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BETWEEN-HAND DIFFERENCES IN BILATERAL POINTING TASKS

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To get a clue to knowing bimanual motor interactions in rapid pointing movements, we analyzed performances in speed between the hands, with ten subjects. Experiment I examined the effect of varying movement direction and the overall differences between the preferred and non-preferrded hands in motor performance. In both unilateral and bilateral pointing tasks, the majority of subjects tended to have a shorter RT with the left hand than with the right hand regardless of movement direction and to have a shorter MT with the right hand than with the left hand. Experiment II also analyzed RTs and MTs of two well-practiced subjects. The same data pattern of motor performances as that of Experiment I was evident in the bilateral pointing task, but in the unilateral pointing task no differences were found in motor output between the hands. The results were interpreted as showing that one source of between-hand differences in RT may lie in the visual scanning and/or the motor output system in hands, and that in the bilateral pointing tasks bimanual motor interactions may become apparent during the movement execution phase.

Key words : bimanual motor interaction, movement organization phase, movement execution phase, handedness, visual scanning, motor output system, pointing task.

INTRODUCTION

The theories developed in the field of motor behavior have, for the most part, focused on whether movements are under open-loop programmed or closed-loop feedback control. Much of the data supporting the theories has been generated from unimanual tasks such as aiming, pointing, positioning, reaching, or tapping. Recently, apart from that dichotomy, some views which compromise the central-peripheral issue (open-loop vs. closed-loop) have been emerging. For example, the impulse-timing view, the mass-spring model, or the coordinative structures (cf. Schmidt, 1980 ; Kugler et al., 1980 ; Kelso et al., 1980 ; etc.). Although some data which confirmed those views has been produced from tasks using two hands, little is known about the mechanism govering between-hand interactions. Therefore, it seems valuable to study the problem of bimanual motor interactions, examining between-hand differences in motor performance.

To investigate two-hand movements, it is necessary to consider handedness. Some researchers have investigated the nature of the differences between the preferred

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and non-preferred hands in motor control and proposed hypotheses to explain the between-hand differences in skill. Flowers (1975) has, using two kinds of tapping tasks, argued that the two hands are equipotential for ballistic movements (rhythmical tapping task), which require the control of sequence of movements but not the positional accuracy, and that the preferred hand is supperior in an aimed-movement test (Fitts' tapping task) where responses are made precisely under current sensory (visual) control. In contrast, Annett et al. (1979) have, using a peg-board task, suggested that the differences between the hands in the control of aiming movements are unlikely to be due to the differential efficiency in processing the feedback information but rather to the greater variability in the mechanism for initiating these movements. To examine the above-mentioned two hypotheses, Honda (1981) have conducted the experiments where eye movements were recorded during bilateral tracing tasks, and proposed one reconciled view that the between-hand differences in skilled movements are primarily due to the left hand's poor ability in motor output and that the differential efficiency in the use of visual monitoring becomes an important factor in the between-hand differences when symmetrical movements of both hands with a low degree of difficulty are required. These studies indicated that visual monitoring plays an important role in executing the tasks, but except Flowers' study, they did not mention between-hand differences in speed during visually-triggered or ballistic movements.

The present study is a basic one to investigate the problem of bilateral motor interactions and the problem of handedness difference, using a rapid pointing task. The aim of this study is to test the hypothesis that there are no RT and no MT differences between the preferred and non-preferred hands and if not, to speculate on what mechanisms between-hand differences are likely to be due to.

EXPERIMENT I

METHOD

Subjects: Eight right-handed male university students, ranging in age between 21 and 26 years, served as subjects. Their handedness was assessed by the H.N. Handedness Inventry (Hatta and Nakatsuka, 1975).

