



Compromised motor planning and Motor Imagery in right Hemiparetic Cerebral Palsy

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ABSTRACT

We investigated whether motor planning problems in people with Hemiparetic Cerebral Palsy (HCP) are paralleled by impaired ability to use Motor Imagery (MI). While some studies have shown that individuals with HCP can solve a mental rotation task, it was not clear if they used MI or Visual Imagery (VI). In the present study, motor planning and MI were examined in individuals with right HCP ($n = 10$) and controls. Motor planning was measured using an object manipulation task, where participants had to anticipate the end of the motor action. MI was measured using a mental rotation paradigm, where participants judged laterality of hands presented from a back view and a palm view. To test if participants used MI or VI we compared reaction times of lateral versus medial rotations, under the assumption that MI is subject to biomechanical constraints of rotated hands, but VI is not. Individuals with HCP had a higher proportion of task failures due to inappropriate grip choice, exemplifying impaired planning. Second, individuals with HCP did not show a reaction time difference between lateral and medial rotations, indicating an impaired ability to use MI. These findings show that compromised motor planning in HCP is paralleled by an impairment in the ability to use MI. Training of MI may be a useful entry-point for rehabilitation of motor planning problems.

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1. Introduction

Converging evidence suggests that the motor deficits in people with Cerebral Palsy (CP) may not only be related to problems with motor execution, but also to problems with action planning (Gordon, Charles, & Steenbergen, 2006; Steenbergen & Gordon, 2006; Steenbergen, Verrel, & Gordon, 2007). This action planning deficit may hinder performance in daily life not only in the affected hand, but also when using the relatively unaffected hand (Steenbergen, Crajé, Nilson, & Gordon, 2009). Recently, studies examining planning in individuals with CP showed that planning problems are more severe when the right body side is affected (Crajé, Van der Kamp, & Steenbergen, 2009; Steenbergen & Van der Kamp, 2008), which corroborates neuroimaging studies showing a left hemisphere dominance for action planning (Haaland & Harrington, 1998; Haaland, Harrington, & Knight, 2000; Schluter, Rushworth, Passingham, & Mills, 1998; Schluter, Krams, Rushworth, & Passingham, 2001).

Action planning can be defined as the ability to anticipate the upcoming action when preparing a movement towards an object. This ability is especially important in sequential movements, where an object is grasped in order to do something

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with it (Gentilucci, Negrotti, & Gangitano, 1997; Johnson-Frey, McCarty, & Keen, 2004; Marteniuk, MacKenzie, & Jeannerod, 1987). For example, when grasping an upside down placed cup to pour coffee in it, most people will use a relatively uncomfortable supinated grip to grasp the cup. However, at the end of the movement, i.e., after rotation, the cup is held with a comfortable (pronated) grip. This preference of people to adapt the initial posture in order to end movements in a comfortable posture has been denominated as the 'end posture comfort effect' (Cohen & Rosenbaum, 2004; Rosenbaum, Vaughan, Barnes, & Jorgenson, 1992).

Action planning in individuals with hemiparetic CP (HCP) has only recently gained attention. Mutsaerts, Steenbergen, and Bekkering (2005, 2006) investigated action planning in individuals with HCP, by measuring performance of the unaffected hand. In these studies, participants were instructed to rotate a six-sided knob either 60°, 120° or 180°, in a clockwise or a counterclockwise direction and they were free to choose how they grasped the knob initially to fulfil the task. Especially in the 180° condition, it was necessary to select an appropriate grip type in order to fulfil the task, because an inappropriate start grip would make it biomechanically impossible to complete the 180° movement. In these critical conditions, HCP participants often (in about 50% of the trials) failed to perform the task, due to an erroneous initial choice of grip type. Instead of adapting the initial grip to the task constraints, the HCP participants chose to start the movement with a comfortable start posture. This finding suggests that only the first movement towards the object was planned, but not the end of the movement, indicating impaired forward planning.

Recently, it is suggested that Motor Imagery (MI) may play an essential role in action planning (Decety, 1996; Deconink, Spitaels, Fias, & Lenoir, 2008; Maruff, Wilson, Trebilcock, & Currie, 1999; Steenbergen et al., 2009). MI is the ability to mentally perform a movement without overt movement execution (Jeannerod & Frak, 1999; Mulder, 2007). As MI reflects the representation of an inhibited motor plan, it has been suggested that motor planning, which involves making a prediction about the future state of a movement, and MI are closely related processes (Johnson, 2000; Mutsaerts et al., 2006). Johnson proposed that 'MI may actually contribute to solving the problem of movement selection, a major component of constructing a premotor plan' (Johnson, 2000, p. 64). In this respect, Johnson et al. (2002) found that similar areas in the posterior parietal cortex were active during end posture planning and during MI.

