Original Article

Difference in response times on hand mental rotation task between the back and palm of the hand in elderly individuals

Izumi Nagashima, Doctoral course, Graduate School of Health Sciences, Kyorin University, Department of Occupational Therapy, Faculty of Health Sciences, Kyorin University
Kotaro Takeda, Faculty of Rehabilitation, School of Health Sciences, Fujita Health University
Yutaka Sato, Graduate School of Technology, Industrial and Social Sciences, Tokushima University
Hideki Mochizuki, Department of Occupational Therapy, Faculty of Health Sciences, Kyorin University
Yusuke Harada, Department of Occupational Therapy, Faculty of Health Sciences, Kyorin University
Nobuaki Shimoda*, Department of Occupational Therapy, Faculty of Health Sciences, Kyorin University

Abstract

Purpose: The hand mental rotation task (HMRT), in which participants judge whether a picture of a hand is of the left or right hand, is thought to induce a participant's motor imagery. The application of this task in rehabilitation has begun. However, the task performance strategy used on presentation with a picture of the back of the hand and the palm in elderly individuals has not been sufficiently elucidated. In this study, we examined the performance strategy of the HMRT in response to pictures of the back of the hand and the palm among elderly individuals. **Participants and methods:** A total of 75 right-handed individuals aged 65 years or older (38 males and 37 females, 74.9 ± 5.8 years old) were included in this study. From the position in which the middle finger was located at 0 degrees vertically, the pictures of the left/right hand and the back of the hand/the palm were turned in increments of 60 degrees in presentation, and the response time (RT) and correctness of responses were recorded. The RT to the left and right arrows was also measured, and the ΔRT was derived by subtracting the RT to the arrows from the RT to the hand pictures. A repeated measures ANOVA was conducted on the ΔRT with three factors: whether the hand was left or right, whether the back of the hand or the palm of the hand was pictured, and the presented angle. **Conclusions:** We suggest that the motor imagery strategy was combined with the visual imagery strategy when pictures of the back of the hand were presented and that the motor imagery strategy was used when pictures of the palm were presented. These results indicate that frequent use of pictures of the palm may be effective when the HMRT is used for rehabilitation of elderly individuals.

Keywords: Motor imagery, Visual imagery, Aging, Rehabilitation, Motor response generation

Introduction

The hand mental rotation task (HMRT) is a task in which participants judge whether a presented picture of a hand in various forms, shown at several angles, is the right or left hand. During task performance, participants are generally instructed as follows: "Please judge whether the hand in the picture is the left or right hand as fast as possible when the hand picture is shown." The indicator of the results of the task performance consist of the rate of correct responses as well as the response time (RT) from the time of presentation of the picture of the hand to the time in which the participant responds. According to the results of many previous studies, the performance strategy of the HMRT is considered a first-person motor imagery strategy to implicitly simulate the exercise in which the participant's hand is laid on the hand picture. This is based on evidence of the association between the rotational angle and the RT (RT profile). When the fingertip is in the direction of the physical center line (i.e., laid on the hand picture shown), the RT when presented with a picture that is turned in a direction that is relatively mobile (medial position) may be shorter,

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*: Corresponding author

whereas the RT when presented with a picture that is turned to the other side (lateral position) may be longer (medial-lateral effect) (Bläsing, 2013; Conson, 2013; Harada, 2016; Saimpont, 2009; Sekiyama, 1982; Shenton 2004; Shibui, 2016; Takeda, 2010; ter Horst, 2010; Zapparoli, 2014, 2016). The following points are also considered to provide evidence supporting the motor imagery strategy: the upper extremity position during task performance affects the RT following presentation of a hand picture (de Lange, 2006; Ionta, 2007, 2009; Parsons, 1994); the motor-related regions, such as the premotor area and the parietal association cortex, are activated during HMRT performance (de Lange, 2006; Kosslyn,1998).

