemiplegia and the hemiplegia group as a whole responded in accordance with expected biomechanical constraints to real movement – i.e. responses were faster to right hands than left hands when the hand stimuli was rotated in a counter-clockwise direction. It was argued that this supported the use of motor imagery in the hemiplegia group, though overall, they were slower and less accurate to respond than a comparison group. That the task appears to have elicited motor imagery in this group when it has not in previous studies (which have used adolescents and young adults) may reflect the increased reliance of children on motor processes when performing such tasks (Funk, Brugger, & Wilkening, 2005) and the specific imagery instructions provided to the children, as recommended by Gabbard (Gabbard, 2009).

However, given the small sample size of the study by Williams et al. (in press), the analysis of left versus right hemiplegia was somewhat limited and requires further exploration.

The aim of the current study was to comprehensively examine the motor imagery ability of young children with hemiplegia, based on their ability to perform the hand rotation task. Groups were compared on factors that may influence performance, such as IQ and attention, and these were accounted for when necessary. Further, responses to stimuli in clockwise and counterclockwise directions were analyzed to determine the likely use of motor imagery for each group. When examining overall response times and accuracy, responses to both left and right hands were considered separately. Finally, the function level of children with hemiplegia was taken into account, given our previous finding that motor imagery deficits in children with Developmental Coordination Disorder are greater in those with more severe levels of motor impairment (Williams, Thomas, Maruff, & Wilson, 2008).

We hypothesized that, in line with our previous study (Williams, et al., in press): 1) the responses of all groups would obey biomechanical constraints of the task (i.e. RTs faster to right hands when rotated counter-clockwise and vice versa); 2) the responses of children with both left and right hemiplegia would be slower and/or less accurate than a comparison group and; 3) children with hemiplegia who are classified as 'low functioning' will be slower and/or less accurate when performing motor imagery compared to children with hemiplegia who are classified as having 'normal or better functioning'.

2.0 Method

2.1 Participants

Children with spastic hemiplegia were recruited via the Victorian Cerebral Palsy Register (VCPR), Melbourne, Australia, which identified 98 children, aged 8-12 years, with a Gross Motor Function Classification System score of I or II and who had no known intellectual disability. Of these, 41 participated in the study. One was unable to complete the assessment due to language difficulties, leaving 21 participants with right-sided hemiplegia (R-HEMI) and 19 with left-sided hemiplegia (L-HEMI). Descriptive information can be found in Table 1, including information on brain abnormalities from neuroimaging scans (when available).

Twenty-one children without motor skill impairment, aged 8-12 years, were recruited from local schools to form a comparison group. Participants were identified by teachers as having typical motor coordination for their age, which was confirmed during assessment, and were free of intellectual impairment or any physical or neurological condition affecting motor development. Age and gender information can be found in Table 1.

2.2 Measures

2.2.1 Estimated IQ and attention.

IQ and attention measures were obtained to ensure group equality. The Wechsler Abbreviated Scale of Intelligence two sub-test version (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 Conners' Rating Scale – Revised (Conners, 2001) provided a measure of attention for each participant. The Cognitive Problems/Inattention T-score from the Parent Short Form was used (M=50, SD=10).

2.2.2 Motor skill assessment.

The McCarron Assessment of Neuromuscular Development (MAND; McCarron, 1997) was used to confirm typical motor development in the comparison group and provide an indication of motor impairment severity in the hemiplegia groups. Scores for 10 tasks are summed to provide a standardised Neuromuscular Development Index (NDI; M=100; SD=15).

2.2.3 Everyday functioning.

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. A score of 85 or less on the Adaptive Behavior Composite (ABC; M=100; SD=15) indicated moderately low to low function, while a score of 86 or higher indicated normal or better function.

2.2.4 Hand rotation task.

Single hand stimuli (9cm by 8cm) were presented on a laptop computer using E-Prime software (Psychology Software Tools, Pittsburgh, PA, USA). The left and right hands were high-resolution images presented in the back view (see Figure 1), centred in the middle of the screen. Hands were presented randomly, in 45° increments between 0-360°, and remained on screen until a response was recorded by pressing a designated key on the computer keyboard or 10s had passed. Responses were recorded to the nearest 1ms.

2.3 Procedure

The study was approved and conducted in accordance with the guidelines of the Human Research Ethics Committee of the Royal Children's Hospital, Melbourne, Australia. Informed consent was obtained from the parent/guardian of all children

prior to assessment either at the hospital or at the child's school. Tasks were counter-balanced among participants during one-on-one assessments.