Apparatus: The apparatus consisted of a rectangular stimulus-response board (93 cm long, 46.5 cm wide, and 0.8 cm thick) mounted on a standard table (76.5 cm high) so that the long edge of the board was parallel to the edge of the table. Figure 1 shows the stimulus-response board in this study. The board contained five red light-emitting-diodes (LEDs), four response targets, and two home keys. These were symmetrically arranged on the board. An LED, which was continuously kept on, was placed at the midpoint between the inner targets and used as the fixation point. The response targets were metal discs, 2 cm in diameter. At the center of each target was a small hole (0.5 cm in diameter), where an LED was set and provided the visual

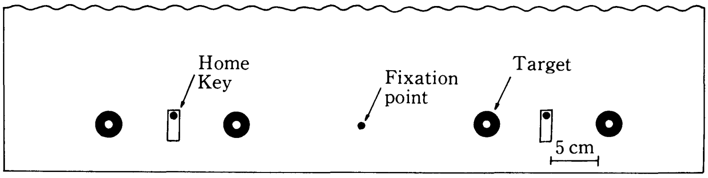

Fig. 1. The stimulus-response board.

stimulus to move a hand. Two home keys, normally-open microswitches, were located between the right targets and between the left targets, respectively. Each target disc was connected to an electrical touching-sensor constructed by a digital IC system. The sound from a speaker, square waves generated from a single-board microcomputer (NEC TK-85), seved as a warning tone (463 Hz). The presentaion times of the warning tone and the stimulus lights were controlled by the microcomputer. Four digi-timers measured the reaction times (RTs) and the movement times (MTs) for both hands with the accuracy of 1 ms.

Procedure : The subject sat in front of the stimulus-response board and positioned his head on an ajustable head-and-chin rest. The distance between the subject's eye and the fixation point was about 35 cm. The board was tilted about 20° from the table against the subject. The subject placed his forefingers on the respective keys and after receiving the warning tone, he kept his eyes on the fixation point. A few seconds (an 1.5 s to 3 s variable foreperiod between the offset of the warning tone and the onset of the visual stimulus) later,

(1) under the one-handed conditions (unilateral pointing task), the subject received the visual stimulus presented for 100 ms either on the left or right side of the fixation point. He was informed in advance on which side the stimulus would be presented. Then the subject released the key ipsilateral to the lighted target and touched the designated target only with the forefinger as quickly as possible.

(2) under the two-handed conditions (bilateral pointing task), the subject received the two stimuli presented for 100 ms on both sides of the fixation point, detached the forefingers from the keys, and then proceeded to hit the respective targets ipsilateral to the hand as fast as possible. The subject was instructed to touch the targets without any reference to RT and MT simultaneity : he was never instructed to initiate or to terminate the movements of the two hands simultaneously.

We instructed each subject with emphasis to perform the movements in his peripheral vision, not to gaze at the moving hand or the target, but to keep the hand and wrist a relatively fixed position during a movement.

Direction of movement could be specified as follows : when the hand was moved in the direction of the fixation point, this movement was called adductive. When the hand was moved away from the fixation point, this movement was called abductive.

The following conditions of movement direction were adopted.

(1) unilateral pointing task
  i) Condition ADD : either the left or right hand for adductive movement.
  ii) Condition ABD : either the left or right hand for abductive movement.
(2) bilateral pointing task
  i) Condition ABD/ADD : the left hand for abductive and the right hand for adductive.
  ii) Condition ABD/ABD : both hands for abductive.
  iii) Condition ADD/ADD : both hands for adductive.
  iv) Condition ADD/ABD : the left hand for adductive and the right hand for abductive.

Prior to the experimental trials, the subject familialized himself with the tasks. The following conditions were used in the experimental trials.

(1) For the unilateral pointing task, the subject perfomed 30 trials for each of 4 combinations of 2 direction conditions and 2 hand conditions, that is, a total of 120 trials, in random sequence.
(2) For the bilateral pointing task, a total of 120 trials, 30 trials for each of 4 direction conditions, were given to the subject.

Each subject performed the trials with a 10 s intertrial interval and was given a 3 min break every 30 trials. If the subject missed the target, that trial was excluded from the data analysis. Also excluded were RTs greater than 500 ms or less than 100 ms, and MTs greater than 250 ms or less than 10 ms.

RESULTS

Results in the bilateral pointing task

Reaction time (RT): Figure 2(a) shows the mean RTs in the bilateral pointing task for each subject separately. Most subjects tended to be faster with the left hand than the right hand, but there were a few individual differences unrelated to movement direction. Thus, a separate ANOVA for each subject was done with hand (left an right) and direction (4 pairs : ABD/ADD, ABD/ABD, ADD/ADD, ADD/ABD) as the fixed factors. Table 1 shows the F ratios for each subject. The main effect of hand was significant in six out of the eight subjects. Three of the eight subjects showed the significant main effect of direction. The significant interaction between the main effects was found in a few subjects. Interestingly, comparing differences between two hand conditions at each direction, the difference between hands was greatest at the Condition ABD/ADD in all subjects.

