Original Article

Performance strategy in the hand mental rotation task in hemiplegic stroke patients

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Abstract

Purpose: We compared the accuracy and response times for a hand mental rotation task (HMRT) in patients with hemiplegic stroke in order to investigate performance strategies adopted when patients were required to determine whether a presented picture showed a left or right hand.

Patients and Methods: Twenty-eight patients with hemiplegic stroke performed the HMRT (14 patients with left-hemisphere brain damage: 59.5 ± 15.8 years; 14 patients with right-hemisphere brain damage: 65.6 ± 14.9 years). Hand pictures featuring various combinations of three factors (left or right hand, palm or back of hand, and six angular orientations were randomly presented. The third finger pointing upward was defined as an angle of 0°, and clockwise rotation occurred in increments of 60°. Participants were instructed to use their non-paralyzed hand to press the button in the determined direction (e.g., in the case of a left hand picture, the left button was pressed) as quickly and as accurately as possible.

Results: The accuracy in the HMRT was lowest for angles of 180°, and an increasing trend in accuracy was observed as the picture was rotated clockwise or counterclockwise towards 0°. The ΔRT was also longest for angles of 180° and tended to decrease as 0° was approached. Moreover, when compared with RTs for pictures of hand angles that were easier to replicate, those for pictures of hand angles that were difficult to replicate were longer.

Conclusion: These results indicate that patients with hemiplegic stroke utilize a mental transformation strategy to perform HMRTs, and that this strategy involves simulation of one's own hand movements (motor imagery strategy).

Keywords : Motor imagery, Hemiparesis, Reaction time, Response time, Motor response generation

Introduction

Motor imagery is defined as a dynamic state during which the representation of a given motor act is internally rehearsed within working memory without any overt motor output (Decety, 1999). Research has indicated that the brain activation for motor imaginary is similar to that for actual movement (Ruby, 2003). It is predicted that motor imagery may improve actual motor function for patients who have experienced hemiplegic stroke exhibit difficulties in moving limbs of the affected side. Therefore, the motor imagery has recently utilized in clinical rehabilitation for those patients (Liu, 2009; Polli, 2016).

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Hand mental rotation tasks (HMRTs) have been used to assess implicit motor imagery ability (Amesz, 2016) as well as for rehabilitation training purposes (Polli, 2016). In an HMRT, a rotated picture (photograph or line drawing) of the left or right hand alone is presented to the participant, who must then distinguish whether the image depicts the left or right hand. Accuracy and response time (RT) are measured during the task. Prolonged RTs have been observed when participants are presented with an image of the hand in a position that is difficult for them to replicate (Sekiyama, 1982; Saimpont, 2009; Takeda, 2010; ter Horst, 2010). Sekiyama (1982) measured RTs for hand pictures in eight angular orientations (fingers pointing upward was defined as an angle of 0°; clockwise rotation occurred in increments of 45°). In the case of the palmar side picture, RT was longest for the right and left hands when the presented angles were 135° and 225°, respectively, which represent the most difficult degrees of movement for each hand. When participants perform the HMRT, it is suggested that the participants simulate movements using their own hand (motor imagery) because of the posture dependent RT (e.g. hand position) (de Lange, 2006; Ionta, 2009) and of the cerebral activities in movement-related areas (e.g. premotor area, parietal association area) during the task (Kosslyn, 1998; de Lange, 2006).

In order to perform rehabilitation training through motor imagery using the HMRT in hemiplegic stroke patients, it is necessary for patients to generate motor imagery to perform the task. However, research has indicated that rotation of the hand is not always internally simulated in the HMRT. For example, Gentilucci et al. (1998) suggested that left-handed participants rotated the presented picture itself rather than their own hand in order to determine if the image displayed a left or right hand. In such cases, motor imagery may not be generated. Previous HMRT studies have reported lower accuracy and increased RTs for patients who have experienced a hemiplegic stroke in comparison to those of healthy participants (Yan, 2012; Amesz, 2016). However, few studies have examined the relationship between the angle of the presented picture and RT when investigating strategies used to perform the HMRT.

