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Original Article

Effects of Motor Imagery Recall Ability on Motor Performance

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Abstract. [Participants and Methods] Using a 3D motion analyzer, the reach-to-grasp movement in 17 healthy men, with varying levels of difficulty (empty or heavy bottles), was measured to determine the differences in kinematic posture control. The influence of differences in motor imagery ability on reach-to-grasp movement was measured using a mental rotation test.
[Results] In heavy conditions, the reach-to-grasp time and grasp time were extended, and the change in the wrist joint dorsiflexion angle was increased. The appearance time of the maximum operating speed and the appearance time of preshaping were shortened. In heavy conditions, the group with low mental rotation test reaction times had decreased grasp times and extended appearances of preshaping.
[Conclusion] The group with high motor imagery ability instantly adjusted the position of the fingertips according to the weight based on motor memory, suggesting that motor imagery ability affects the reach-to-grasp movement. It is necessary to consider motor image ability when measuring upper limb posture control.

Key Words: reach-to-grasp movement, motor imagery, mental rotation task

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1. INTRODUCTION

The reach-to-grasp movement is an important physical function in stroke patients as well as in patients recovering from shoulder joint surgery; however, it may entail compensatory movements including excessive scapular elevation and trunk lateral flexion[1)]. It has been suggested that the underlying mechanism of such compensatory movements may be a change in the central nervous system. In particular, it has been reported that immobility and fear of movement for a certain period after surgery may lead to alteration of the central nervous system and decreased smoothness of movement[2,3)]. Thus, rehabilitation for the central nervous system has been applied from the early postoperative period. For example, "Graded Motor Imagery" (Step 1: Discrimination between left and right; Step 2: Explicit imagery; Step 3: Mirror therapy)[4,5,6)], which increases the difficulty level of exercise images in successive stages, and "Brain-Targeted Treatment" are used[7)]. Conversely, it is difficult to quantitatively evaluate the recall ability of motor imagery; for these measurements, subjective evaluations, including the Kinesthetic and Visual Imagery Questionnaire and Movement Imagery Questionnaire, are primarily used. In recent years, a mental rotation test (MRT) has been developed to objectively estimate the recall ability of motor imagery from the correct response rate to visual stimuli and reaction time using a personal computer[8)]. In the MRT, a photographic image of a rotating limb is used as a visual stimulus, and the individual determines whether

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it is the left or right limb. In addition to obtaining multiple objective indicators, such as correct answer rate and reaction time, it is convenient to set the task content and the environment and therefore facilitate wide-ranging implementation. For these reasons, MRT is thought to be the most appropriate method for objectively evaluating the recall ability of motor imagery[9,10]. In recent years, studies have shown significant correlations between the reaction time for the MR of the foot stimuli and some postural sway values during unipedal standing [11]. In this study, two reach-to-grasp tasks with different motor imagery recall difficulty levels were set for healthy participants.

The relationship between motor imagery ability and static performance has been reported in the past in this way. However, the relationship with dynamic performance in actual motion has not been clarified to date. If the relationship between athletic imagery ability and athletic performance is clarified by this study, it may help to develop a physical therapy program to improve athletic performance. Therefore, the purpose of this study was to compare the posture control of the reach-to-grasp movement kinetically. Another study aim was to measure the recall ability of motor imagery using MRT and to examine the influence of the differences in recall ability of motor imagery on the reach-to-grasp movement. As a research hypothesis, reach-to-grasp movement requires the brain to predict the shape of the hand according to the movement trajectory and the object in advance[12]. Therefore, it is considered that the exercise performance of the group with low motor imagery ability also decreases in the task with high difficulty.

2. SUBJECTS AND METHODS

The participants were 17 healthy young men who were all right-handed (mean age 24.8 ± 5.4 years, average height 171.2 ± 4.8 cm, average body weight 61.3 ± 5.6 kg, upper limb length 72.9 ± 3.3 cm). Only males of the same age were included to eliminate the confounding factor of differences in muscle strength between males and females, as well as age-related variation in strength[13]. Individuals with histories of surgery due to orthopedic disease and those with histories of neurological disorders were excluded. The study was approved by the Research Ethics Committee and written informed consent was obtained from the participants (authorization number: 15-Ifh-77).