Movement time (MT): Figure 2(b) shows the mean MTs for each subject. Most subjects showed the trend that the right hand had a shorter MT than the left hand. This trend contrasted with that of RT data in the bilateral pointing tasks. The significant main effect of hand was found in six of the eight subjects. The main

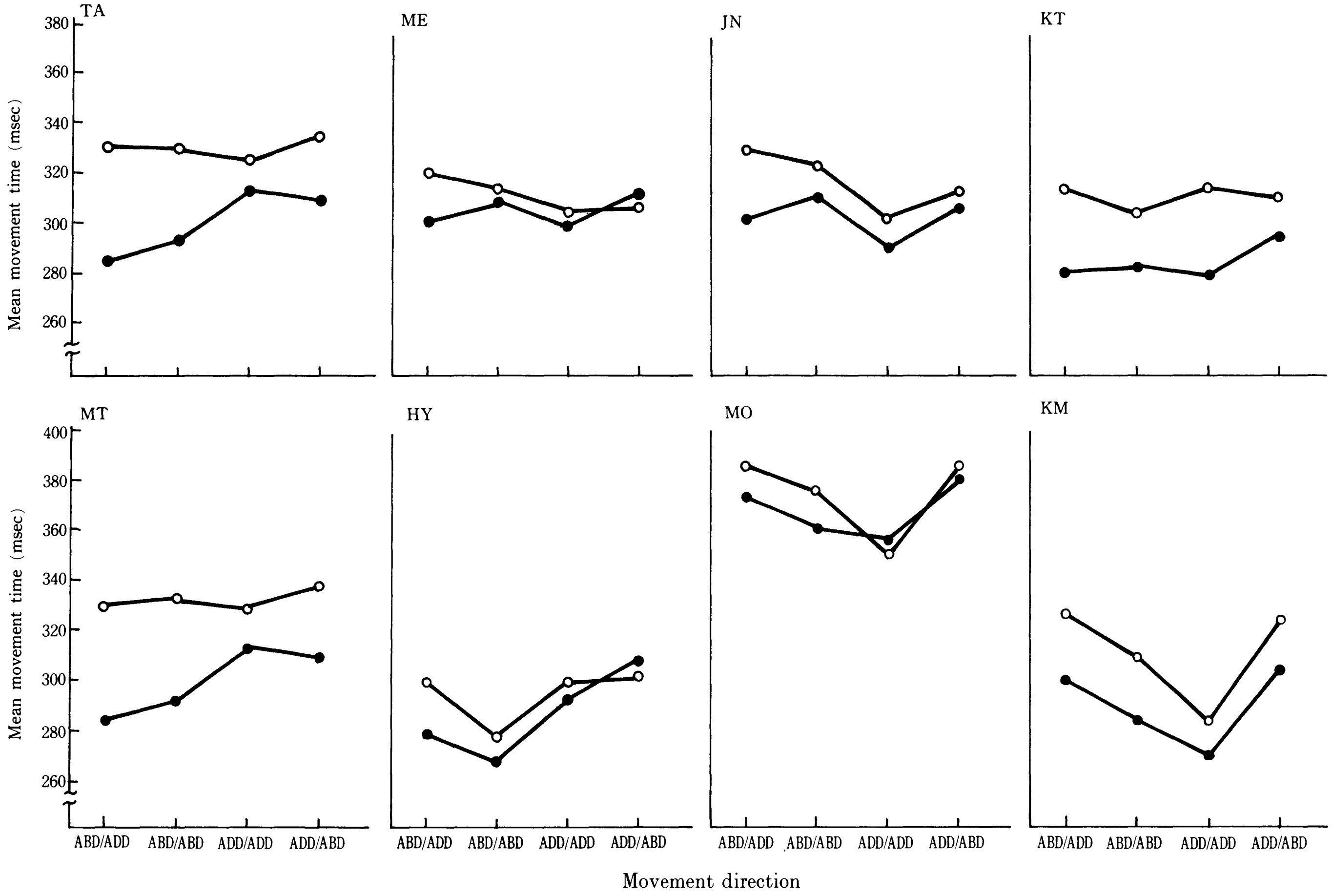

Fig. 2(a). Mean RTs in the bilateral pointing task ; preferred hand (○) ; non-preferred hand (●).