Therefore, in the present study, we compared the accuracy and RTs of patients with hemiplegic stroke for various angles of image presentation in order to elucidate performance strategies utilized in the HMRT.

The purpose of the study and research methods were explained to all participants in a study manual. Written consent was obtained from all participants. The present study was approved by the institutional review boards of the Faculty of Health Sciences, Kyorin University (Approval No. 26-50) and Tsurumaki Onsen Hospital (Approval No. 186).

Patients and Methods

1. Participants (Table 1)

A total of 28 right-handed patients with hemiplegic stroke were selected as participants. Patients who did not understand the details of the study, as determined by the therapists, and who had difficulty in performing the task were excluded. The dominant hand was confirmed using a method previously described by Sakano et al. (1985), which is based on the Edinburgh Handedness Inventory developed by Oldfield (1971), and the laterality quotient was calculated when the participants performed HMRT. Patients also underwent assessment using the Mini-Mental State Examination and Stroke Impairment Assessment Set within one week of the HMRT.

Table 1: Characteristics of the patients (*Mean* ± *Standard Deviation*)

		Lesion side		*p* value
		L (n = 14)	R (n = 14)	
Age		59.5 ± 15.8	65.6 ± 14.9	0.30[a]
Sex	M	7	7	1.00[b]
	F	7	7	
L.Q.		98.6 ± 5.4	100 ± 0.0	0.75[a]
Days after onset		78.4 ± 27.1	86.9 ± 23.1	0.57[a]
Inpatient days		58.8 ± 29.3	63.2 ± 25.9	0.73[a]
MMSE [0-30]		28.4 ± 3.6	28.3 ± 2.2	0.43[a]
SIAS-Total [0-64]		50.9 ± 11.9	52.7 ± 18.1	0.67[a]
SIAS-Motor [0-25]		12.9 ± 6.2	14.9 ± 9.2	0.45[a]

M: male. F: female. L: left. R: right. [a]Mann-Whitney U test. [b]Chi-square test. L.Q.: Laterality Quotient ranging from -100 for left-banders to +100 for right-handers. MMSE: Mini-Mental State examination. SIAS: Stroke Impairment Assessment Set.

2. Experimental Procedure

Before the HMRT, patients completed a left-right selection task in which an image of an arrow pointing to the left or right (left-right arrow task) was displayed. Patients then practiced the HMRT using six hand pictures prior to engaging in the experimental task. All experiments were conducted in a quiet setting with no distracting sounds. A laptop computer (Latitude 15, 3000 series, 15.6 model, Dell-Japan Corp., Kawasaki, Japan) was placed on the desk in front of the participants, who subsequently rested their chins on a chin stand and placed the paralyzed hand on the knee of the same side. The hand of the non-paralyzed side was placed between the left and right buttons on the desk in order for participants to indicate their responses (space between buttons: 18 cm). The non-paralyzed hand was covered so that it was not visible to the participant. Participants were instructed to use their non-paralyzed hand to press the button in the determined direction as quickly and accurately as possible (e.g., in the case of a left arrow image or left hand picture, the left button was pressed). E-prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA, USA) was used for presentation of pictures and measurement of the time from the picture presentation to button press (RT).

For the left-right arrow task (Figure 1a), an image of an arrow pointing to the left or right was used as the display image. Following the presentation of a fixation point for 1.5 seconds, participants were presented with an image of a left or right arrow in a random order, at which point they were required to indicate whether the arrow pointed to the left or right. Accuracy and RT were recorded for 15 trials each for left and right arrows.

For the HMRT (Figure 1b, c), 24 hand pictures featuring various combinations of three factors (left or right hand, palm or back of hand, and six angular orientations) were randomly presented in four times for each picture. The third finger pointing upward was defined as an angle of 0°, and clockwise rotation occurred in increments of 60°. Accuracy and RT were recorded for a total of 96 trials.

