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Mental and physical movements of hands: Kinesthetic information preserved in representational systems

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Correspondence between mental and physical movements of one's own hands was investigated. Line drawings of a human hand were shown in one of five forms; each form occurred as either a left or a right hand, and could appear in any one of eight directions in the picture plane. The subjects were asked to imitate the drawing by moving their own hands and to rate the physical difficulty in the imitative movements. The measured difficulty was compared with the previous data; reaction time (RT) in the identification of the left-right version of the same stimuli (Sekiyama, 1982). Both difficulty and RT showed similar trends, as a function of angular departure of the stimuli from upright, suggesting that the left-right identification is based on mental movements of representations of subjects' own hands. It was argued in terms of kinesthetic information preserved in representations.

Key words: kinesthetic representation, mental rotation, imitative movement.

Mental rotation has been used as an experimental paradigm to investigate the nature of internal representations. On the basis of much work on mental rotation, Shepard and his colleagues have asserted that mental images are internal representations that preserve perceptual aspects of the corresponding stimuli in the external world (Shepard & Metzler, 1971; Cooper & Shepard, 1973, 1978). Although Shepard did not mean that the mental images always appear in the form of visual ones (Cooper & Shepard, 1975, 1978), in fact, his experiments have not paid special attention to other perceptual aspects of images.

On the other hand, some researcher have pointed out that mental rotation can operate on a spatial representation that is not specifically visual but spatial. Marmor and Zaback (1976), using a same-different judgment task of haptically presented figures, suggested mental rotation by the blind. Carpenter and Eisenberg (1978) found that the orientation of an image of a haptically presented letters is affected by the position of the hand with which the subject touches the letter. Both studies suggest non-visual—haptic, in this case—spatial component of images.

In line with these studies, Sekiyama (1982) found it convenient to explain the results of her mental rotation experiment in terms of visual-kinesthetic images than visual ones. Using the task of mental rotation of hands, she reported a suggestive case where we may use internal representations of our own hands which preserve kinesthetic information. The present investigation intended to obtain supportive evidence for her interpretations.

In Sekiyama's experiment, various human hands viewed from different angles were visually presented in pictures, one at a time. The hand could be either a left or a right hand and could appear in any one of eight different directions in the picture plane in 45 deg step. The subject was asked to determine whether the picture represented a left hand or a right hand. Reaction time (RT) varied systematically according to angular departure of the stimulus from upright. More important was that the RT function for left hands and those for right hands did not show identical trend; they were

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mirror-reversed each other. Sekiyama found that the mirror-reversed relation between left and right hands corresponds to the " manageable direction " of each hand in actual hand movements. When we rotate our hands in the frontal plane, in general, left hand can be rotated clockwise more easily than counterclockwise, and right hand can counterclockwise more easily than clockwise. Obtained RT functions were harmonious with this fact. Therefore, she interpreted the results as follows: To identify the left-right version of hands presented visually in various directions, the subject mentally moves internal representation of his/her own hands that preserve kinesthetic information. Such a representation may be a part of what is called body image.

Sekiyama's (1982) finding extends mental rotation beyond visual realm. However, a problem remained to be settled in her investigation: Are the results really due to kinesthetic factors rather than visual familiarity? i.e. those positions that are difficult to rotate the hands into are also the ones that have not been seen very often. The present investigation began with taking a psychological measurement of kinesthetic difficulty in actual movements of one's own hands into various positions. Then the measured difficulty was compared with the RT obtained by Sekiyama (1982). Her study had taken it for granted on a priori ground, that the " manageable directions " of hand movements are mirror-reversed between left and right hands. In fact, some medical data on motion range of limbs and hands suggest such a mirror-reversed relation (e.g., Hoppenfeld, 1976). Yet in order to argue the " manageable directions " of *mental* movements, it is necessary to measure such direction of *physical* movements with some psychological method. Comparison between the previous RTs and kinesthetic difficulties was made especially from the viewpoint of how they varied as a function of spatial orientation of the hand. If the previously obtained RT functions represent the kinesthetic factors well, the measured difficulty and the RT will reveal similar functions.

Method

Subjects

Subjects were seven students of psychology department at Osaka City University, one male and six females. All were right-handed and with normal or corrected vision. None of them participated in Sekiyama's (1982) previous experiments.