For the hand rotation task, participants were seated in front of a laptop computer, which had two keys marked with stickers to designate them left (D key) and right (K key) for the purpose of responding. Participants rested their left index finger on the D key and right index finger on the K key. Researchers showed the participants example pictures of the hands, explaining how they would appear on the screen in rotated positions. They were asked to decide as quickly and accurately as possible whether the hand was left or right and to imagine their own hand in the position of the hand on the screen to help them decide. They responded by pressing the appropriate key. There were five practice trials and 40 test trials, each followed by a random delay of 2-3s.

2.4 Data Analysis

All analyses were conducted using SPSS, v.17. Group means for age and descriptive measures (IQ, NDI, ABC and attention) were submitted to individual univariate analysis of variance (ANOVA) to isolate group effects. The critical value for significance was adjusted using a bonferroni correction, resulting in a critical p of .013. Post-hoc tests were conducted using Tukey's HSD procedure and partial eta squared (η^2) was calculated to determine effect size.

For the hand task, anticipatory responses (less than 250ms) were removed prior to mean response times (RT) and accuracy (proportion correct) being calculated for each participant at each angle of rotation. To determine whether groups conformed to biomechanical limitations of the task, responses to left and right hand stimuli in clockwise (CW; responses to stimuli at 45, 90 and 135°) and counter-clockwise

(CCW; responses to stimuli at 225, 270 and 315°) directions were examined. Mean response time (RT) and accuracy were calculated for each group in each direction, to left and right hand stimuli separately, and submitted to a 2 (direction; CW, CCW) x 2 (laterality; left, right) x 3 (group; R-HEMI, L-HEMI, Comparison) repeated measures ANOVA. The multivariate approach was utilised to protect against violations to the assumption of sphericity and multivariate partial η^2 was calculated as a measure of effect size. Significant findings were followed up using pairwise comparisons of estimated marginal means with bonferroni corrections.

To analyse RT and accuracy overall, a commonly used technique in mental rotation studies to increase reliability of estimates by increasing the number of trials at each angle was employed (see, for example, Harris, et al., 2000; Roelofs, van Galen, Keijsers, & Hoogduin, 2002). This involved combining data from the same angular rotation, regardless of direction. For example, responses to stimuli at 90° and 270° were combined as both were 90° from the upright. This provided four trials at each of five angles (0° - 180°) for each hand (left/right). Mean RT and accuracy were both then submitted to 2 (laterality) x 5 (angle) x 3 (group) repeated measures ANOVA. The multivariate approach was again used and significant findings were followed up with pairwise comparisons of estimated marginal means.

Participants in the R- and L-HEMI groups were grouped according to function (low / normal) based on ABC scores. Participant's mean RT and accuracy at the five angles from 0-180° were then submitted to 2 (laterality) x 5 (angle) x 2 (function level) repeated measures ANOVA, using the multivariate approach and pairwise comparisons to follow up significant findings. A bonferroni correction was applied to the critical value for all repeated measures ANOVAs conducted, resulting in a critical value for significance of $p = .008$.

Finally, we determined the mean accuracy across angles for the hemiplegia groups and conducted a correlation analysis to determine the relationship between the overall mean accuracy and ABC score. A partial correlation was conducted, controlling for IQ, and using Cohen's (1988) guidelines for interpretation, where $r > 0.5$ is large, 0.5-0.3 is moderate, < 0.3 is small.

3.0 Results

Five participants (3 in L-HEMI group; 2 in R-HEMI group) with an estimated IQ < 70 were excluded from analysis, leaving 35 participants with hemiplegia. Group means for age and IQ, NDI, ABC and attention can be viewed in Table 2. Of the 35 children with hemiplegia, parent questionnaires were not returned or were incomplete in six cases.

3.1 Group Characteristics

ANOVA indicated that there was no significant difference between the groups on age, $F(2,53) = 2.11$, $p = .13$, $\eta^2 = .07$ or attention, $F(2,44) = 1.02$, $p = .37$, $\eta^2 = .04$. A significant group difference was identified 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 all three measures, the hemiplegia groups scored significantly lower than the comparison group: IQ - R-HEMI ($p < .003$), L-HEMI ($p < .017$); NDI - R-HEMI ($p < .001$), L-HEMI ($p < .001$) and; ABC - R-HEMI ($p = .004$), L-HEMI ($p < .001$).