The application of the HMRT in rehabilitation of patients who have experienced a stroke (Harada, 2016, Liu, 2009, Poli, 2016) or complex regional pain syndrome (Moseley, 2004) has been initiated. The clinical application of this task is based on the premise that this task induces implicit motor imagery in participants. However, it has been reported that no medial-lateral effect is found in the RT profile following presentation of pictures of the back of the hand and that the RT depends only on the rotational angle (Bläsing, 2013; ter Horst, 2010; Zapparoli, 2014, 2016). These facts suggest that the participant's hand is not turned using motor imagery but that the picture is turned mentally in the HMRT, in which the picture is of the back of the hand (visual imagery strategy).

Most of the people undergoing this form of rehabilitation are elderly individuals. Notably, the mean ages of stroke patients exceed 70 years in Japan (Yamaguchi, 2014). It has been reported that the RT profile of young people is different from that of elderly individuals (Saimpont, 2009). The task performance strategy may vary depending on the generation of participants. To apply the HMRT to rehabilitation, it is necessary to understand what kind of RT profile is shown by elderly individuals in response to hand pictures. However, previous studies have been performed in young people (Bläsing, 2013, ter Horst, 2010, Zapparoli, 2014, 2016) and young elderly individuals (Zapparoli, 2016). The difference in the RT profile between the generations, in particular elderly individuals, is less well defined. This study aims to examine the task performance strategy among elderly individuals (aged 65 years or older), based on the RT profile on presentation of pictures of the back of the hand and the palm of the hand during the HMRT.

The participants were informed of the purpose and method of this study through a written explanation of the study, following which their signed consent to participate in this study was obtained. This study was performed under the approval of the ethical review board of the Faculty of Health Sciences, Kyorin University (approval number: 27-32).

Participants and Methods

1. Participants (Table 1)

The participants were 38 male and 37 female individuals aged 65 years or older (mean ages 75.4 ± 6.1 and 74.9 ± 5.8 years for the male and female participants, respectively); all participants were right-handed. The Edinburgh handedness inventory by Oldfield (1971) was used to evaluate the handedness of the participants. On the basis of a self-administered questionnaire, it was confirmed that the participants had no history of present or past central nervous system disorders or psychiatric disorders, nor did they have any current dysfunction in the upper extremities or visual function.

Table 1: Characteristics of the participants (*Mean*± *SD*)

	Total	Male	Female	*p* value
n	75	38	37	0.91[a]
Age	74.9±5.8	75.4±6.1	74.4±5.5	0.45[b]
L.Q.	96.4±7.3	97.3±6.5	95.4±8.0	0.26[b]

L.Q.: Laterality Quotient ranging from −100 for left-handers to +100 for right-handers. *SD*: standard deviation. [a]: Chi-square test. [b]: Welch's *t*-test.

2. Experimental procedures

Before the HMRT, participants completed a Left and right choice task of the arrow (30 images). The participants then practiced the HMRT using six hand pictures, before the actual HMRT was conducted (96 pictures). E-prime 2.0 (Psychology Software Tools, Inc., Pittsburgh, PA, USA) was used for stimuli presentation and measurement of accuracy of response and

measurement of RT. The measurement protocols are mentioned below. These methods are the same as those used in our previous study on the HMRT performed in stroke patients (Harada, 2016) and patients with schizophrenia (Shibui, 2016).

1) Experimental setup

The experiment was performed in a quiet setting with no distracting sounds. A 15.6-inch laptop computer (Latitude 15 3000 Series, Dell-Japan Corp., Kawasaki, Japan) was placed on the desk in front of the participants. An external keyboard (TK-FCP026BK, ELECOM Corp., Osaka, Japan) was covered with a paperboard perforated at the F and J keys. The participants were instructed to lightly touch the F and J keys with their left and right index fingers, respectively. During the HMRT, a cover was placed to prevent participants from seeing their hands.