MI is often measured using a mental rotation paradigm: pictures of hands (or other body parts) are presented in different orientations and participants have to make a laterality judgment, that is, decide whether a left or a right hand is presented. Several studies have shown that the time to judge hand laterality is similar to the time needed to execute a corresponding movement, i.e., reaction time increases as a function of rotation angle (Johnson, 2000; Mutsaerts, Steenbergen, & Bekkering, 2007; Parsons, 1994). Crucially, if participants indeed use MI to solve the task, that is mentally rotate the hands from a 'first-person' perspective, then reaction times should be longer for stimuli that are rotated laterally than for medial rotations as the latter are easier to perform. This was indeed found in studies using this paradigm (De Lange, Helmich, & Toni, 2006; Parsons, 1994; Ter Horst, Van Lier, & Steenbergen, 2010). As an alternative, participants can use Visual Imagery (VI) to solve the task. When using VI participants rotate the picture from a 'third-person' perspective, instead of rotating their own hand. Thus, based on the RT profile per se (RT increase with increased angle of rotation of the stimulus) it cannot be concluded how participants solve the task, i.e., using MI or VI. A critical, and sensitive, method to dissociate if participants use a VI or a MI strategy, is to compare the reaction times between conditions where the hands are rotated in a medial direction (i.e., towards the body midline) with rotations in a lateral direction (i.e., away from the body midline). Biomechanically, rotating your hands in a medial direction is easier than rotating your hands laterally. As a result, when participants use MI to perform the mental rotation task, reaction times should be longer for lateral rotations than for medial rotations, as the latter are easier to perform (DeLange et al., 2006; Parsons, 1994; Ter Horst et al., 2010). Therefore, in our analysis, we will specifically focus on difference in reaction time between medial and lateral rotations.

The ability to use MI in individuals with HCP has only received very limited attention and the existing data are inconclusive. Mutsaerts et al. (2007) investigated MI in individuals with left and right HCP using palm view pictures of hands. Results showed a linear increase in reaction time as a function of rotation angle in participants with left HCP, but not in individuals with right HCP. Mutsaerts et al. concluded that MI was impaired in the right HCP group, but not in the left HCP group. However, in a follow-up study of Steenbergen, Van Nimwegen, and Crajé (2007), where only pictures of hands from a back view were used, a linear RT increase was found for individuals with both left and right HCP. As there was no asymmetry in responses to hand stimuli of the left and right hand, Steenbergen et al., concluded that these participants may have used an alternative strategy to solve the mental rotation task, i.e., VI. In essence, both studies differed with respect to the view of the displayed hands (palm and back view, or only back view). Importantly, in a recent study, Ter Horst et al. (2010) showed that palm view stimuli more directly elicit MI, while back view stimuli resulted in VI. This facet of the stimulus set may have caused the difference among both studies. Moreover, as in both studies no comparisons between medial and lateral rotations were made, it could not be established whether participants indeed used MI or VI.

The aim of the present study is to examine motor planning and MI capacities concurrently in adults with HCP. Ten participants with right sided HCP (left 'unimpaired' hand), and 10 control participants performed two tasks: a motor planning task and a MI task. Participants with right sided HCP were included as previous research consistently showed a planning disorder in this group. For the planning task, we used a paradigm similar to Mutsaerts et al. (2005, 2006), where participants had to rotate a hexagonal knob over 60°, 120° and 180°. Performance was measured in the relatively unaffected hand, as it may be impossible to perform the tasks with the affected hand and therefore the results would have reflected motor execution problems instead of motor planning problems. Consistent with Mutsaerts et al., we measured the proportion of task failure to evaluate planning. Based on the findings of Mutsaerts et al. (2005, 2006) we expected to find more task failures in the HCP group.

For the MI task we used a mental rotation task with hand pictures from a back view and from a palm view, to investigate whether stimuli rotations over 1 or 2 axes results in different strategies to solve the task, i.e., MI or VI. Crucially, when MI is used to solve the task we expect to find a reaction time difference between the lateral and medial rotated stimuli.

2. Method

2.1. Participants

In total 20 individuals participated in the study: 10 participants with the diagnosis HCP at the right body side (6 male, mean age 19.1 y/m, SD 0.9 y/m) and 10 right handed age-matched control participants (5 male, mean age 22.2 y/m, SD: 2.1 y/m). All participants had normal or corrected to normal vision. The participants with HCP were recruited via a school of special education and via the Dutch society of parents of physically disabled children ('BOSK'). As a consequence, only limited information about the brain pathology was available. To get a good clinical picture of each participant we assessed severity of the hand function impairments by the Box and Blocks test (Mathiowetz, Volland, Kashman, & Weber, 1985) and the Purdue Pegboard test (Tiffin, 1985). Both tests were performed with the affected hand and the unaffected hand, and the ratio between the scores of both hands gives an indication for the severity of hand function impairment (see Table 1 for participant information). Thus, a score near 0 exemplifies a strong difference among the impaired and unimpaired hand indicating a severe paresis, whereas a score closer to 1 indicates that hand function among both hands is similar. Participants received money or course credit for their participation. All participants gave informed consent prior to the experiment. The study was approved by the local ethics committee, in accordance with the 1964 declaration of Helsinki.