Stimuli

The same stimuli that were used by Sekiyama (1982) were employed. These were line drawings of a human hand, adopted from the mental test of Thurstone (1938). Eighty stimuli ($8 \times 2 \times 5$) were constructed by rotation and reversal of five human hands; they are depicted in Fig. 1. On a given experimental trial, any one of these five forms (right hands) or their mirror images (left hands) appeared in any one of eight different directions in the picture plane in 45 deg steps from 0 deg to 315 deg. The eight directions were defined by the clockwise angular departure from the upright. Each stimulus subtended about 10 deg of visual angle.

Procedure

The subject sat in front of a translucent screen. The subject's hands were put on the table. All the subjects were told that they were going to see pictures of a human hand in diverse forms and various direc-

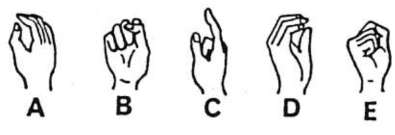

Fig. 1. The five stimulus forms.

tions, and that they were to move their own hands and imitate the picture with the hands. They were instructed that the imitations would be completed when one of their own hands achieved congruity with the picture in three aspects; the left-right version of hand, the form, and the direction. Therefore, in the case that the stimulus represented a left hand with its fingertips pointing downward, the subject was required to move his/her left hand as far as its fingertips pointed downward and its form coincided with that of the stimulus.

Each stimulus was presented on a slide which was rear-projected onto the screen. The order of presentation was randomized. On each trial, the subject imitated the stimulus by moving his/her own hands. After an imitation was completed, instructions asked him/her to rate the "struggle" for the imitation, i.e. how much difficulty the subject felt to set the hand at that position. The instruction stressed that "struggle" implied the physical and bodily struggle for setting his/her hand in the state designated by the picture. The subject rated it orally on a 5-point scale, where 0 represented the least and 4 the greatest. Each stimulus remained illuminated until the subject finished the rating. On each trial, it was only after the rating was completed that the subject was permitted freeing the hand with which he/she had imitated the stimulus. Inter-stimulus interval was about 3 s. The experimenter observed the subject's hand movements in each trial and recorded them by drawing a picture of a hand and arrows on the three-dimensional coordinates. Each subject went through two sequences of 80 trials.

Results

On each trial, all the subjects managed to imitate the stimulus with their correct hand. Although some subjects occasionally imitated it with the wrong hand at first, after all they achieved the imitation with the correct hand.

Figure 2a shows mean "struggle" ratings as a function of angular departure of the stimulus from upright, for each form and for left and right hand. Each point represents 14 observations obtained from seven subjects. As was expected, these rating functions are quite similar to the previous RT functions to be compared. For comparison, the RT functions in Sekiyama (1982, experiment 2) are also shown in Fig. 2b. First, the rating functions also show the mirror-reversed relation between left and right hands. In the case of form B, for example, the peak

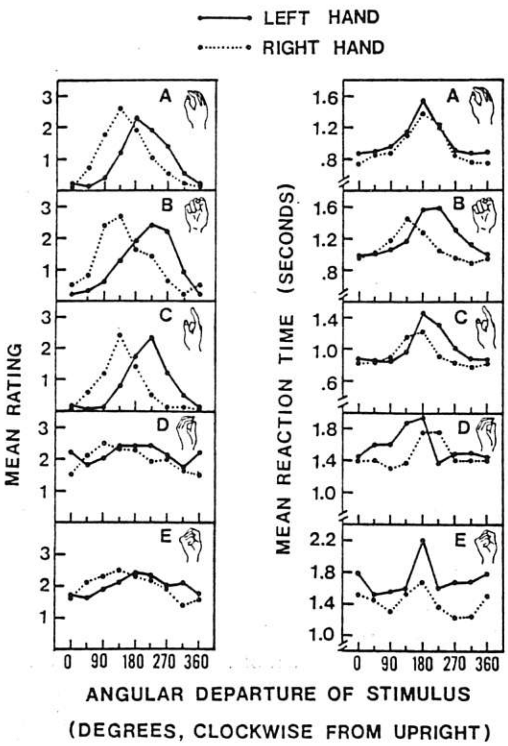

Fig. 2 a. Mean ratings of "struggle" for imitative movements, as a function of angular departure of the stimulus from upright. Solid lines show the ratings for left hands, dotted lines for right hands.