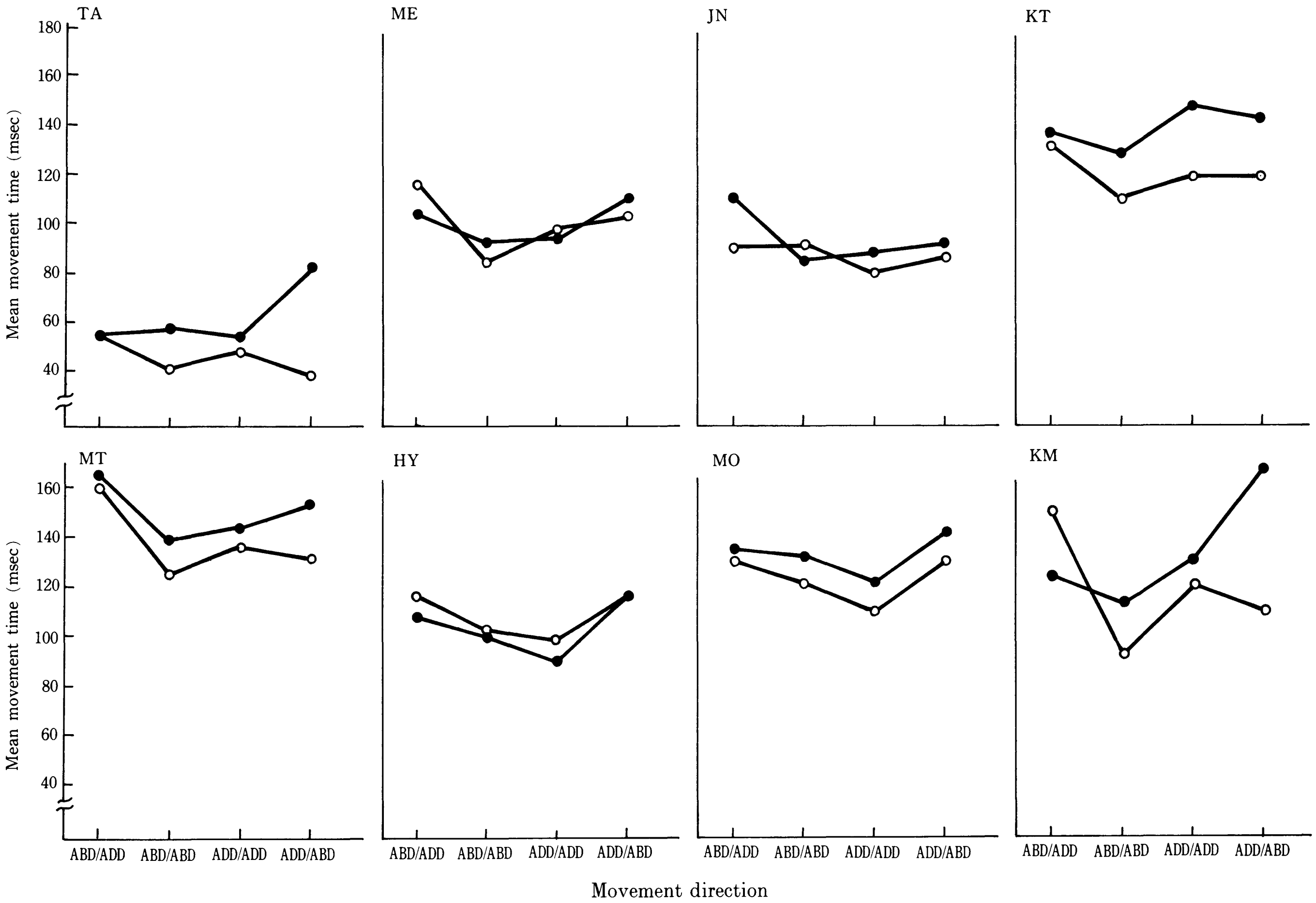

Fig. 2(b). Mean MTs in the bilateral pointing task ; preferred hand (○) ; non-preferred hand (●).

Table 1. F-ratios for each subject in the bilateral pointing task.