2.2. Material and procedure

2.2.1. Planning task

Participants were comfortably seated at a chair in front of a table. On the table the device with the hexagonal knob was placed (see Fig. 1A). The device consisted of two main parts: a wooden background disk (diameter 40 cm) with 6 LEDs on it and the hexagonal knob (diameter 11 cm, depth 6 cm) that was mounted in the center of the disk. The knob could freely rotate on the vertical axis (see Mutsaerts et al., 2005, 2006 for details).

Participants were asked to grasp the knob with a full power grip, that is, with the fingers at one side of the knob and the thumb on the opposite side yielding six possible ways to grasp the knob (see Fig. 1B). Performance was measured in the relatively unaffected hand. After performing the experiment, we asked participants which grip was most comfortable. Most participants found grip type 3 most comfortable. The device was placed as such that it was impossible for participants to use grip type 6. Especially in the 180° rotation condition this constraint made it important to plan the movement in advance, as a comfortable start posture (grip type 3) would result in a task failure (see Mutsaerts et al., 2006).

A typical trial had the following sequence. First, participants pressed the button of a button box and waited until the LEDs were switched on. The LEDs were switched on to indicate the rotation angle that had to be made and in which direction the knob had to be rotated. Participants were instructed to release the buttonbox after they had made a decision how to grasp the knob. Then, they grasped and rotated the hexagonal knob in the instructed direction and rotation angle. During the experiment six rotation angles were used: 60°, 120° and 180° clockwise (CW) and 60°, 120° and 180° counterclockwise (CCW). Every rotation angle was repeated 10 times resulting in 60 trials. Before the experiment started 10 practice trials were performed. In total the experiment took about 15–20 min to perform. As dependent variables we measured the proportion task failure (i.e., the proportion of trials that ended with grip type 6).

2.2.2. MI task

Participants were comfortably seated on a chair positioned in front of a table, on which a 19" computer screen was placed. The screen was 60 cm in front of the participant, which resulted in a visual angle of approximately 2°. Participants were

Table 1
Participant information.

Part	Age (y/m)	Sex	Box and Blocks			Purdue Pegboard		
			AH	UH	Ratio	AH	UH	Ratio
1	18.8	M	20	69	0.29	4	28	0.14
2	19.3	F	11	76	0.14	0	31	0
3	17.5	M	9	63	0.14	0	20	0
4	19.2	M	33	49	0.67	2	23	0.09
5	20.11	M	26	49	0.53	0	30	0
6	17.8	F	18	47	0.38	0	32	0
7	21.11	M	60	57	1.05	23	22	1.05
8	17.8	M	60	56	1.07	20	27	0.74
9	19.3	F	16	49	0.33	0	28	0
10	15.7	M	56	47	1.20	21	22	1.05

Note: AH, affected hand; UH, unaffected hand; ratio = (score AH)/(score UH).

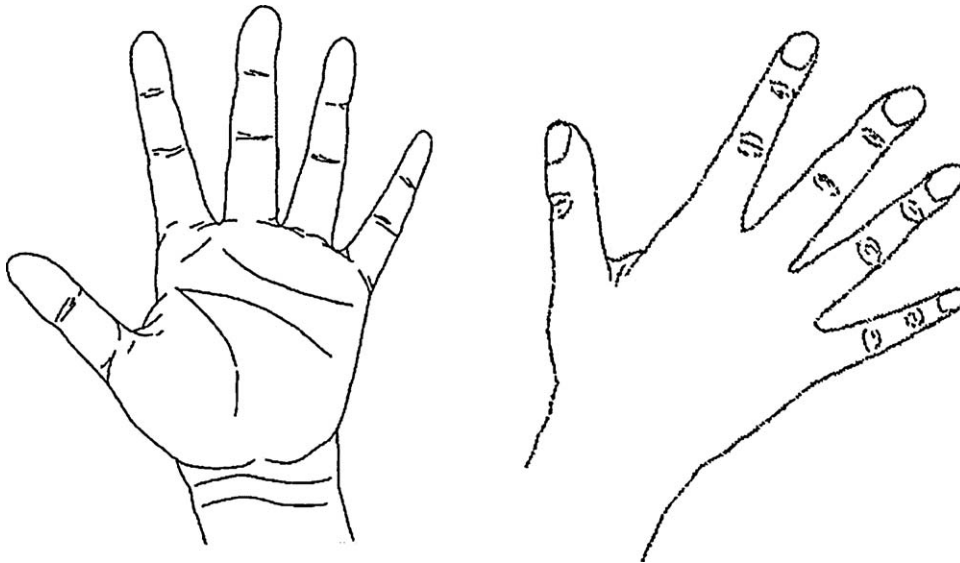


Fig. 1. Two examples of stimuli used in the experiment. The left picture is a palm view left hand with 0° rotation and the right picture is a back right left hand with 40° rotation.

instructed to make laterality judgments of the displayed hands (by pressing either a left or a right button with respect to the left middle finger or the left index finger), and to be as accurate and fast as possible. Reaction time and errors were measured. The experiment was controlled by a computer running Presentation 12.2.09 (Neurobehavioral Systems, Albany, USA)

The stimuli consisted of line drawings of left and right hands, which were drawn from two perspectives: back view and palm view (see Fig. 2 for examples). The palm and back view stimuli were presented in random order. The hand pictures were rotated in 10 different orientations (0°, 40°, 75°, 110°, 145°, 180°, 215°, 250°, 285°, and 320°). Notably, the direction of rotation differs per hand: a 40° rotation is a 40° medial rotation for the left hand stimuli and a 40° lateral rotation for the right hand stimuli. Every stimulus was repeated 10 times resulting in 400 trials. All stimuli were presented in random order. Before the actual experiment started, there was a practice session of 10 trials. The total experiment took about 30 min. The experiment was divided in two blocks.