2) Left and right choice task of the arrow (Figure 1a)

An image of an arrow pointing to the left or the right was used as stimulation image. Following the presentation of a fixation point for 1.5 s, participants were presented with an image of a left or right arrow at random. The participants were required to indicate whether the arrow pointed to the left or the right. They were instructed to push the F or J key as fast and accurately as possible in response to an arrow pointing to the left or right, respectively. The image of left or right arrow disappeared once the participant pushed the key, and the next image was then presented after the fixation point was shown. The accuracy and the time between the image presentation and the key push (RT) were recorded for 15 trials each for left and right arrows.

3) HMRT (Figure 1b, c)

Pictures in which all fingers were spread was used for stimulation. The hand pictures in which the middle finger was pointed upward were defined as an angle of 0°, and rotation occurred in increments of 60° clockwise (0°, 60°, 120°, 180°, 240°, and 300°). The total of pictures used was left or right hand (2) × palm or back of the hand (2) × presented angle (6) × repetition (4), totaling 96 pictures, which were presented randomly following the presentation of the fixation point (1.5 s). The picture disappeared once the participant pushed the key, and the next picture was then presented after the fixation point was shown. The participants were instructed to push the F or J key accurately and as quickly as possible when they judged the hand of the picture to be the left or right hand, respectively. The accuracy and the time between the presentation of the hand picture and the time at which the key was pushed (RT) were recorded for each picture.

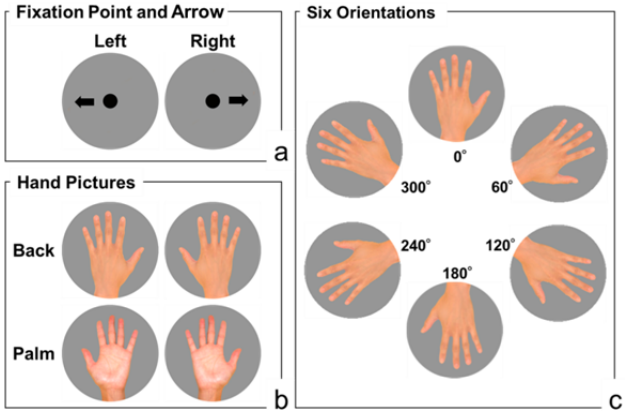

Figure 1: The fixation point and arrow (a), hand images of the back of the hand and the palm of the left and right hands (b), and the six orientations for the hand mental rotation task (c). The same figures were used in our previous study (Harada, 2016; Shibui, 2016).

3. ΔRT

First, the mean RT to the presentation of the left and right arrows of the participants was calculated excepting incorrect answers. There was no difference in the mean RT between the left arrow presentation and right arrow presentation between any of the participants (paired t test, $p = 0.153$).

Next, to attenuate the effect of individual differences in motor function as manifested in key pressing, the mean RT in response to left arrow presentation was subtracted from the RT to the left hand pictures for each participant. The mean RT to right arrow was also subtracted from the RT to the right hand pictures. After that, average values were calculated for each condition of hand pictures (the left/right hand, the back of the hand/the palm, the six presented degrees) excluding incorrect answers, and

these were taken to be representative values (ΔRT: Harada, 2016; Shibui, 2016; Zappaloli, 2016). For the ΔRT, a repeated measures ANOVA was conducted with the within-participant factors consisting of three factors; whether the presented hand was left or right, whether the back of the hand or the palm were presented, and the presented angle.

The significance level was set as 5%. Statistical analyses were performed using SPSS Statistics software (Ver.24.0, IBM Corporation, Armonk, USA). Multiple comparisons in subsequent tests were corrected for using the Bonferroni method. Before ANOVA, the sphericity was tested. The degree of freedom was corrected by obtaining ε_{GG} using the Greenhouse-Geisser method when the sphericity could not be assumed.

Results

For the ΔRT, a significant interaction between the left/right hand × the back of the hand/the palm × the presented angle was observed (F (5, 370) = 12.87, ε_{GG} = 0.76, $p < 0.001$). Therefore, a repeated measures ANOVA was conducted by defining the left/right hand and the presented angle as two factors in each picture of the back of the hand/the palm.