Ss	RT			MT		
	main effect		interaction	main effect		interaction
	hand (df=1/232)	direction (df=3/232)	(df=3/232)	hand (df=1/232)	direction (df=3/232)	(df=3/232)
TA	34.48 ***	1.43	0.08	43.93 ***	1.22	0.57
ME	2.97	2.44	2.68 *	1.42	30.98 ***	15.02 ***
JN	13.72 ***	6.14 ***	0.93	9.15 **	9.18 ***	4.21 **
KT	78.90 ***	1.58	2.61	68.93 ***	8.88 ***	5.96 ***
MT	66.10 ***	3.47 *	3.48 *	20.32 ***	20.51 ***	1.85
HY	5.76 *	14.73 ***	2.55	2.93	8.69 ***	0.77
MO	1.12	7.69 ***	0.70	22.72 ***	8.85 ***	2.40
KM	22.00 ***	17.37 ***	0.54	24.40 ***	22.19 ***	26.10 ***

* : $p<.05$, ** : $p<.01$, *** : $p<.001$

Table 2. Correlation coefficients between RT and MT in the bilateral pointing task.

Ss	movement direction							
	ABD/ADD		ABD/ABD		ADD/ADD		ADD/ABD	
TA	0.13	-0.03	0.11	0.00	0.20	0.10	0.29	-0.04
ME	-0.13	0.01	0.18	0.05	0.09	0.01	-0.13	0.03
JN	0.16	0.00	-0.36	0.03	0.05	0.02	-0.14	0.00
KT	-0.22	-0.03	-0.30	-0.01	-0.63	0.01	-0.59	0.00
MT	-0.03	0.00	-0.37	0.00	-0.18	-0.01	-0.03	0.01
HY	0.14	0.07	0.25	0.08	0.08	0.01	0.28	0.00
MO	-0.15	0.01	0.11	0.01	0.22	0.01	-0.12	0.05
KM	0.05	-0.05	0.09	-0.10	-0.15	0.00	-0.20	-0.09

ADD : adductive movement, ABD : abductive movement

direction effect was also significant in seven out of eight. That is, the right hand tended to have a shorter MT than the left hand, but there was some variance attributable to hand or movement direction.

Correlation between RT and MT. Table 2 shows the average within-subject correlation coefficients between RT and MT obtained at each direction. There were found no apreciable correlations between the two in all subjects : the correlations between RT and MT were very low in almost all cells. This means that the motor organization phase reflected in RT may be relatively independent of the movement execution phase reflected in MT.

Results in the unilateral pointing task

Reaction time (RT): The overall means for the hands in each movement direc-

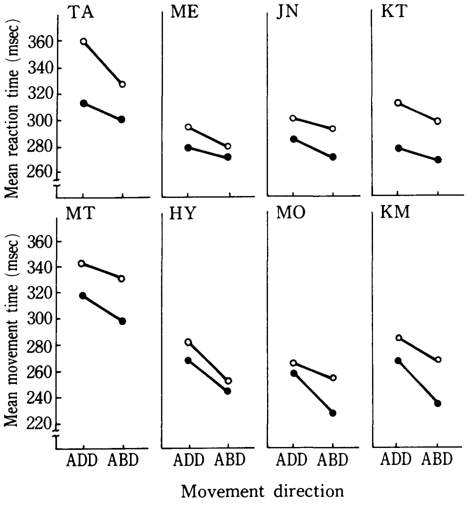

Fig. 3(a). Mean RTs in the unilateral pointing task; preferred hand (○); non-preferred hand (●).

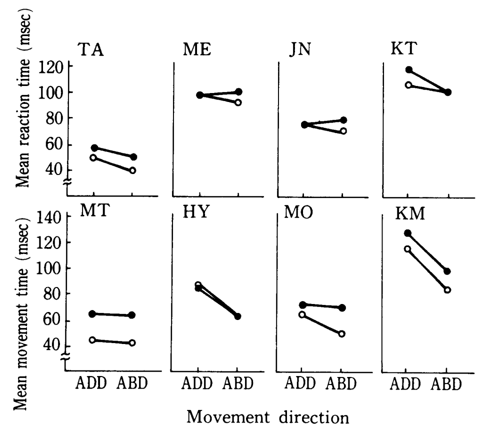

Fig. 3(b). Mean MTs in the unilateral pointing task; preferred hand (○); non-preferred hand (●).

tion are shown in Figure 3(a). This results were also separated for individual subjects to be compared with the results in the bilateral pointing task. According to the two-way ANOVA, the highly significant main effect of hand was found in all subjects, indicating that the subjects showed a shorter RT with the left hand than with the right hand. Table 3 lists the *F* ratios for each subject.