3.2 Clockwise Versus Counter-Clockwise Responses

Figure 2 shows the effect of direction of stimulus rotation on RT and accuracy. For RT, analysis identified a significant interaction between hand and direction of rotation, Wilks' $\Lambda = .79$, $F(1,52) = 13.75$, $p = .001$, $\eta^2 = .21$. No other significant

interactions or effects were identified (all $p > .05$). Responses to left hands were faster when presented CW compared to CCW ($p = .002$), with the opposite being true for right hands ($p = .031$). Also, responses to stimuli in a CCW direction were faster for right hands, compared to left ($p = .001$). Though the opposite was true in a CW direction, the difference failed to reach significance ($p = .073$).

Similarly, analysis of accuracy data identified a significant interaction between hand and direction of rotation, Wilks' $\Lambda = .86$, $F(1,52) = 8.17$, $p = .006$, $\eta^2 = .14$. No other significant interactions were identified (all $p > .05$), but a significant effect was found for group, $F(2,52) = 5.46$, $p = .007$, $\eta^2 = .17$. Responses to left hands were more accurate in a CW direction than CCW ($p = .009$), with the opposite true for right hands ($p = .032$). Further, in a CW direction, responses were more accurate to left hands than to right ($p = .021$) and the opposite was true in a CCW direction ($p = .009$). Finally, the L-HEMI group was significantly less accurate than the comparison group ($p = .005$). No other group differences were identified.

3.3 Response Time

There were no significant interactions between RT and IQ (all $p > .05$). As a result, IQ was removed as a covariate. An interaction effect between group and angle did not reach the adjusted critical value for significance ($p = .008$), Wilks' $\Lambda = .73$, $F(8,98) = 2.06$, $p = .048$, $\eta^2 = .14$. No interactions or effects involving hand (left/right) were identified. As such, Figure 3a shows the RT patterns for each group with left and right hands combined. There was a significant effect for angle, Wilks' $\Lambda = .26$, $F(4,49) = 34.46$, $p < .001$, $\eta^2 = .74$, but no effect for group, $F(2,52) = 1.93$, $p = .16$, $\eta^2 = .07$.

3.4 Accuracy

There was a significant interaction between IQ and angle for accuracy data, Wilks' $\Lambda = .74$, $F(4,43) = 3.80$, $p = .010$, $\eta^2 = .26$, and as such, IQ remained as a covariate. After partialling out the variance associated with IQ, a significant interaction between group and angle was identified, Wilks' $\Lambda = .57$, $F(8,86) = 3.46$, $p = .002$, $\eta^2 = .24$. As with RT, no interactions or effects involving hand (left/right) were identified and Figure 3b shows the accuracy patterns for each group with left and right hands combined. The effect for angle was significant in both the R-HEMI and comparison groups ($p = .004$ and $<.001$ respectively), but not the L-HEMI group ($p = .79$). There were significant group differences at 45º, 90º and 135º ($p = .013$, .004 and .044 respectively), but differences at 0º did not reach significance ($p = .059$). There was no group difference at 180º ($p = .29$). The comparison group were significantly more accurate than the L-HEMI group at 45º ($p = .005$), 90º ($p = .004$) and 135º ($p = .015$) and the R-HEMI group at 90º ($p = .004$). There was only one difference between the R- and L-HEMI groups, at 45º, where the R-HEMI group were significantly more accurate ($p = .023$).

3.5 Functional Level

Of the 29 children for whom parent questionnaire data were available, 7 were classified as low function, six of whom were in the L-HEMI group. Parents of these children rated them considerably lower in function across all domains of the Vineland. Independent t-tests revealed no significant differences between the sub-groups for IQ ($p = .28$), or attention ($p = .24$). The low function sub-group scored lower than the normal function sub-group on the MAND NDI (53.8 vs. 65.9), though this difference did not reach significance ($p = .16$). Mean RT and accuracy for the

hand task can be seen in Figure 4. Analysis of RT found a significant effect for angle, Wilks' $\Lambda = .30$, $F(4,23) = 13.39$, $p < .001$, $\eta^2 = .70$, but no significant interactions and no other main effects (all $p > .05$). Repeated measures ANOVA on accuracy identified an interaction between stimulus laterality and function level, though this was not significant at the adjusted critical value, Wilks' $\Lambda = .81$, $F(1,26) = 6.00$, $p = .021$, $\eta^2 = .19$. No other significant interactions were found.