2.3. Data analysis

2.3.1. Planning task

For every participant the proportion of task failures was calculated. The proportion 'task failure' was analyzed using a repeated measures ANOVA with two within factors (Direction: clockwise and counterclockwise; and Rotation: 60°, 120° and 180°) and one between factors (Group: HCP and control).

2.3.2. MI task

Our main research question was to scrutinize the strategy used by participants to solve the mental rotation task, either by MI or VI. To answer this question we analyzed differences in RT between medial and lateral stimuli of hands in the palm view and back view conditions. A difference between RT in lateral and medial conditions point to a MI strategy to solve the task, whereas no difference between RT in lateral and medial conditions indicates that participants used VI. To investigate whether participants used MI to perform the mental rotation task, we compared the averaged RT for the lateral and medial rotations. Thus, for both the palm and back view stimuli the reaction times were averaged for 40°, 75°, 110° and 145° separately for the lateral and medial rotations resulting in 4 RT values per participant: palm view – medial, palm view – lateral, back view – medial and back view – lateral. The 0° and 180° conditions were not used for analysis, as these rotations cannot be classified as medial or lateral. Paired sampled *T*-tests (with Bonferroni correction, yielding an alpha level of .05/4 = .0125) were performed separately for the HCP group and the control group.

3. Results

To investigate if the severity of HCP was related to the experimental measures we calculated Pearson correlations between the hand function tests (i.e., Box and Blocks and Purdue Pegboard) and the experimental tasks: (a) planning task (proportion task failure) and (b) the MI task (the RT difference scores between medial and lateral rotations). Regarding hand function, we found a significant correlation between Box and Blocks and Purdue Pegboard ($r(9) = .963, p < .001$). However, no significant correlations between hand function and planning and between hand function and MI were found.

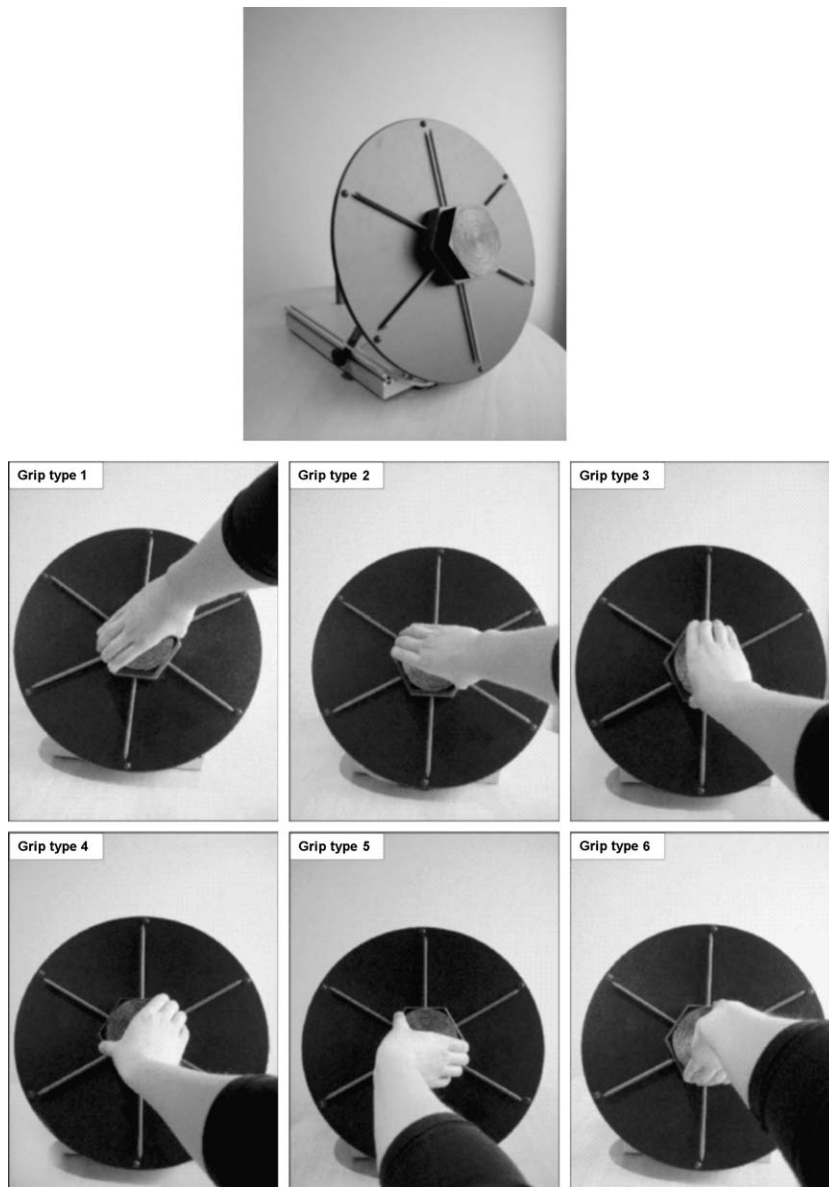


Fig. 2. The apparatus with the hexagonal knob (A). An arrow is attached to every side of the knob and points at the LEDs at the wooden background. In (B) the six grip types that can be used to grasp the knob are shown. Notably, in our experiment grip type 6 was not possible.