3. Data Analyses

For accuracy, correct rate was calculated for each picture. Regarding the left-right arrow task, a two-factor repeated-measures analysis of

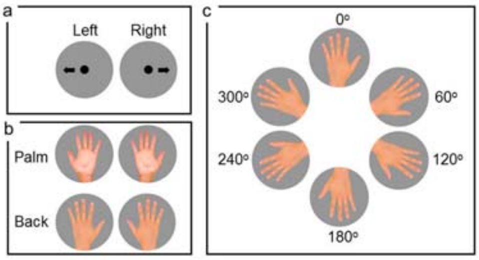

Figure 1: (a) Fixation point and arrow. (b) Hand pictures. (c) Six orientations for the hand mental rotation task.

variance (ANOVA) was performed using the hemisphere of damage (lesion side) as the between-subjects factor and the direction of the presented image (left/right) as the within-subjects factor. For the HMRT, we performed a three-factor repeated-measures ANOVA using the lesion side as the between-subjects factor, and the left/right status of the presented hand picture and angle of presentation as within-subjects factors.

For RT, we first calculated the mean RT value without incorrect responses for each picture. With regard to the left-right arrow task, a repeated-measures ANOVA was performed using lesion side as the between-subjects factor and the direction of the presented image (left/right) as the within-subjects factor. Regarding the response to the hand pictures, we first subtracted the RT of the arrow from the hand picture RT. That is, we subtracted the mean RT for left-facing arrows from the RT for left hand pictures (ΔRT). A similar calculation was performed for the right hand. For ΔRT, we performed a three-factor repeated-measures ANOVA using lesion side as the between-subjects factor, and the left/right status of the presented hand picture and angle of presentation as within-subjects factors.

SPSS Statistics (Ver. 24.0, IBM Corporation, Armonk, USA) was used to perform all statistical analyses. The significance level was set at $p < .05$. Bonferroni correction was used for multiple comparisons in subsequent analyses. Moreover, ε_{GG} was calculated for the Greenhouse-Geisser correction, and the degrees of freedom were corrected when the data did not satisfy the assumption of sphericity.

Results

The correct rate and RTs for the left-right arrow task exhibited no significant main effects or interactions with regard to lesion side and arrow direction (Table 2).

However, significant main effect of correct rate was observed with regard to angle of presentation in the HMRT ($F(5, 26) = 7.71$, $\varepsilon_{GG} = 0.68$, $p < .01$): Correct rate (mean ± standard error of the mean ($M \pm SEM$)) was significantly lower for angle of 180° (75.0 ± 4.2%) than for angles of 0° (88.6 ± 2.2%), 60° (90.4 ± 2.4%), and 300° (87.9 ± 2.3%) (Bonferroni corrected $p < .05$). Interactions between the left-right status of pictures and lesion side were noted $F(1, 26) = 5.14$, $p < .05$), though no significant differences were observed in *post hoc* tests (Figure 2, Table 3).

For the ΔRT of the HMRT (Figure 3), the three-way ANOVA revealed a significant interaction between left-right status and angle of presentation ($F(5, 130) = 6.90$, $\varepsilon_{GG} = 0.69$, $p < .01$). The ΔRT for right hand pictures (2.14 ± 0.28 s) was significantly longer than that for left hand pictures (1.62 ± 0.22 s) for images presented at an angle of 120° ($p < .01$). On the other hand, the ΔRT for left hand pictures (2.36 ± 0.28 s) was significantly longer than for right hand pictures (1.61 ± 0.18 s) for images presented at an angle of 240°. Similarly, the ΔRT for left hand pictures (1.70 ± 0.26 s) was significantly longer than that for right hand pictures (1.30 ± 0.11 s) when images were presented at an angle of 300°.