Finally, within the hemiplegia groups, there was a strong correlation between ABC scores and mean accuracy on the hand tasks, after partialling out the effect of IQ, $r = .51$, $p = .009$.

4.0 Discussion

This study aimed to provide insight into the ability of children with hemiplegia to perform the hand rotation task, used as a measure of motor imagery ability. The results of the study raise some interesting issues. Firstly, in line with our first hypothesis and our previous study (Williams, et al., in press), we are confident that motor imagery was used by all three groups, as the results of the CW and CCW analyses indicated that they conformed to the biomechanical limitations of the task. Such effects would not be expected if the hands were being treated as objects. It is interesting that the presence of hemiplegia did not disrupt this effect, despite the additional biomechanical constraints associated with the disorder.

In line with Steenbergen et al. (2007), who used the same form of stimuli as our current study, we found a significant effect for angle on RT in all groups. We hypothesized that the responses of the hemiplegia groups would be significantly slower than the comparison group, but this was not supported. Although the hemiplegia groups were generally slower than the comparison group, they were not

significantly so and the interaction between group and angle was not significant at the adjusted critical value. This is in contrast to Steenbergen et al. and our previous study (Williams, et al., in press), where significantly slower responses were observed in the hemiplegia group.

We also hypothesized that accuracy would be reduced in both hemiplegia groups compared to the comparison group. This was only true for the L-HEMI group who were significantly less accurate than the comparison group at three of the five angles. While there was a significant effect of angle for both the R-HEMI and comparison groups, the patterns across angles were somewhat different (see Figure 3). The comparison group was fairly consistent between 0-90°, but dropped off sharply at 135-180°, which is a typical pattern of response (Kosslyn, et al., 1998; Thayer & Johnson, 2006). In contrast, the accuracy of the R-HEMI group was variable across angles. For example, at 45°, they were significantly more accurate than the L-HEMI group, with no difference to the comparison group, but at 90°, they were significantly less accurate than the comparison group, with no difference to the L-HEMI group.

Taken together, the RT and accuracy results indicate that both hemiplegia groups were a little slower to respond than the comparison group (though not significantly so) and were, at times, less accurate. This was particularly the case for the L-HEMI group. These findings do not support the hypothesis that MI deficits are more likely to be observed in individuals with right hemiplegia. This finding is intriguing, given that there do not appear to be any major differences in the make-up of our L- and R-HEMI groups. However, our comparisons based on function level go some way towards explaining these findings.

Six of the seven children identified as low functioning based on the Vineland ABC score were in the L-HEMI group. There were no differences in RT between the

low and normal functioning children with hemiplegia, with both showing effects for angle. There was a reduced level of accuracy in the low functioning group, though this did not reach significance at the adjusted critical value. However, the correlation between function level and mean accuracy was strong and significant. Thus it appears that the reduced accuracy of the L-HEMI group may be linked to the high proportion of children in that group who were low functioning.

Taken together, these findings indicate that children with hemiplegia are capable of performing tasks that elicit the use of MI. The speed and accuracy with which they do so can vary and may be related less to the side of hemiplegia and more to the functional level of the child. Such a result may not be surprising if we consider that motor processes may be less lateralized in children with congenital hemiplegia as a consequence of cortical reorganisation. Reorganisation can result in cortical projections to the hemiplegic hand being ipsilateral or mixed, as opposed to contralateral (Carr, Harrison, Evans, & Stephens, 1993; Staudt, et al., 2004). Little is known about how such reorganisation affects other motor processes in the brain, but we do know that when projections reorganize to the ipsilateral side, the afferent projections do not necessarily reorganize in the same pattern (Thickbroom, Byrnes, Archer, Nagarajan, & Mastaglia, 2001). This results in a mismatch between the hemisphere sending commands and receiving sensory feedback, which might slow down online movement corrections and affect how movements are represented internally, as kinaesthetic input is required to accurately update movement predictions (Wolpert & Ghahramani, 2000).

Children with corticomotor projections that have reorganised generally exhibit lower levels of hand function (Holmström, et al., 2009), which could potentially explain our finding that children with poorer function levels are less accurate at

performing a motor imagery task. The relationship could also be suggestive of a

failure to properly develop internal representations of movement in children with low

function levels as a result of their limitations in motor execution. That is, representing

movements internally may be difficult for an individual who has always had great

difficulty in executing movements. Alternatively, 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.