To test whether planning and MI were related we calculated the correlation between the proportion task failure (indicating planning deficits) and the RT difference scores between medial and lateral hand stimuli (indicative of MI or not), for the two groups separately (see Fig. 3). No significant correlations were found. For the control group the correlation was .346 ($p = .32$), and for the CP group .308 ($p = .40$).

3.1. Planning task

The proportion task failure, i.e., the proportion of trials that ended in posture 6, is presented in Fig. 3. A significant effect of Group ($F(1, 17) = 100.10, p < .01$) was found, indicating that the proportion task failure was significantly higher in the CP group compared with the control group. The repeated measures ANOVA showed a linear main effect of Rotation Angle ($F(2, 34) = 6.71, p < .01$), indicating the proportion of task failures increased with rotation angle. There was no interaction effect of Group \times Rotation Angle, suggesting the linear increase was similar in the control group and the HCP group. Further, two significant interaction effects were found. The significant interaction between Rotation \times Direction ($F(2, 34) = 3.51, p < .05$) reflected that more errors were made in the 180° CW condition than in the 180° CCW condition. The significant interaction

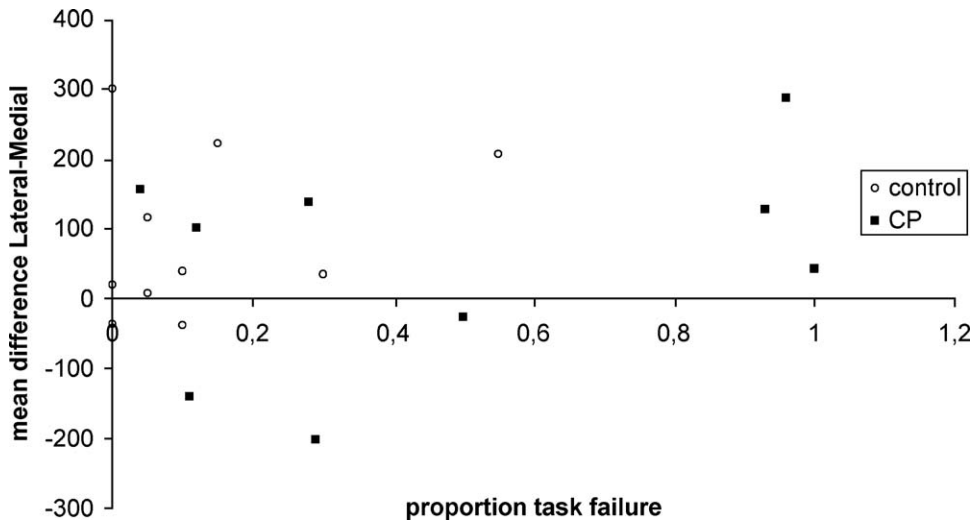


Fig. 3. Scatterplot of the proportion task failures (x-axis) and the RT difference scores between medial and lateral rotations (y-axis).

between Direction \times Group ($F(1, 17) = 4.92, p < .05$) indicated that the proportion of task failure in the control group (but not in the CP group) was higher in the CW conditions than in the CCW conditions.

3.2. MI task

Participants were able to perform the mental rotation task. They made a small number of errors: 7% (range: 4–16%) in the CP group and 5% in the control group (range: 2–11%). One CP participant made more than 50% errors. Therefore the data of this participant were excluded from further analyses, as this participant was merely guessing. To give an impression of the pattern of reaction times, the reaction time data are presented in Fig. 4. Notably, an asymmetric RT pattern centered around 180° reflects a difference between lateral and medial rotations. For example, for the right hand stimuli a rotation angle of 145° represents a 145° lateral rotation, whereas a 215° rotation angle represents a 145° medial rotation. For the left hand this pattern is the opposite: a rotation angle of 145° represents a 145° medial rotation, whereas a 215° rotation angle represents a 145° lateral rotation.