Fig. 2 b. Mean RTs in the identification of left and right hands, as a function of angular departure of the stimulus from upright (reported by Sekiyama, 1982).

of the function is at 225 deg for left hand and at 135 deg for right hand. Second, within each stimulus form, the rating function is similar in trend with the RT function, especially in form B and C.

Figure 3 consists of correlation charts for each stimulus form, depicting the correlation between mean ratings in the present experiment and mean RTs in the previous experiment.[2] It clearly shows positive linear correlations. The correlation coefficient within each form is given at the bottom of each panel. High correlations of .75, .85, and .85 were found in form A, B, and C, respectively. These three coefficients were highly significant ($p<.001$, $df=14$). It substantiates the similarity between the rating functions and the RT functions. However, the correlation between " struggle " ratings and RTs did not reach significant level in form D ($r=.22$) or E ($r=.33$).

Figure 4 illustrates the hand movements actually observed in the experiment.[3] It covers and classifies the right hand's movements. As for the left hand, the *symmetrically same* movements were observed. This point is notable. Let us take up form C, for example. The right hand in this form could be rotated counterclockwise over a wider range in the frontal plane—almost 225 deg—, while the range of its clockwise rotation was relatively small—only 135 deg. On the other hand, the left hand in this form could be rotated clockwise over a wider range, while the range of its counterclockwise rotation was relatively small. In other words, the " manageable direction " of the left hand and that of the right hand were opposite to each other, or symmetrical about the body axis. Note that this symmetry and the range of the movements correspond with the RT functions demonstrated in Fig. 2b.

Let us examine Fig. 4. There were two types of the starting positions of the movements; (i) some positions in the frontal plane whose departure from the upright were 0 deg, 315 deg, or 270 deg

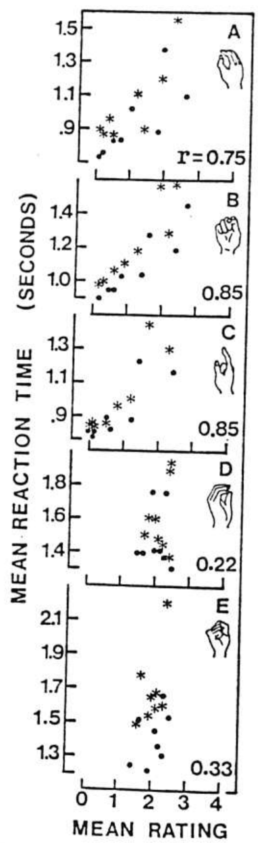

Fig. 3. Correlations between ratings and RTs. Solid circles represent the data for right hands and asterisks for left hands. Correlation coefficients are also shown.

[2] The correlation here is not over individuals, but over angular departures. One might argue that a within-subject design and an over-individuals correlation were preferable. However, the measures taken in this investigation—RTs and ratings—are presupposed to be reproducible, irrespective of personality factors. Therefore, the present investigation was constructed by a between-group design to exclude such personality factors.

[3] When the subject tried to imitate the stimulus with his/her erroneous hand (i.e. with the right hand for the stimulus representing a left hand), such movements were excluded from the record and the final movements that achieved the correct imitation was recorded.

(as for the left hand, they were 0 deg, 45 deg, or 90 deg), (ii) a position in the horizontal plane where subjects' fingertips were toward the screen. As classified in Fig. 4, there were six types of movements: (a) Direct reach, vertical, diagnoal, or sometimes lateral. (b) (a)-type movement plus axial rotation. (c) Rotation in the frontal plane (*xy*-plane), the starting positions of which were (i). (d) (c)-type movement plus axial rotation. (e) Reflection or twist not in the frontal plane, the pivot of which was the wrist, and the starting position of which was (ii). (f) Simply stretching the arm laterally or downward to see it from an "imaginary eye" behind the subject.