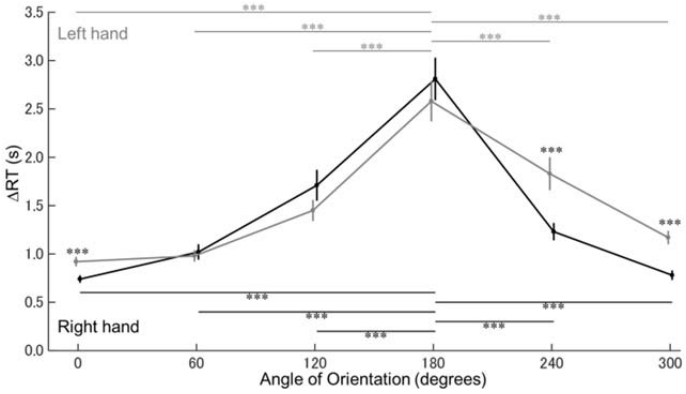

Figure 2: ΔRT (*Mean* ± *SEM*) on presentation with images displaying the back of the hand plotted against the orientations at which they were presented (0°, 60°, 120°, 180°, 240°, and 300°) for the left hand (gray) and the right hand (black). Asterisks with a horizontal line indicate a significant difference between the orientation angles for each hand. Asterisks near line plot indicate a significant difference between the images of left and right hands at each orientation. *** $p < 0.001$.

For the pictures of the back of the hand, a significant interaction was observed between the left/right hand× the presented angle (F (5, 370) = 7.15, ε_{GG} = 0.50, $p < 0.001$). Figure 2 shows the RT profile for pictures of the back of the hand. The ΔRT for the picture presentation at 180° together with the pictures of the left and right hands (*Mean* ± *SEM*, 2.58 ± 0.21 s, 2.81 ± 0.22 s, respectively) was significantly longer than the ΔRT for all other presented angles (all $p <$ 0.001). In addition, the ΔRT for the left hand picture presented at 0, 240, and 300° (0.92 ± 0.05 s, 1.83 ± 0.17 s, and 1.17 ± 0.07 s, respectively) was significantly longer than the ΔRT for the right hand picture at the same angles (0.74 ± 0.04 s, 1.23 ± 0.09 s, and 0.78 ± 0.05 s, respectively; all $p < 0.001$).

For the pictures of the palm, a significant interaction

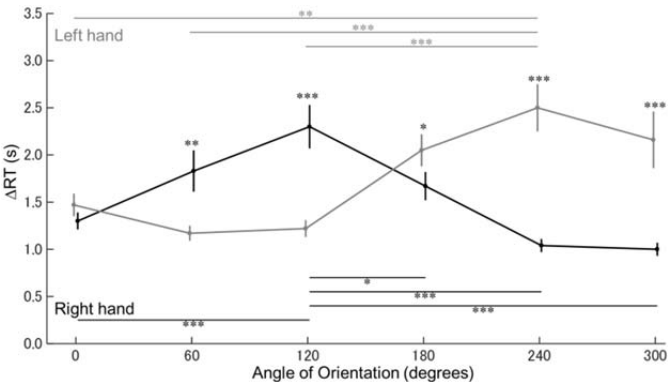

Figure 3: ΔRT (*Mean* ± *SEM*) on presentation with images displaying the palm of the hand plotted against the orientations at which they were presented (0°, 60°, 120°, 180°, 240°, and 300°) for left hand (gray) and the right hand (black) images. Asterisks with a horizontal line indicate a significant difference between the orientation angles for each hand. Asterisks near line plot indicate a significant difference between the images of left and right hands at each orientation. * $p < 0.05$. ** $p < 0.01$. *** $p <$ 0.001.

between the left/right hand × the presented angle was observed (F (5, 370) = 23.51, ε_{GG} = 0.47, $p < 0.001$). Figure 3 shows the RT profile in response to pictures of the palm. Regarding the left hand picture, the ΔRT at 240 degree (2.50 ± 0.25 s) was significantly longer than the ΔRT at 0°, 60°, and 120° (1.47 ± 0.12 s, 1.17 ± 0.08 s, 1.22 ± 0.09 s; $p < 0.01$, $p < 0.001$, and $p <$ 0.001, respectively). As for the right hand picture, the