Table 2: Correct rate and RT for the left-right arrow task (*M* ± *SEM*)

			Left arrow	Right arrow
Correct Rate (%)	Lesion side	L	99.0 ± 0.7	99.5 ± 0.5
		R	99.5 ± 0.5	99.0 ± 1.0
RT (s)	Lesion side	L	0.59 ± 0.05	0.60 ± 0.07
		R	0.72 ± 0.08	0.62 ± 0.04

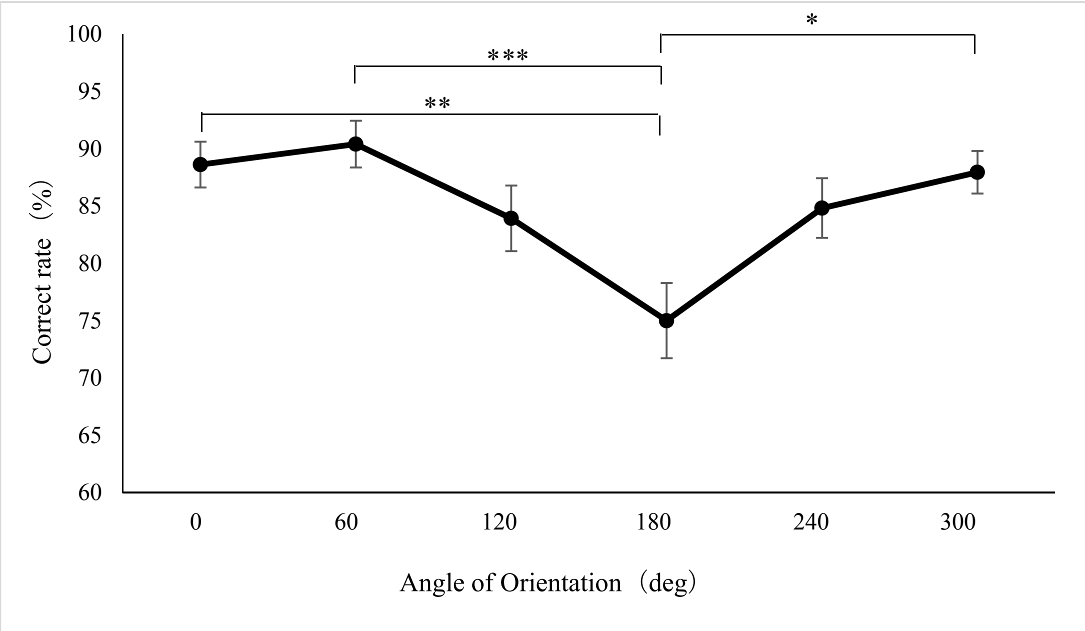

Figure 2: Correct rate plotted against the orientations (0°, 60°, 120°, 180°, 240°, and 300°). The correct rate at 180° was significantly lower than those at 0°, 60°, and 300°. *Bonferroni corrected $p<.05$. **Bonferroni corrected $p<.01$. ***Bonferroni corrected $p<.001$.

Table 3: Correct rate and ΔRT for the hand mental rotation task (*M* ± *SEM*)

			Left hand picture	Right hand picture
Correct Rate (%)	Lesion side	L	83.0 ± 5.2	87.9 ± 3.1
		R	86.3 ± 2.8	83.2 ± 3.0
ΔRT (s)	Lesion side	L	2.23 ± 0.50	1.85 ± 0.32
		R	1.68 ± 0.20	1.66 ± 0.17

Discussion

The present study investigated the relationships among left-right status of hand pictures, angles of presentation, and lesion side in patients with hemiplegic stroke in order to elucidate performance strategies adopted by such patients in an HMRT. The cognitive processes involved in the HMRT are visual encoding, transformation of mental rotation, comparison, decision-making, and motor response generation (Seurinck, 2004). When comparing the time needed to mentally rotate the image during this process, it is assumed that there is no difference between left and right