We calculated the averaged reaction times for the lateral and medial conditions (i.e., the averaged RT of 40°, 75°, 110° and 145°) in the palm and back view conditions, separately for both groups (see Fig. 5). Paired sampled *T*-tests (with Bonferroni

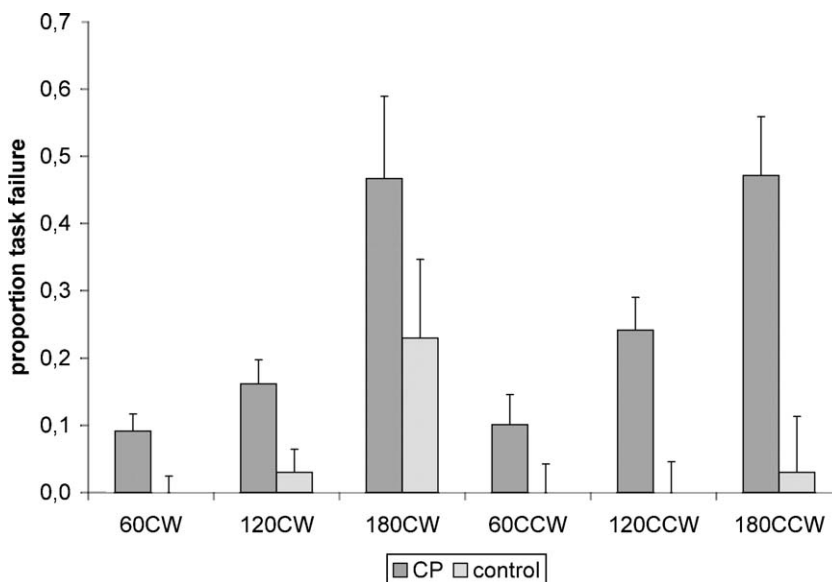


Fig. 4. The proportion of task failure in the planning task (y-axis) for the different rotations (x-axis). Dark grey bars represent the CP group and light grey bars represent the control group. Error bars represent 1 SE.

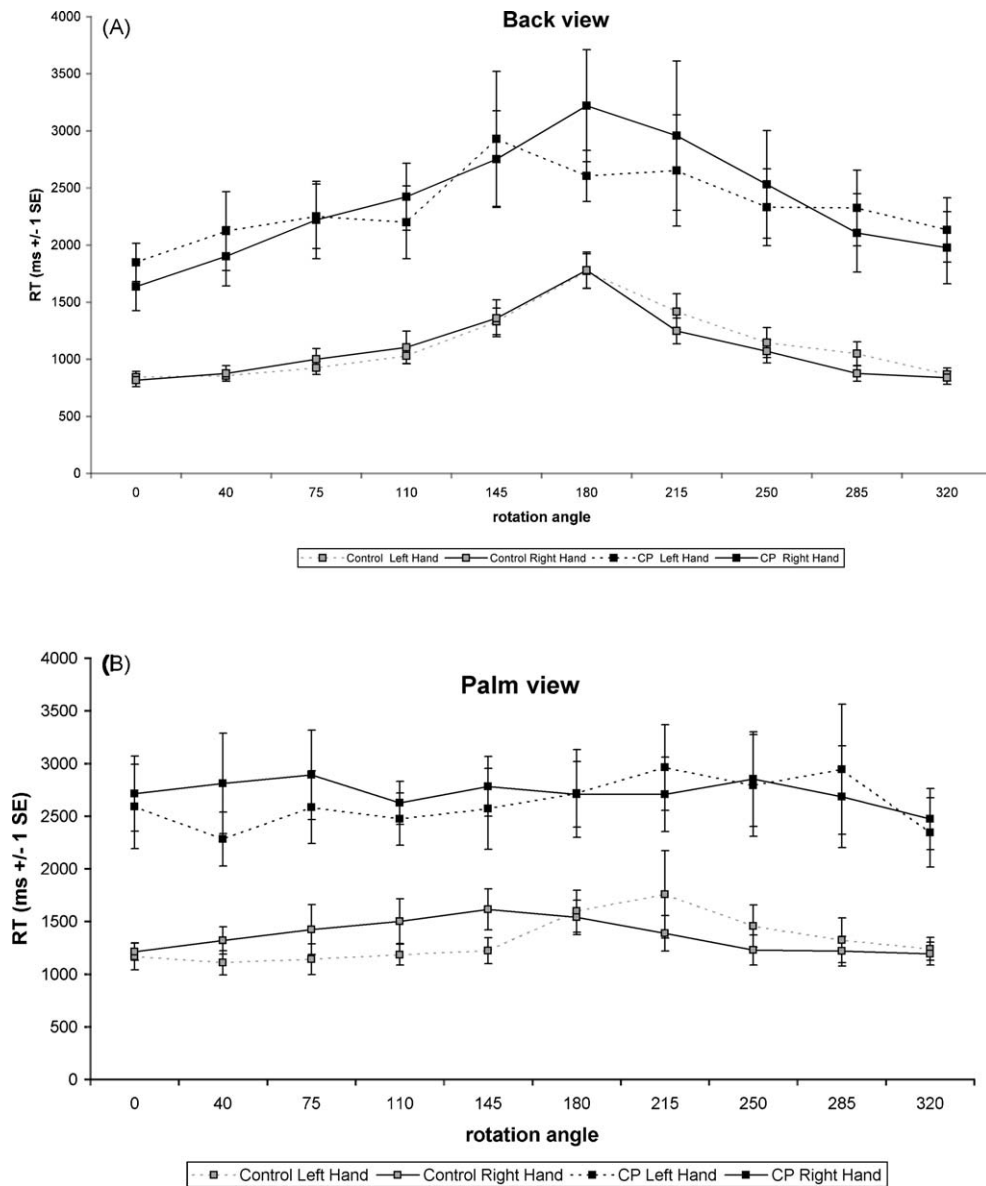


Fig. 5. Mean reaction times (y -axis) for the 10 rotation angles (x -axis), separated for hands (straight lines for the right hand stimuli and dotted lines for the left hand stimuli). The control group is represented in grey and the HCP group in black. Error bars represent 1 SE.