(a) and (b) occurred when the angular departure of the stimulus from the upright was relatively small. (c) was prevailing

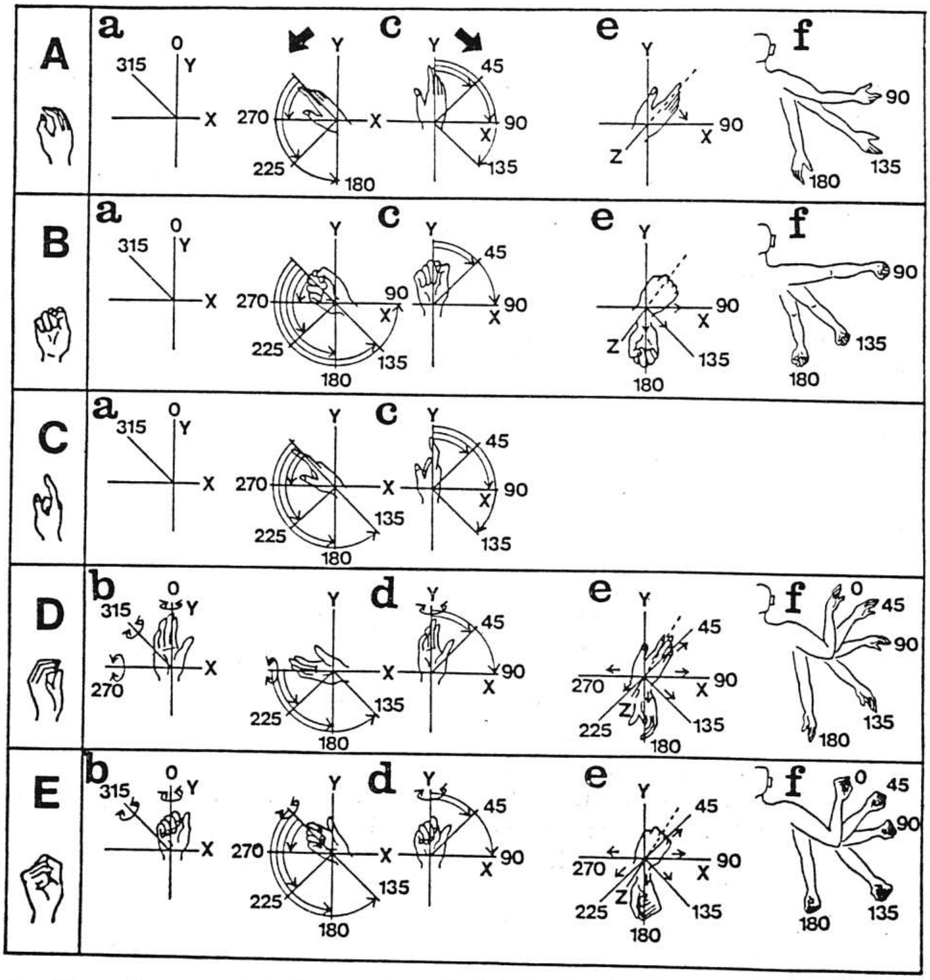

Fig. 4. Observed movements in the experimental trials for the stimuli representing right hands. (a) Direct reach. (b) (a)-type movement plus axial rotation. (c) Rotation in the frontal plane (*xy*-plane), the pivot of which was the elbow. (d) (c)-type movement plus axial rotation. (e) Reflection or twist, the pivot of which was the wrist, and the starting position of which was a position in the horizontal plane where subjects' fingertips were toward the screen. (f) Simply stretching the arm to see it from an "imaginary eye" behind the subject.

form A, B, and C. In the case of form D and E, the subjects were divided in movement types; (d) was relatively prevailing but (e) and (f) were more often observed than in the case of the other forms. These variety may be related with the fact that correlation was not significant within form D or E.

Discussion

The purpose of the present experiment was to obtain supportive evidence for the interpretation of the previously obtained RT functions in terms of kinesthetic factors. The idea in the background of the present investigation was as follows: When the subject judges whether a hand presented visually in an unfamiliar direction represents a left or a right hand, he goes through an internal process that resembles the external muscular movements of his own hands, in other words, he mentally moves his " internal hands ". To develop such an argument, we should demonstrate the correspondence between the internal and the external processes in the form of observational data. Therefore, this investigation was conducted to compare the indexes of the two processes; the index of the internal process was the RTs obtained by Sekiyama (1982), and those of the external one were the " struggle " ratings and the observed actual hand movements.