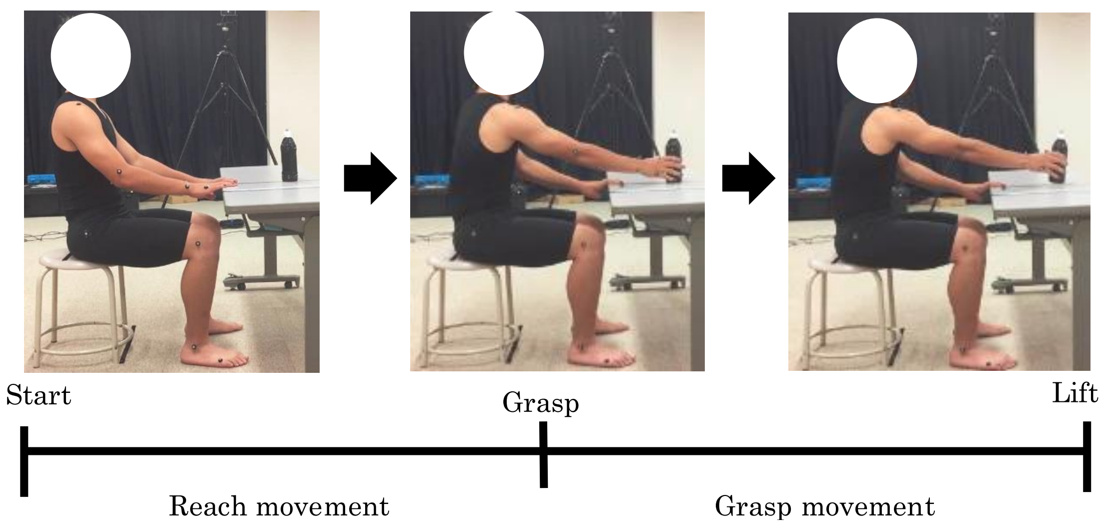
In the reach-to-grasp movement task, the measurement challenges consisted of gripping a 500 ml plastic bottle with the right hand and lifting it to shoulder level. The starting position involved sitting on a chair, with both hands placed on a desk. Motor imagery consisted of 2 tasks: an easy task (empty condition) using an empty 500 ml polyethylene terephthalate (PET) bottle, and a difficult task using a 500 ml bottle containing 1 kg of lead (heavy condition). The participants were informed of the contents of the PET bottles by the examiner. The distance was measured from the starting position until the bottle reached 110% of the upper limb length. The participants were instructed to perform the task as quickly as possible. The tasks were performed 5 consecutive times in both the empty and heavy conditions.

The measurement equipment consisted of a 3D motion analysis apparatus (Vicon Motion Systems Corporation, UK) such as a Vicon Vantage camera V5 (4 units), a Vicon Bonita and B10 camera (3 units), and infrared reflective markers with a diameter of 9.5 mm and 6 mm, with a total of 22 units attached to the body of the participant. The markers were positioned at the sides of the acromion, right elbow lateral epicondyle, medial epicondyle, ulnar styloid, radial styloid, second metacarpophalangeal joint, fifth metacarpophalangeal joint, thumb, forefinger, middle finger, ring finger, pinky finger, both the anterior superior iliac spine and upper rear iliac spine, both greater trochanters, both outer knee joints, both sides of the lateral malleolus, both sides of the calcaneus, both the first metatarsophalangeal joints, both the fifth metatarsophalangeal joints, and the object (2 points on the bottom of the PET bottle, 1 point on the lid of the PET bottle). The measurement frequency was set to 100 Hz.

After measurement, a model was created using DIFF (Data Interface File Format) provided by the Clinical Gait Analysis Study Group. The “upper arm” was defined as a line connecting the middle point of the shoulder joint center, lateral epicondyle of the right elbow, and the midpoint of the medial epicondyle. The “forearm” was defined as the line connecting the midpoint of the lateral and medial epicondyles of the right elbow joint and the midpoint of the ulnar styloid process and the radial styloid process. The “hand” was defined as the line connecting the midpoints of the ulnar styloid process and radial styloid process, and the midpoint of the second metacarpophalangeal joint and the fifth metacarpophalangeal joint. The relative angle between the upper arm and the forearm was calculated as the elbow joint angle, and the relative angle between the forearm and the hand was calculated as the wrist joint angle.

The analysis of measurement data was conducted in 2 phases: reach movement and grasp movement. Reach movement was defined as the start of movement (when the forward speed of the radial styloid process had become 10 mm/s or more) to gripping the PET bottle (when any of the speed of the longitudinal acceleration or lateral acceleration of the tip of the PET bottle had become 10 mm/s or more). Details are shown in Fig. 1.

Figure 1. Analysis categories.



Grasp movement was defined as gripping the bottle until the PET bottle was lifted (when the vertical speed of the PET bottle tip reached 10 mm/s or more). Extraction parameters were as follows: the reach to grasp time (s), reach time (s), grasp time (s), radial styloid process maximum forward speed (mm/s), maximum advance speed appearance time (%), hip flexion angle change (degrees), elbow flexion angle change (degrees), wrist dorsiflexion change (degrees), wrist crook angle change (degrees), preshaping distance (mm), and occurrence time of the preshaping (%).