The findings of this study have contributed to a greater understanding of MI

ability in children with hemiplegia and provide positive support for the trialling of MI

interventions in this group as a way to improve motor planning, though training may

need to be tailored to a child's level of function. Further support for such

interventions may be gathered by addressing some of the limitations of the current

study. In particular, the fact that we were limited in the level of information we had

regarding the extent and location of neural damage in our hemiplegia groups, as well

as cortical projection patterns, meant that we were unable to fully resolve the nature

of the relationship between functional level and MI ability. Also, in working with

children, the number of trials was restricted to 40, meaning that to analyse responses

from 0-180°, we needed to combine angles that were the same orientation from 0°

(e.g. combining responses to 45° and 315°) to allow sufficient responses at each angle

for analysis. This is a common technique when analysing such data (Harris, et al.,

2000; Roelofs, et al., 2002; Williams, Thomas, Maruff, Butson, & Wilson, 2006).

However, this technique could be criticised given our findings that responses to left

and right hands differed when presented in CW compared to CCW directions. In spite

of this, we are confident that our results were not clouded, as all groups showed the

same pattern of performance and significant interactions involving hand were still

identified when present in the low function group.

Finally, the measure of function used in the current study was a subjective

parent questionnaire. Although we did collect data on motor skill level in the children,

this was done using a measure which is standardised for all children, and not

specifically for those with hemiplegia. As a result, it was difficult to separate the

children with hemiplegia into typical and low function on this measure as almost all

children with hemiplegia scored in the clinical range. The Vineland Questionnaire

was deemed appropriate as it reflects the everyday functioning of the children and

better identifies those that are less functional. Despite this, future research may wish

to investigate functional level with a more objective measure.

5.0 Conclusions

This research demonstrated that children with hemiplegia were capable of

performing simple tasks using MI and that their accuracy when doing so was

dependent less on the side of their hemiplegia and more on their level of everyday

functioning. The next step in furthering understanding of MI ability in children with

hemiplegia should involve a more extensive examination of the neural factors which

might contribute to the variability observed within the hemiplegia groups. The results

are a positive finding for researchers interested in examining MI intervention

programs as a method of improving motor planning, as it needed to be established in

the first instance that children with hemiplegia were capable of engaging in MI tasks. As such, the results of this study are an important first step.

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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)
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)
NDI	60.63 (22.80)	61.87 (17.31)	105.10 (13.31)
ABC	98.64 (14.26)	94.60 (19.29)	120.36 (10.15)
Low function (n)	1	6	0
Attention	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.

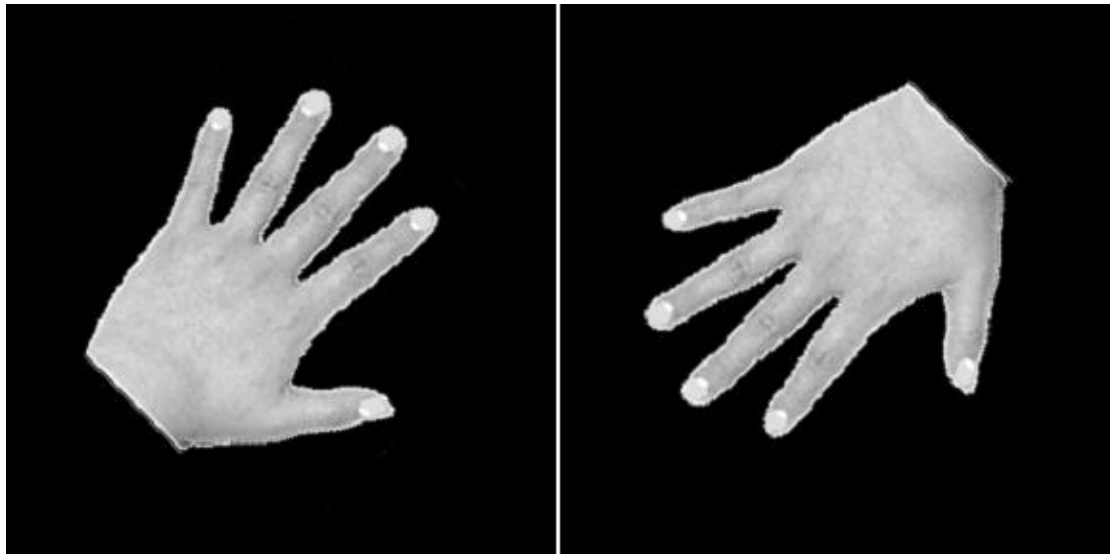*Figure 1.* Hand stimuli: left hand at 45° and right hand at 225°.