correction, yielding an alpha level of $.05/4 = .0125$) were performed separately for the HCP group and the control group. Thus, for the palm and back view condition separately, the averaged RT of the medial rotations was compared with the averaged RT of the lateral rotations. These analyses showed that the difference between medial and lateral rotations was only significant in the palm view condition in the control group ($T(9) = -3.689$, $p < .01$). These findings exemplify that the control participants used MI in the palm view condition, but not in the back view condition. Our findings suggest that the CP participants were not using MI in either of the conditions (Fig. 6).

4. Discussion

The aim of the present study was to concurrently examine motor planning and Motor Imagery (MI) in individuals with Hemiparetic Cerebral Palsy (HCP) under the assumption that disorders in motor planning and MI are paralleled. There were three main results. First, motor planning was impaired in the HCP group as we found significantly more task failures in this group compared to controls. Second, in the mental rotation task we found no significant differences between the lateral and medial rotations for both the back and palm view stimuli for the CP group, suggesting that these participants were not engaged in MI. Taken together, these two main findings confirm our assumption. Third, in the control group we found a

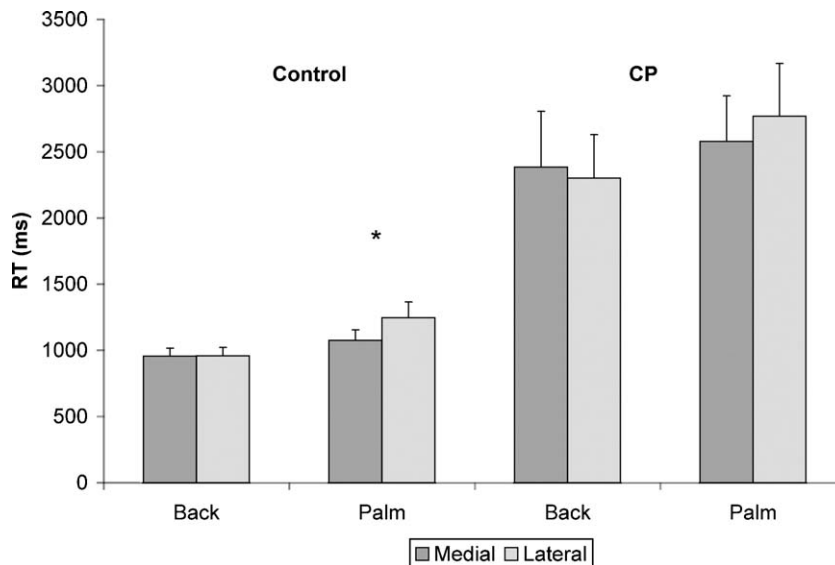


Fig. 6. Mean reaction times for the lateral and medial rotations in the palm and back view stimuli, separately for the control group and the CP group. Dark grey bars represent lateral rotations, light grey bars represent medial rotations. Error bars represent 1 SE. * = $p < .05$.

significant difference between lateral and medial rotations (suggesting the use of MI) in the palm stimuli, but not in the back stimuli. Below we will elaborate on these results.

Converging evidence indicates that individuals with CP have problems with anticipatory motor planning. As MI reflects the representation of an inhibited motor plan, it has been suggested that motor planning (which involves making a prediction about the future state of a movement) and MI are related processes (e.g., Johnson, 2000), and as such it is hypothesized that problems with MI may also be present in this group (Mutsaerts et al., 2006; Steenbergen, Van Nimwegen, et al., 2007). Previous studies investigating MI in CP are not unequivocal whether these participants can or cannot use MI. In the present study we used a mental rotation task with pictures of hands from a back view and from a palm view perspective. To evaluate whether participants used an MI or a VI strategy to solve the task we compared the RTs of the lateral and medial orientations, under the assumption that MI is subject to biomechanical constraints of rotated hands, but VI is not.

First, in the planning task we found significantly more task failures in the CP group, suggesting impaired planning in the CP group. This finding is consistent with previous studies that also found impaired planning in individuals with CP (Crajé et al., 2009; Mutsaerts et al., 2005; Steenbergen & Gordon, 2006). The device was placed as such that it was impossible for participants to use grip type 6, and accordingly, a task failure was scored when participants ended the movement with grip type 6. Especially in the 180° rotation condition this constraint made it important to plan the movement in advance, as a comfortable start posture (grip type 3) results in a task failure (see Mutsaerts et al., 2006). In the CP group, task failures were observed in about 50% of the trials. In the 180° condition a movement ended in a grip type 6 when participants started the movement with a grip type 3, the grip type that most participants denominated as a comfortable grip. The use of a comfortable start grip implies a strategy of planning the first movement towards the object, but not the upcoming movement, thus impaired planning. This finding is consistent with previous findings (Crajé et al., 2009; Mutsaerts et al., 2005, 2006) and may be regarded as a step-by-step planning strategy (Steenbergen & Van der Kamp, 2004).