Movement time (MT): Figure 3(b) shows the mean MTs. In contrast with RT, the right hand tended to have a shorter MT than the left hand, though there were some individual differences related to direction. Two-factor ANOVA revealed that the main effect of hand was significant in five subjects; the main effect of direction, in

Table 3. F-ratios for each subject in the unilateral pointing task.

Ss	RT			MT		
	main effect		interaction	main effect		interaction
	hand (df=1/232	direction (df=3/232)	(df=3/232)	hand (df=1/232)	direction (df=3/233)	(df=3/232)
TA	60.69 ***	4.30 **	23.92 ***	13.11 ***	0.54	15.79 ***
ME	6.88 **	0.86	6.60 ***	2.61	5.36 **	1.56
JN	14.59 ***	0.34	6.00 ***	1.55	3.12 *	0.19
KT	54.19 ***	0.34	6.67 ***	4.12 *	4.81 **	13.52 ***
MT	38.49 ***	0.52	10.36 ***	16.52 ***	0.07	0.89
HY	4.89 *	0.48	38.18 ***	0.41	0.55	70.79 ***
MO	11.53 ***	3.78	20.06 ***	7.93 **	1.34	3.34 *
KM	17.31 ***	1.68	20.30 ***	7.65 **	0.14	44.08 ***

*: $p<.05$, **: $p<.01$, ***: $p<.001$

two ; the interaction, in four. The effect of varying movement direction proved to be relatively small, similarly to the result of RT in the unilateral pointing task.

Correlation between RT and MT. Table 4 shows the average within-subject correlations between RT and MT obtained for each direction. Though there were a few exceptions, the correlations between the two proved very low in almost all cells similarly to the situation of Table 2. Again as in the unilateral pointing task, the covert movement organization phase seems to be independent of the overt movement execution phase.

Table 4. Correlation coefficients between RT and MT in the unilateral pointing task.

Ss	movement direction			
	left hand		right hand	
	ABD	ADD	ADD	ABD
TA	-0.34	-0.08	0.03	-0.06
ME	0.01	0.09	-0.13	-0.05
JN	-0.05	-0.24	-0.05	-0.05
KT	-0.14	-0.31	-0.14	-0.14
MT	-0.09	0.20	-0.13	0.14
HY	0.13	-0.07	0.22	-0.07
MO	-0.46	-0.23	-0.43	-0.68
KM	0.23	0.01	-0.28	-0.26

ADD : adductive movement, ABD : abductive movement

EXPERIMENT II

Experiment I showed that in both bilateral and unilateral pointing tasks most subjects had a shorter RT with the non-preferred hand than with the preferred hand, an though less clear, they had a shorter MT with the preferred hand than with the non-preferred hand. The results might be caused by a low degree of skill acquisition because it seems that a little variance of both RT and MT data was likely to be due to the lesser practice. How stable are the differences in speed between the preferred and non-preferred hands ? Doing more practice may erase the observed between-hand differences in Experiment I.

The aim of Experiment II was to answer the question whether the left hand's shorter RT and the right hand's shorter MT were caused by a low degree of skill acquisition. For this purpose, subjects were well practiced.

METHOD

Subjects : Two male university students, aged in their 20's and right-handed for preference, served as subjects. Neither had taken part in Experiment I.

Apparatus : The apparatus was the same as in Experiment I.

Procedure : The procedure for Experment II was similar to that of Experiment I, except that in Experiment II, the subjects performed the same experimental conditions of the bilateral pointing task as in Experiment I, repetitively for a series of four days (four sessions) and that the visual stimulus was kept presesnted until the subject has finished executing a pointing task. Each subject performed repetitively the bilateral pointing tasks of Experiment I for a series of three days in order to become well-practiced, and then, on the fourth day, we conducted Experiment I involving both unimanual and bimanual pointing tasks.