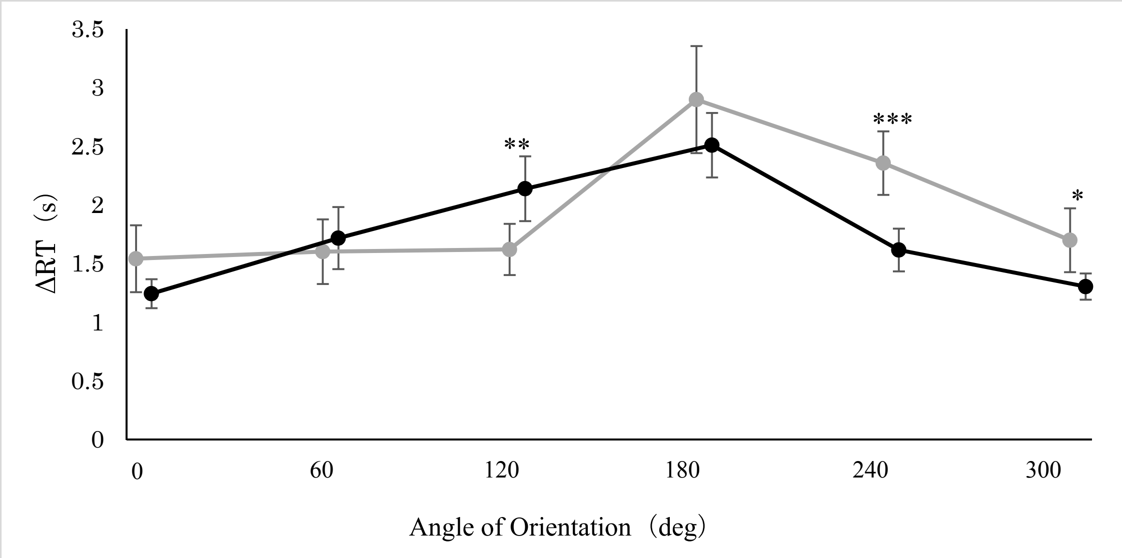

Figure 3: ΔRT ($M \pm SEM$) plotted against the orientations (0°, 60°, 120°, 180°, 240°, and 300°) for left hand pictures (grey) and right hand pictures (black). *p<.05. **p<.01. ***p<.001.

button pressing in terms of the time from decision making (decision to press either button) to motor response generation (actually pressing the button). Zappaloli et al. (2016) took individual age-related differences in motor function into account and subtracted RT of the baseline task, which did not include a mental rotation from RT of HMRT. Therefore, in the present study, although no significant differences were observed, we also compared the time needed to perform mental rotation by subtracting RTs for the arrow task from those of the HMRT.

Accuracy in the HMRT was lowest for 180° angles of presentation, which represented the largest angular difference from upright at 0°. A trend of increasing accuracy was observed as the picture was rotated clockwise or counterclockwise towards 0°. Furthermore, ΔRT was also longest in for angle of 180° and tended to decrease as 0° was approached. The process of mentally rotating, shrinking, or expanding a mental image (visual imagery or motor imagery) is referred to as mental transformation and is said to be a strategy used to perform a mental rotation task (Chen, 2013). The results of the present study also indicate that patients with hemiplegic stroke utilize this mental transformation strategy to perform HMRTs.

In the present HMRT, ΔRT for right hand pictures was longer than that for left hand pictures at 120°, while ΔRT for left hand pictures was longer at 240° and 300° when compared with that for right hand pictures. For these angles, the apex of the fingers of the left or right hand are pointed to the lateral side of the body. That is, ΔRT was longer when the picture was presented at an angle that was difficult for the hand to be moved into. It is known that the time it takes to perform motor imagery for movement differs from the time it takes time to perform the actual movement (Decety, 1989). Considering this viewpoint, a number of previous studies concerning HMRT that targeted healthy adults have concluded that, when RT was longer for angles that are easy to move to, in comparison with angles that are difficult to move to, the patient was determined to have performed motor imagery (Sekiyama, 1982; Saimpont, 2009; Takeda, 2010; ter Horst, 2010). Similar results were also obtained by the present study, where it was shown that patients with hemiplegic stroke also utilize motor imagery when performing the HMRT.