The MRT used PC-based software (EXPLAB for Windows, ver. 1.3, Yachiyo Shuppan, Japan) and randomly presented 48 photos with the right and left palm surfaces; the back of the hand rotated clockwise by 0°, 90°, 180°, and 270°. The participant was sitting upright on a chair and was instructed to press the keyboard buttons corresponding to the answers (right hand or left hand) as quickly and accurately as possible with the left and right index fingers. Measurement was taken once (16 × 3 trials) after prior practice (16 × 3 trials), and the correct answer rate (%) and reaction time (s) from the presentation of the photos to the responses were calculated.

A total of 17 participants were divided equally into the following groups based on their response speed: fast group (6 participants), intermediate group (5 participants), and slow group (6 participants). Of these, the intermediate group data were not used, and the fast and slow groups were compared[14)]. In a previous study, analysis of reliable data revealed that the correct answer rate exceeded 80%[15)]. In this study, as the rate was greater than 80%, it was determined that the data were reliable for analysis.

After confirming the normality test of each measurement using the Shapiro-Wilk test, a parametric test is used for the interval scale or proportional scale according to the purpose. For nominal and ordinal scales, the analysis was performed using nonparametric tests. For the kinematic analysis of reach-to-grasp movements, the average of 5 trials for each parameter was calculated and compared the empty and heavy conditions using the Mann-Whitney U test and t test. R2.8.1 (CRAN, freeware) was used for statistical processing, and the significance level was set to 5%.

3. RESULTS

In the kinematic analysis of the reach-to-grasp movement, there was no significant difference in the reach time when comparing the movement time of both the empty and heavy conditions. The reach-to-grasp time ($p<0.01$) and the grasp time ($p<0.01$) were significantly extended under the heavy condition (Table 1).

In terms of the joint angle, the change in the wrist dorsiflexion angle increased significantly under the heavy condition ($p<0.05$). With respect to motion speed, the appearance time of the maximum motion speed was significantly shortened under the heavy condition ($p<0.05$). The maximum diameter of the hand was significantly reduced under the heavy condition ($p<0.05$).

The correct answer rate of the participants' MRT was 92.83 ± 4.99%, and the reaction time was 1.056 ± 0.288 s. With regard to the effect of differences in the MRT reaction time on the reach-to-grasp movement, the fast group had significantly shorter reaction and maximum aperture appearance times ($p<0.05$) under the heavy condition compared to the empty condition.

Table 1. Comparison of kinematic analysis between empty and heavy conditions

	empty condition (mean ± SD)	heavy condition (mean ± SD)
reach to grasp time (s)	0.55 ± 0.11	0.62 ± 0.13*
reach time (s)	0.48 ± 0.06	0.49 ± 0.06
grasp time (s)	0.07 ± 0.03	0.13 ± 0.06*
Δ hip flexion angle (deg)	0.84 ± 0.40	1.14 ± 0.51
Δ elbow flexion angle (deg)	36.4 ± 5.4	37.2 ± 5.9
Δ wrist dorsiflexion (deg)	11.1 ± 3.6	14.4 ± 5.0**
Δ wrist measure angle (deg)	16.5 ± 3.5	20.7 ± 9.2
maximum operating speed (mm/s)	840 ± 213	933 ± 299
occurrence time of the maximum operating speed (%)	55.8 ± 10.7	49.2 ± 12.8**
pre-shaping distance (mm)	134.9 ± 11.7	135.5 ± 11.8
occurrence time of the pre-shaping (%)	84.8 ± 5.1	72.1 ± 7.0**

*p<0.01, **p<0.05. deg, degree; mm, millimeter; s, second; SD, standard deviation.

Table 2. Comparison of kinematic analysis between fast group and slow groups

	fast group (mean ± SD)	slow group (mean ± SD)
reach to grasp time (s)	0.66 ± 0.04	0.76 ± 0.01
reach time (s)	0.53 ± 0.05	0.57 ± 0.01
grasp time (s)	0.13 ± 0.00	0.18 ± 0.00*
Δ hip flexion angle (deg)	0.86 ± 0.40	1.15 ± 0.32
Δ elbow flexion angle (deg)	33.7 ± 6.4	37.2 ± 6.9
Δ wrist dorsiflexion angle (deg)	16.4 ± 3.0	16.9 ± 8.2
Δ wrist crook angle (deg)	14.3 ± 6.9	19.6 ± 9.5
maximum operating speed (mm/s)	1002 ± 362	805 ± 122
occurrence time of the maximum operating speed (%)	52.5 ± 16.0	43.3 ± 14.3
pre-shaping distance (mm)	137.9 ± 19.9	128.2 ± 14.6
occurrence time of the pre-shaping (%)	74.9 ± 27.8	64.7 ± 26.9*

*$p<0.05$. deg, degree; mm, millimeter; s, second; SD, standard deviation.