RESULTS

Results in the bilateral pointing task

Reaction time (RT): The mean RTs at the final session in the bilateral pointing task are shown in Figure 4(a) for each subject separately. According to the two-factor

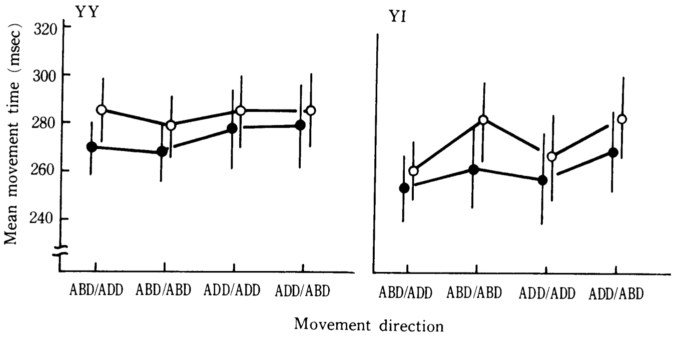

Fig. 4(a). Mean RTs in the bilateral pointing task ; preferred hand (○) ; non-preferred hand (●).

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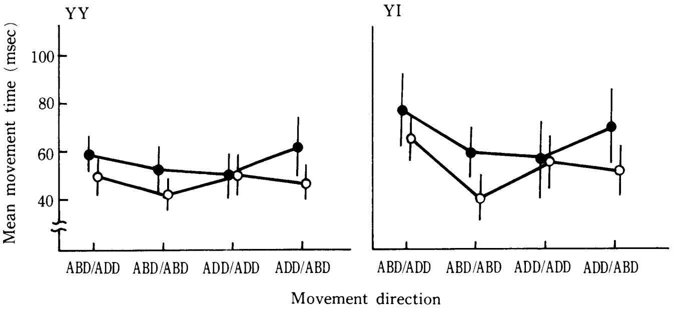

Fig. 4(b). Mean MTs in the bilateral pointing task ; prefferred hand (○) ; non-preferred hand (●).

ANOVA, the main effects of hand and direction were found significant in both subjects (hand : YY, $F\ (1,232)=14.23$, $p<.01$; YI, $F\ (1,232)=18.02$, $p<.01$/direction : YY, $F\ (3,232)=3.38$, $p<.05$; YI, $F\ (3,232)=11.45$, $p<.01$). There was no significant interaction between the main effects. Both subjects showed a shorter RT with the left hand than with the right hand. This result was consistent with that of Experiment I.

Movement time (MT): Figure 4(b) shows the mean MTs obtained at the final session. The two-factor ANOVA yielded the significant main effects of hand and direction (hand : YY, $F\ (1,232)=48.58$, $p<.01$; YI, $F\ (1,232)=32.56$, $p<.01$/direction : YY, $F\ (3,232)=12.94$, $p<.01$; YI, $F\ (3,232)=16.83$, $p<.01$). The interaction was also significant (YY, $F\ (3,232)=6.53$, $p<.01$; YI, $F\ (3,232)=4.56$, $p<.01$). Interestingly, each subject tended to have a still shorter MT with the right hand when the movement direction of it was abductive. On the other hand, the left hand's MT tended to be shorter in symmetrical movements of both hands.

Results in the unilateral pointing task

Reaction time (RT): Figure 5(a) shows the mean RTs in the unilateral pointing task. The two-factor ANOVA revealed the significant main effect of hand for both subjects and the significant interaction only for YI. This results indicate that the non-preferred hand initiated pointing movements faster than the preferred hand in both subjects.

Movement time (MT): The means are shown in Figure 5(b). According to the two-factor ANOVA, there were no significant main effects of hand and direction in YY, but in YI, the main effect of direction was significant ($F\ (3,232)=9.48$, $p<.01$). The interaction was not significant in both subjects. That is, the between-hand differences in speed were not showed in the overt movement phase.

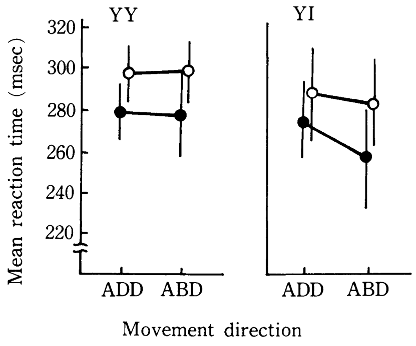

Fig. 5(a). Mean RTs in the unilateral pointing task ; prefferred hand (○) ; non-prefferred hand (●).