Figure 2. Response patterns to clockwise (CW) and counter-clockwise (CCW) stimuli. Error bars indicate ±2 SE.
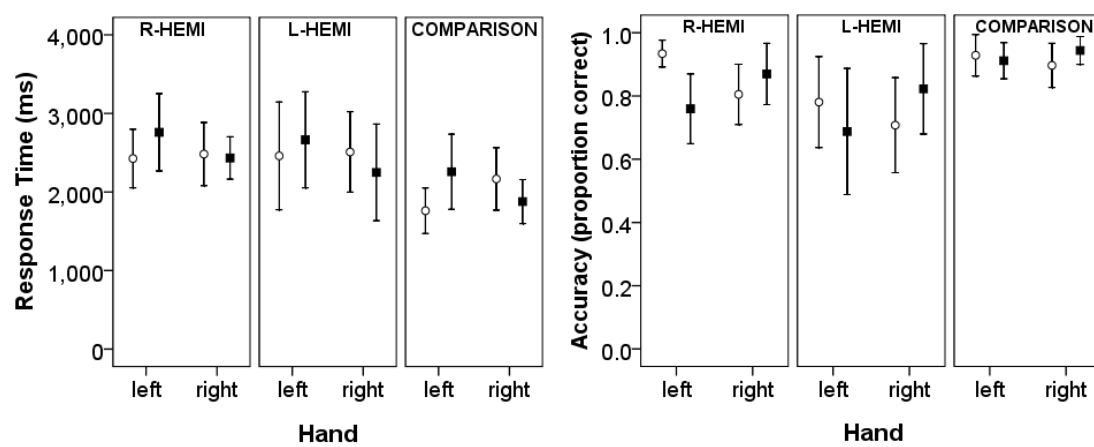
Figure 3. Mean response time and accuracy across angle. Error bars indicate ±2 SE.
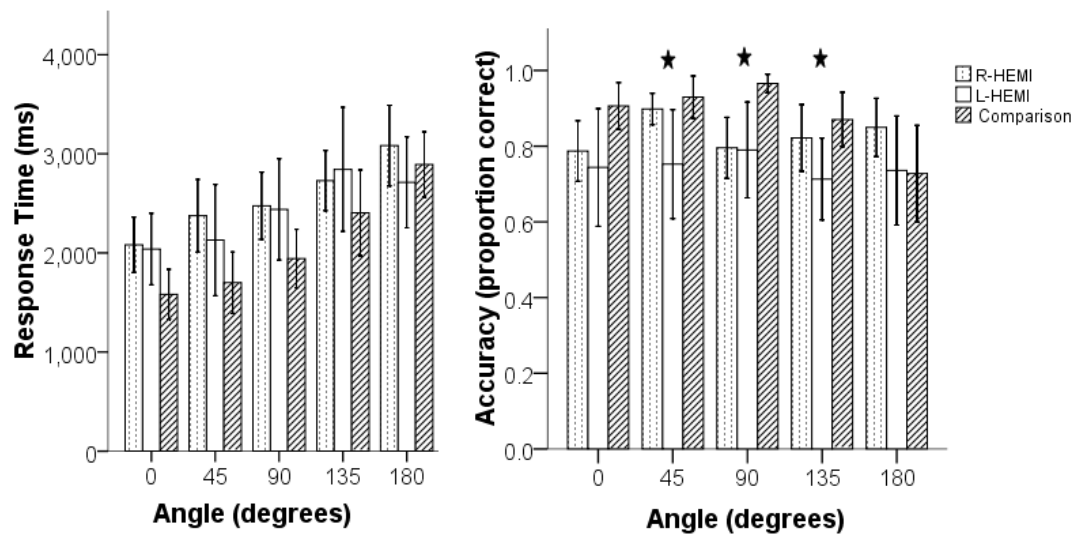
Stars indicate *p* < .05.

Figure 4. Mean response time and accuracy to left and right hands across angle for

low and normal function groups. Error bars indicate ±2 SE.