4. DISCUSSION

In terms of the operating time, there was no significant difference in the reach time between the empty and heavy conditions. However, the reaching grasp time and the grasp time were significantly extended under the heavy condition. Podda et al.[16)] compared the reach-to-grasp movement time for light and heavy objects and reported that the operating time was significantly increased for heavy objects. Burg et al. reported that the motion speed decreased during the first half of the operation when lifting a heavy object and the operation time was extended in the motion analysis of the lifting operation due to the difference in weight[17)]. These results suggest that the reach-to-grasp movement and grasp time are significantly prolonged under heavy conditions where it is difficult to predict the weight[18)]. Furthermore, in terms of the joint angle, the change in the dorsiflexion angle of the wrist joint increased significantly under heavy conditions in the comparison between the empty and heavy conditions. During the reach-to-grasp movement, the wrist joint is known to be dorsiflexed, and the results of this study were consistent with those of previous studies[19,20]. The length-tension relationship of the external finger flexor muscle is optimized and the grip strength is increased by dorsiflexing the wrist joint[21]. Therefore, it is thought that the change in the dorsiflexion angle of the wrist joint increases significantly under heavy conditions of unknown weight. With respect to the operating speed, the appearance time of the maximum operating speed was significantly shorter under heavy conditions.

The trajectory of velocity change during the reach-to-grasp movement has a symmetrical bell shape[22]. The acceleration phase decreases and the rate of the deceleration phase increases in tasks requiring cautiousness, as well as in complex motion tasks[23].

Based on these facts, it is thought that movements are carried out very carefully under heavy conditions when the weight is unknown. In the present study, there was no significant difference in the maximum diameter of preshaping between empty and heavy conditions. During the reach-to-grasp movement, preshaping is performed using the 5 fingers according to the shape of the object and the purpose of the work. The shape of the hand changes depending on the shape and size of the object[24]. In the present study, the size and shape of the object were the same under both conditions. Therefore, it is assumed that there was no significant difference in the maximum diameter of preshaping. By contrast, the appearance time of the maximum caliber of the hand was 84.8% in the empty condition and 72.1% in the heavy condition, therefore significantly shorter in the heavy condition.
The maximum value of preshaping has been shown to appear at approximately 70–80% of the exercise time, regardless of the exercise speed[25]. This was consistent with the results of the present study. As the appearance time of preshaping is almost the same as the appearance time of the maximum operating speed, it may be that, in heavy conditions, in addition to the appearance time of the maximum operating speed, the appearance time of preshaping was significantly shorter.
Looking at the relationship between reach-to-grasp movement and recall ability of motor imagery in the heavy condition, the grasp time was shorter in the group with the low MRT reaction time. MRT had a high percentage of correct answers, and the shorter the reaction time, the higher the motor imagery ability[8]. It has also been reported that MRT and shoulder muscle strength and range of motion are correlated, and that there is a positive correlation between MRT reaction time and standing posture fluctuation[11,26]. Motor imagery can evaluate sharpness (ability to image clearly) and controllability (ability to freely manipulate and convert the image you imagined), and MRT can evaluate controllability[27]. In the reach-to-grasp movement, when lifting a heavy object, it is necessary to lift the object efficiently and instantaneously by changing the position of the fingertips based on the sensorimotor memory according to the weight of the object[28]. Therefore, in the group with a fast MRT reaction time, it is thought that the fingertip position can be adjusted according to the heavy object based on the past motion memory, thereby improving the efficiency and shortening the grasp time. In a systematic review of post-stroke patients, the relationship among motor imagery ability and the Timed Up and Go test and 10 meter gait speed was determined[29]. In this study, it was again shown that the difference in motor imagery recall ability affected the motor speed. Preshaping means adapting the shape of an object and the shape of the hand according to the work purpose at the stage of a predictive motion program. Pre-shaping enables an object to be gripped properly and lifted efficiently[30,31]. The expression of preshaping is said to be controlled in coordination with the reaching movement and the finger movement based on the perception information about the position, size, shape, and axial direction of the object[32]. Preshaping was quickened because of impaired visual motor conversion in the non-dominant hand after strokes[33]. As a result, preshaping appeared early because of a decrease in the recall ability of motor imagery, and was then adjusted while receiving visual-somatic sensory feedback. Consequently, preshaping appears early and adjusts while receiving visual and somatosensory feedback because the ability to recall motor images is reduced. This study suggests that visual and somatosensory feedback is required, prolonging the movement time. Furthermore, as only the

aspects of the reaching movement and the gripping movement were analyzed, it is necessary to analyze other factors, such as the lifting movement, and to examine the mechanism of the upper limb operation in more detail. The clinical significance of this study suggests that motor imagery ability affects postural control.

There were limitations of the present study, and future research may be improved by using object-based MRT (3-D object MRT, etc.) which can address the confounding factor of spatial cognition.

Funding and Conflict of interest

No funding. The authors declare no conflicts of interest.

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