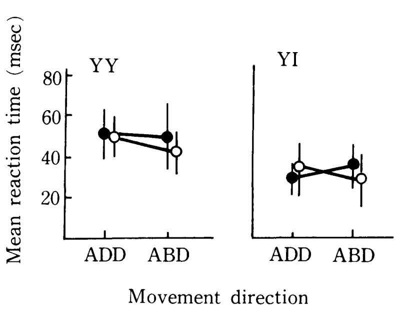

Fig. 5(b). Mean MTs in the unilateral pointing task ; prefferred hand (○) ; non-prefferred hand (●).

Discussion

The hypothesis which we designed to test in the experiments, that there are no RT and no MT differences between the preferred and non-preferred hands, must be generally rejected in the bilateral pointing tasks. On the contrary, the part of the hypothesis concerning MT could be maintained in the unilateral pointing tasks when the subject is highly skilled in the tasks.

The results in Experiment I showed that in the bilateral pointing task the majority of subjects tended to have a shorter RT with the left hand than with the right hand, and to have a shorter MT with the right hand than with the left hand. This trends were also shown in the unilateral pointing movements. Therefore, the results obtained in the bilateral pointing task would be relatively due to those of the unilateral pointing task. In addtion, the correlations between both measures, RT and MT, were almost all low. This suggests that the organization and execution phases of the movements, or the processes underlying RT and MT, should be regarded as independent of each other in the pointing tasks. In this sense the two measures should be examined separately.

The consitent finding across Experiments is that most subjects responded significantly faster with the non-preferred hand than with the preferred hand. Two ideas may help to interprete this result: the difference between the left-right visual fields, and the motor output system in hands. Sekular et al. (1973) have showed that two brief visual stmuli presented in rapid sequence, one to the left and one to the right, are perceived as if the first stimulus occurred to the left, regardless of the actual order of presentation. This effect does not depend on whether the stimuli are presented to the same or opposite retinal hemifields. Thus, if this kind of the rapid visual scanning was used during a stimulus presentation in the present pointing tasks, then the subject could perceive the visual stimulus in the left hemifield sooner. And as a result, the left hand's shorter RT might be a product of the visual scanning. On the other hand, little is known about the motor output system in hands. Therefore, we only point out one possibility that the between-hand differences in RT may underlie in the motor output system in hands.

The results of MT in Experiment I and II indicate that the preferred hand tends to be faster than the non-preferred hand. This suggests that the preferred hand may move to a target in space along an optimal or shorter orbit than the non-preferred hand, though we had no opportunity to investigate microscopically the fine movements of the hand. On initiating the movements overtly, the preferred hand's muscles involving in lateral pointing movements could contract more efficiently than the non-preferred hand's. Annett et al. (1979) have suggested that the non-preferred hand is more noisy than the preferred hand.

Although in the bilateral pointing tasks the left hand's shorter RT and the right hand's shorter MT than the contralateral hand were shown in both Experiment I and

II, in the unilateral pointing task, there was a discrepancy in MT data between Experiment I and II. That is, in Experiment I, the right hand had significantly a shorter MT than the left hand in all subjects, while there was no significant difference in MT between the hands in Experiment II though it was with only two subjects. Flowers (1975) has suggested that for ballistic movements the two hands are equipotential and skill is a direct function of practice. The pointing movements in the present study were triggered off visually, and they were made in a near-ballistic mode when the subjects became well-practiced. Thus, it seems that the between-hand differences in MT were non-significant.

In addition, in Experiment II, no difference in MT between the hands was significant in the unilateral pointing task, while the right hand significantly a shorter MT than the left hand in the bilateral pointing task. Particularily, bimanual motor interactions are likely to emerge in the bilateral pointing movements, which cannot be expected from the results in the unilateral pointing movements. As shown in Figure 4(b), the preferred hand tends to have a shorter MT in the abductive movements of the hands and the non-preferred hand tends to have a shorter MT when the hands are executing bilateral symmetrical movements. It seems that the bimanual motor interactions concerning such directional biases are due to the facilitation or interference effects in the motor output system. However, since the MT data in Experiment II were obtained from only two subjects, it is necessary to examine the generalizability of the bilateral motor interactions, using many subjects.

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