ΔRT at 120 degree (2.30 ± 0.23 s) was significantly longer than the ΔRT at 0°, 180°, 240°, and 300° (1.30 ± 0.09 s, 1.67 ± 0.15 s, 1.04 ± 0.07 s, 1.00 ± 0.07 s; $p < 0.001$, $p < 0.05$, $p < 0.001$, and $p < 0.001$, respectively). In addition, at all presented angles except 0°, significant differences were found between the ΔRTs for the left- and right-hand pictures. At 60° and 120°, the ΔRT for the right-hand picture (1.83 ± 0.22 s and 2.29 ± 0.23 s, respectively) was significantly longer than that for the left-hand picture at the same angle (1.17 ± 0.08 s and 1.22 ± 0.09 s; $p < 0.01$ and $p < 0.001$, respectively). Inversely, at 180°, 240°, and 300°, the ΔRT for the left-hand picture (2.05 ± 0.17 s, 2.50 ± 0.25 s, and 2.16 ± 0.30 s, respectively) was significantly longer than that for the right-hand picture at the same angle (1.67 ± 0.15 s, 1.04 ± 0.07 s, and 1.00 ± 0.07 s; $p < 0.05$, $p < 0.001$, and $p < 0.001$, respectively).

Discussion

To examine the HMRT induced motor imagery for stroke rehabilitation, it was necessary to investigate the task performance strategy for the HMRT among elderly individuals who were in the generation targeted for stroke rehabilitation. In this study, we performed the HMRT in right-handed elderly individuals and found that there was a difference in the RT profile (rotational angle related RT) of the responses to pictures of the back of the hand and pictures of the palm of the hand.

In this study, with regard to the response to pictures of the right and left hands, the RT to the arrow was subtracted from the RT in the HMRT and the results were considered as the ΔRT and used for analysis. A remarkable influence of aging on the physical performance of pushing of a button should be considered when a task to measure RT is performed in elderly individuals (Woods, 2015; Yordanova, 2004). Considering that unevenness increases with aging in the task to measure RT (Deary, 2005; Der, 2006; Fozard, 1994), the individual differences in physical performance are also more likely to be increased compared to those for young people. However, there are few reports that consider this point in the HMRT. Zapparoli *et al.* (2016) took the individual differences in physical performance of participants into consideration. They subtracted the RT of a physical performance task from the RT of the HMRT, and defined it as ΔRT. In this study, by subtracting the RT of the arrow presentation in the task, it was thought that the influence of physical performance in elderly individuals, who showed great individual difference, was attenuated and that results reflecting the cognitive process were obtained in the HMRT.

The value of the ΔRT on presentation with pictures of the back of the hand was the highest at 180° (with the highest difference in the rotational angle from 0°) in pictures of both the left and right hands. The ΔRT decreased as the orientation approached 0° in both the clockwise and counterclockwise rotation. These results were similar to the results of previous studies that investigated the influence of the rotational angle by adding up the RTs on presentation of pictures of the left and right hands by Bläsing *et al.* (2013), ter Horst *et al.* (2010), and Zapparoli *et al.* (2014). These results were also similar to the results observed in the mental rotation task with figures and characters (Gaylord, 1975, Hertzog, 1991, Jacewicz, 1987); the participants showed the possibility of using the visual imagery strategy. Whereas there was no difference in the ΔRT on presentation with pictures of left and right hands at 60° and 120°, a medial-lateral effect was found at 240° and 300°; the ΔRT for left hand pictures was significantly longer than the ΔRT for the right hand pictures, which showed a medial-lateral effect. From the viewpoint that time-consuming actual movement also takes time in motor imagery (Decety, 1989), in many previous studies on the HMRT in healthy adults, when the RT is longer on presentation with pictures in the lateral position than those in the medial position, it is considered that the participants execute the motor imagery as a performance strategy (Bläsing, 2013; Conson, 2013; Harada, 2016; Saimpont, 2009; Sekiyama, 1982; Shenton 2004; Shibui, 2016; Takeda, 2010; ter Horst, 2010; Zapparoli, 2014, 2016). Thus, the medial-lateral effect found at 240° and 300° suggests that elderly individuals used the motor imagery strategy in addition to the visual imagery strategy for responses to pictures of the back of the hand. This additional motor imagery strategy by elderly individuals was not found in previous studies