In the left-right arrow task, although patients with left-hemisphere damage pressed the button with their left hand (non-paralyzed side)—that is, their non-dominant hand—no differences in accuracy and RT were observed when compared with those of patients with right-hemisphere damage who pressed the button with their dominant right hand. Rabbitt et al. (1978) reported that responses with the dominant hand were faster than those performed with the non-dominant hand in healthy participants, although their study utilized a different task than that included in the present study. However, Sato et al. (1997) reported that, when compared with patients with left-hemisphere damage, those with right-hemisphere damage experience decreased attention and processing speed, which are required for information processing. In the present study, patients with right-hemisphere damage responded using their dominant hand. However, these patients experienced decreased function with regard to information processing due to damage of the right hemisphere, which may explain the lack of difference between these patients and those with damage of the left hemisphere in terms of RT.

Based on previous studies that have focused on patients with an amputated dominant or non-dominant hand (Nico, 2004), and on participants holding their right hands behind their backs during HMRTs (Ionta, 2009), it can be surmised that HMRT is performed by principally utilizing motor imagery of the dominant hand or left-hemisphere dominant brain function (de Lange, 2006). When left-right determinations are made based on motor imagery of the dominant hand (right hand), responses to left hand pictures are delayed more than responses to right hand pictures (de Lange, 2006; Ionta, 2009; Takeda, 2010). Furthermore, research suggests that, in comparison to patients with right hemisphere damage, responses are delayed in right-handed patients with left hemisphere damage who have a paralyzed right hand, as the speed of motor imagery correlates with that of the actual movement (Decety, 1989). Although the HMRT utilized in the present study did not reveal a significant interaction between ΔRT and lesion side, responses to left hand pictures tended to be faster than those for right hand pictures. Furthermore, when compared with those of patients with right hemisphere damage, the responses of patients with left hemisphere damage tended to be faster (Table 3). As RT for arrows pointing left or right did not exhibit this sort of trend (Table 2), there may be specific effects of motor imagery with regard to hand pictures. That is, motor paralysis of the right hand (dominant hand) produces an effect only in response to pictures of that hand.

Similar to the results of the present study, Amesz et al. (2016) reported that there was no difference in RT based on left- or right-hemispheric damage, though Kemlin et al. (2016) reported that the RTs of patients with left hemisphere damage were longer than those of patients with right hemisphere damage. Daprati et al. (2010) performed the HMRT in patients with both left and right hemisphere damage, revealing that, in cases where the patient exhibited moderate motor paralysis, there was no significant difference in RT between lesion sides. However, in cases where the patient exhibited severe motor paralysis, the RTs of patients with left hemisphere damage were longer than those of patients with right hemisphere damage. When motor paralysis is severe, there is a high possibility that the speed of motor imagery slows, resulting in increased RTs. It is possible that no interactions were observed in the present study because we did not control for the severity of paralysis in the present study. No differences in the severity of motor paralysis were noted between the groups of the present study, though the degree of paralysis varied widely from mild to severe. In order to examine differences in RT between lesion sides, it is necessary to control for the severity of motor paralysis in future studies.

The results of the present study revealed no significant differences in accuracy on the HMRT between patients with left hemisphere damage and those with right hemisphere damage. Previous studies have reported conflicting results with regard to accuracy in such tasks, suggesting that accuracy in patients with left hemisphere damage is lower (Tomasino, 2004) or higher (Daprati, 2010) when compared to that of patients with right hemisphere damage. In comparison to the stimuli used by Tomasino et al. (2004), the hand pictures used in the present study were easy to understand and showed all fingers of the hand extended. Moreover, when compared with participants in the study by Daprati et al. (2010), the severity of motor paralysis of the included patients was low, and as a result, accuracy was high, and no differences were noted according to lesion side. Accuracy and ΔRT are associated with not only the severity of motor paralysis, but also with higher brain functions such as attention, spatial cognition, and left/right cognition. When controlling for the severity of motor paralysis, caution is required when patients with severe paralysis are recruited as participants for studies involving HMRTs.

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