We have now three kinds of data to be compared together. These data are interrelated as follows: (1) The ratings of " struggle " for the actual hand movements exhibited similar trend with the RTs for the visual judgments, when depicted as a function of angular departure of the stimulus from the upright. (2) The observed actual hand movements revealed the " manageable directions " of both hands and the symmetry of the " manageable directions " between both hands, which were consistent with those inferred from the RTs. That is, the left hand could be rotated clockwise more easily than counterclockwise, and the right hand could be rotated counterclockwise more easily than clockwise.

These facts suggest that the internal process of judging whether a visually presented hand represents a left or a right hand is analogous to the external process of the actual hand movements to imitate the visually presented hand. That is, both the internal process and the physical movements are accompanied by kinesthetic or proprioceptive information and restricted by it. It seems that the subject tends to mentally moves his " internal hand ", like his real hand, in the " manageable direction ", and that the mental movements, like the physical movements, are not beyond the range of actual movement of arms.

Consider the internal process that the subject goes through to identify the left-right version of visually presented hands in diverse directions. In the process, the subject may voluntarily generate an " internal hand " to match with a visually presented hand. When there is an angular difference between the " internal hand " and the visually presented hand, either will be transformed to achieve congruity with the other. According to the above consideration, it is the " internal hand " that is transformed. It seems to be transformed *from* its canonical position *into* congruence with a visually presented hand, preserving kinesthetic information. Note that in the present experiment, subjects' hands were actually moved *into* the position designated by the picture.

Where is the canonical position of the " internal hand "? The observation exhibited that the starting positions of the imitative hand movements are upright and its vicinity in the frontal plane or a position in the horizontal plane where the subject's fingertips are toward the screen. If we assume that those starting positions of physical hand movements represent the canonical position of " internal hand ", pictures at such positions are to be identified faster. The RTs are harmonious with the prediction.

All these results support the interpretation of the previously obtained RTs in terms of the kinesthetic factors of representations. However, this does not mean that the representations of our own hands do not include any visual components. O'Connor and Hermelin (1975) reported that the blind could identify left and right hands which were presented haptically as plastic casts, but that they made more errors than the blindfolded sighted subjects, perhaps for lack of ready visual images. McKinney (1964) suggested that younger children sometimes made errors in the finger localization test where they were to point the finger touched by the experimenter in a bind box, perhaps due to interference by the visual components of their hand schema. It seems that the visual components and proprioceptive components of hand images sometimes cooperate and sometimes interfere. In the present experiment, two components may have cooperated.

Two of the five stimulus forms yielded insignificant correlation between the RTs and the ratings. A few reasons may be possible. One is the amount of the movements, i.e. the distance from the canonical positions of hands to those designated by the stimuli. The rating functions (Fig. 2a) illustrate only the physical " struggle " in moving one's own hands; they take no account of the amount of the physical movements. On the other hand, the RT functions (Fig. 2b) are supposed to represent the amount of the mental movements, as well as the " struggle " in them. In the case of type (c) and (d) movements (see Fig. 4), the amount and the " struggle " may increase correspondingly according to the discrepancy between the canonical position and the stimulus' position. However, in the case of type (e) and (f) movements, the " struggle " hardly seems to be related with the amount of the movements. From such a point of view, the insignificant correlation in form D and E may be a matter of course; note that type (e) and (f) movements were more often observed in these forms than the other forms.

Another possible reason is familiarity. Form D and E seem less familiar than the other forms in respect of both motor and visual experience. This factor may have affected the RTs in the identification task.

Although we have described the " internal hand " and mental movements in terms of sensory (kinesthetic) factors, consideration as to motor factors may be required. Such efferent factors remain to be examined.

Finally, it should be noted that the subjects verbally reported that they became aware of the left-right identity of the stimulus often *not before* the imitative movements, but *during* the movements. Nevertheless they could imitate the stimulus with their correct hand almost always without trial and error. This coincides with what is said to be the function of mental rotation; mental rotation has been thought to have to do with checking or confirming a hypothesis rather than with making the required discrimination in the first place (e.g., Corballis, Zbrodoff, Shetzer, & Butler, 1978). It seems that our subjects extracted some information concerning the left-right version of a stimulus prior to the imitative movements and checked the hypothesis during the physical movements. It suggests that physical movements functioned just as mental movements.

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