Second, in the mental rotation task for the CP participants we did not find significant differences between the lateral and medial rotations of hand stimuli. This result suggests that they did not use MI to solve the task. Had they done so, then the rotation would have been subject to the biomechanics of the rotation and, likewise, a difference in RT between lateral and medial rotations would be expected. This finding confirms previous findings that have suggested a deficit in the use of MI in participants with CP (Mutsaerts et al., 2007; Steenbergen, Van Nimwegen, et al., 2007). Theoretically, MI is grounded within motor theories of internal forward models (Miall & Wolpert, 1996; Wolpert, 1997). It is argued that these models control movements by predicting the future state of the moving limb based on a copy of the motor command, viz. the efference copy. Our MI results suggest a deficit in these internal models. Similar results were obtained in children with DCD. They were also shown not to be automatically engaged in MI when performing a mental rotation task (Maruff, Wilson, Trebilcock, & Currie, 1999; Wilson et al., 2004), much like our results with participants with CP. This deficit to use MI was denoted as the Internal Modeling Deficit, to emphasize that it reflects an impairment in the build-up of internal forward models. Individuals with CP have problems with the internal representation of hands. This has repercussions for action planning, as action planning involves making a prediction about a future state of the hand. For example, in the planning task that was used participants had to predict the end posture after knob rotation. In the 180° condition inappropriate planning resulted in task failures, which happened in about 50% of the trials in the CP group, suggesting impaired planning. As such our study provides direct evidence for impaired planning and impaired MI in CP.

At this point it is important to note that the extent to which MI can be used is not an ‘all-or-nothing’ phenomenon. That is, it may be suggested that participants with CP *can* use MI, but that this capacity is less well developed compared to healthy control participants. This can be illustrated by our finding that the RT data in the CP group for the palm view stimuli show a trend towards a lateral-medial difference, but this failed to reach conventional levels of significance. Likewise, using EEG registration, we recently showed differential neural activity among mildly and severely affected participants with CP (Van Elk et al., *in press*). Specifically, source localization analyses showed increased activity of motor areas during a mental rotation task in the mild group as compared to the severely affected participants. Consistent with this, Williams, Thomas, Maruff and Wilson (2008) found that MI was more impaired in children with severe Developmental Coordination Disorder (DCD), than with mild DCD.

In sum, the impairment in action planning may be promoted by an impairment in the internal forward model. These insights open up a new avenue for rehabilitation of CP. It is evident that rehabilitation of motor planning disorders must operate on these MI impairments (see Steenbergen et al., 2009). In this respect, Wilson, Thomas, and Maruff (2002) examined the effects of MI-training in children with DCD (7–12 years) on motor skills. The results of this training showed that MI-training was equally beneficial compared with traditional motor training. Although rehabilitation studies that use MI-training for the treatment of developmental disorders are scarce, converging evidence in patients with acquired brain damage has shown that MI-training may be beneficial for recovery of motor function (Page, Levine, & Leonard, 2007). The results from children with DCD and patients with stroke are promising. Still, until present, no studies on the use of MI-training for upper-limb rehabilitation in CP have been done despite it being a theoretically feasible method to activate the immature networks involved in motor control. In fact, MI is proposed to be a backdoor mechanism to access the motor system (Sharma, Pomeroy, & Baron, 2006). Therefore, for individuals with motor planning problems this cognitive MI-training may be useful to improve motor skills. However, first research is warranted to investigate if participants with impaired MI capacities can learn to use MI.

Finally, an unexpected finding in the control group was the lack of significant difference between lateral and medial rotations for the back view stimuli, despite the difference for palm view stimuli. This finding suggests that different strategies were used for the different hand perspectives: MI was used for the palm view stimuli and VI for the back view stimuli. This finding corroborates recent findings from our lab that showed that palm view stimuli are more likely to elicit MI than back view stimuli (Ter Horst et al., 2010). These findings extend and refine previous studies on mental rotation tasks as they exemplify that engagement in MI critically depends on the type of stimuli used (here, back view and palm view). Moreover, these findings suggest that MI-training is best performed using palm view stimuli. If only back view stimuli are used, engagement is unlikely to occur, and participants may use an alternative strategy. However, for MI-training to be effective it is a prerequisite that participants are engaged in MI as only then neural networks are active that are similar to those that are active during actual movement.

In sum, this study is the first to examine the relation between motor planning and MI in individuals with CP. Our results confirm the hypothesis that there is a relation between MI and motor planning as we found impaired planning and impaired MI in the CP group. Nonetheless, we did not find a correlation between the planning and the MU measurements. We think, this (null) finding may be due to the low variance at the motor tasks. Further research, for example with more challenging motor planning tasks, need to be performed to investigate this topic. These findings are an important departure point for a promising new way of upper-limb rehabilitation in this group of participants (see Steenbergen et al., 2009).

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