that tested young people and young elderly people who were considered to mainly use the visual imagery strategy (Bläsing, 2013; ter Horst, 2010; Zapparoli, 2014, 2016). The elderly individuals show decreased visual information processing ability as compared with young people (Brown, 2012, Guest, 2015) as well as decreased occipital lobe activity during visual attention task performance (Cabeza, 2004). This decreased ability is even observed in the mental rotation task with figures and characters, which are thought to use the visual imagery strategy (Gaylord, 1975; Hertzog, 1991; Jacewicz, 1987). In addition, in elderly individuals, it is known that performance of a forced two-choice reaction task may be improved by applying both hearing (Laurienti, 2006) and vibration (Mahoney, 2014) stimulation together with visual stimulation as compared to those on stimulation of each single modality (Laurienti, 2006; Mahoney, 2014). Therefore, it is considered that elderly individuals may overcome deterioration of function of a single sense by utilizing multiple modalities (Laurienti, 2006). The elderly participants in this study appeared to use the motor imagery strategy in addition to the visual imagery strategy in response to the pictures of the back of the hand, unlike young people, to supplement the visual information processing ability, the activity of the occipital lobe, and the mental rotation task performance.

The RT profile for the pictures of the palm was greatly different from that for the pictures of the back of the hand. The ΔRT in identification of the pictures of the right and left hands were the longest at 120° and 240°, respectively. In previous studies, it has been suggested that the position of the participant's hands during the task may influence the task performances (de Lange, 2006; Ionta, 2007, 2009; Parsons, 1994). The position of the participant's hand in this study was the medial position in which the back of the hand was turned up which meant that the participant's hand position was most similar to the angle of the pictures presented at about 60° and 300° for the left and right hands, respectively. If the right or left hand is moved on the presented hand picture from this position, the most difficult presented angle may be 120° and 240° for the pictures of the right and left hands, respectively. The ΔRT on presentation with the hand picture at those angles was the longest ΔRT in both the right and left pictures, which strongly suggests that elderly individuals may use the motor imagery strategy when the palm picture is presented. In addition, a medial-lateral effect was also found in the palm picture; the ΔRT of a right hand was longer than that of a left hand at 60° and 120°, and the ΔRT of a left hand was longer than that of a right hand at 240° and 300°. These results are similar to the results of previous studies (Bläsing, 2013; ter Horst, 2010; Zapparoli, 2014, 2016), and suggest that elderly individuals may perform with motor imagery strategy for the palm pictures similarly to younger people.

This study suggests that the performance strategy by elderly individuals in the HMRT includes the motor imagery strategy in addition to the visual imagery strategy on presentation of pictures of the back of the hand, unlike that in young people. Conversely, the elderly individuals performed the HMRT by the motor imagery strategy on presentation with pictures of the palm of the hand, similar to that in younger people. The application of the HMRT in rehabilitation has been promoted (Harada, 2016; Liu, 2009; Moseley, 2004; Polli, 2016), and elderly individuals belong to the generation that requires rehabilitation the most. The results that pictures of the palm of the hand induce motor imagery in comparison with the pictures of the back of the hand in this study may indicate that the frequent use of pictures of the palm of the hand allows the elderly individuals to perform effective rehabilitation through the HMRT. By comparing the correct response rate of the HMRT and the ΔRT among the generations and examining the task performance strategy as well as the changes in the performance with aging, we hope to provide basic information that is essential for clinical application in the future.

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