APPLIED HUMAN SCIENCE
Journal of Physiological Anthropology

Lateral Difference in the Reproduction of Arm Positioning Movement: An Examination of the Hypothesis on the Levels of Psychological Processes

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Abstract. The purpose of this study was to determine whether the hypothesis on the levels of psychological processes (Hatta, 1977, 1978) accounts for lateral differences in arm positioning movement (a spatial localization task). Fifteen right-handed male subjects were asked to perform a constrained criterion movement, 12 cm in length, with the left or right arm. Then, after a 10-sec retention interval, they were asked to perform the movement with the same arm, estimating lengths of 6, 12 or 24 cm. Different levels of psychological processes were assumed to be involved in estimating these various movement lengths—half, the same, or double that of the original. All possible combinations of the arm (left/right) and three movement length were tested. The CE scores were lower (more accurate) for the left arm (half; 1.5 ± 8.1 mm, same; 4.3 ± 6.2 mm, double; 5.9 ± 20.3 mm) than those for the right arm (half; 5.9 ± 7.6 mm, same; 10.6 ± 10.6 mm, double; 11.8 ± 23.6 mm) in all conditions, indicating a lateral difference (the right hemisphere dominance) in arm positioning tasks. This typical lateral difference, which displayed no significant difference among conditions, is supposed to be mediated by complex or high-level psychological processes. These psychological processes are required by the subjects in the estimation of the various movement lengths. This study suggests that the level of psychological processes is a crucial factor in the manifestation of lateral differences in the performance of arm positioning movements.

(Appl Human Sci, 17 (2): 41-47, 1998)

Keywords: lateral difference, arm positioning movement, psychological process, hemispheric specialization

Introduction

Cerebral hemisphere specialization in both split-brain patients (Beaton, 1985; Gazzaniga, 1983; Sperry, 1982) and normal subjects (Beaton, 1985; Bradshaw, 1989; Gazzaniga, 1983) has been studied, primarily using visual, auditory, and tactile tasks. For motor tasks, it has been found that, in right-handed people, the left hemisphere is superior in the performance of sequential motor tasks (Edwards and Elliott, 1987; Elliott, 1985; Haaland and Delaney, 1981; Kimura, 1977; Kimura and Archibald, 1974; Kimura and Davidson, 1975; Nachshon and Carmon, 1975; Todor and Kyprie, 1980; Wyke, 1967), and the right hemisphere is superior in spatial discrimination (Guiard et al., 1983; Ingram, 1975; Kimura and Vanderwolf, 1970; Nachshon and Carmon, 1975; Nishizawa and Saslow, 1987). Most studies which have examined laterality effects on motor performance have used finger movement tasks and have shown evidence of laterality effects on performance, such as left hemisphere superiority in finger tapping and right hemisphere superiority in finger positioning.

Hemispheric specialization in motor functions has shown lateral differences in the performance of arm and foot movements. Wyke (1967, 1971) has examined the effects of lesions on the rapidity of arm movement, and has found that left hemisphere damage caused a bilateral deficit whereas right hemisphere damage caused a contralateral deficit. Todor et al. (1982) have examined lateral asymmetries in the performance of arm, wrist, and finger tapping for right-handed normal subjects, reporting right hand superiority in the rate of rapid tapping for the arm as well as for the wrist and finger. This supports the findings of Kimura and Davidson (1975). Thus, it appears that the right hand (i.e., the left hemisphere) has dominance over the left hand (i.e., the right hemisphere) in rapid tapping.

In contrast to the large number of studies using tapping tasks to show left hemisphere superiority in right-handed subjects, there have been relatively few studies on the role of the right hemisphere in motor tasks (Carnahan and Elliott, 1987; Carson et al., 1990; Fujioka, 1989; Kurian et al., 1989; Roy and MacKenzie, 1978;

Wallace, 1977; Wrisberg and Winter, 1985). Carnahan and Elliott (1987), using a foot positioning task, have shown right hemisphere superiority. Kurian et al. (1989) have found left arm dominance in the reproduction of elbow angular positions, using a long-term memory paradigm. Furthermore, Fujioka (1989) has examined lateral dominance in hand movements used to explore a target on a vertical board in front of the body, and have found left hand superiority in the absence of any visual information. In contrast to these findings which indicate a left side advantage in arm and foot spatial tasks, Roy and MacKenzie (1978) have shown that no lateralization effects occurred in bilateral arm positioning tasks, when a short-term memory paradigm was used. Other studies (Imanaka et al., 1995a; Carson et al., 1990; Wallace, 1977; Wrisberg and Winter, 1985) on lateralization effects on the reproduction performance of arm positioning movements have also shown no evidence of left side advantage in arm positioning. In summary, studies examining lateral dominance in limb movement tasks suggest that, in tapping tasks, lateralization effects reveal a typical right limb advantage, while, in arm positioning tasks, no lateralization effects (e.g., a left arm advantage) are evident.

Spatial information used in limb localization tasks is believed to be processed by the right cerebral hemisphere. Limb positioning tasks can also be considered to be spatial localization tasks in which information processing for the execution of the task is made in the right hemisphere (Grünewald et al., 1984; Kurian et al., 1989; Roy and MacKenzie, 1978). The most fundamental and crucial factors causing lateralization effects may be the specialization of each hemisphere (the right hemisphere is specialized in processing spatial information) and the anatomical relationship between each hemisphere and the contralateral limb used in a task. In research on motor tasks involving finger and hand movements, performance on one side of the body is believed to be served by the motor cortex of the contralateral cerebral hemisphere (Brinkman and Kuypers, 1972, 1973; Kuypers, 1978, 1982). When a positioning movement is performed by the left arm, the right hemisphere probably processes spatial information and also produces motor commands to be sent to the left arm. In contrast, when the right arm is used for the positioning movement, the right hemisphere probably processes spatial information while the left hemisphere produces the motor commands to be sent to the right arm. In this case, some information loss is likely to occur during inter-hemispheric communication (Imanaka et al., 1991). Therefore, left arm performance in positioning movements should, in theory, be superior to the right arm. However, with one exception (Kurian et al., 1989), no study using arm positioning tasks (Imanaka et al., 1995a; Carson et al., 1990; Roy and MacKenzie, 1978; Wallace, 1977; Wrisberg and Winter, 1985) has shown a left arm advantage. This is inconsistent with theoretical predictions.

A possible explanation for the lack of lateralization effects in arm positioning movements can be found in several studies of Hatta and his co-workers (Hatta, 1977, 1978; Hayashi and Hatta, 1978; Yamamoto and Hatta, 1980), using visual and tactile tasks. Hatta and his co-workers have suggested that when a task requires relatively high-level or complex "psychological processes", such as mental rotation (Hayashi and Hatta, 1978; Yamamoto and Hatta, 1980), mental transformation (Hatta, 1978), and mental inferential thought (Hatta, 1977), lateralization effects are likely to appear. On the other hand, when a task requires low-level or simple psychological processes, such as simple perception (Hatta, 1978), lateralization effects may not appear because even the non-dominant hemisphere for the task can process the information needed for such simple psychological processes. Accordingly, it is possible that the arm positioning tasks used in previous studies (e.g., Roy and MacKenzie, 1978; Wrisberg and Winter, 1985) are simple tasks involving low-level psychological processes alone. When an arm positioning task entails higher psychological processes, such as mental inferential thought, left arm performance should be superior to right arm performance.

To test this hypothesis, this study examined lateral differences in arm positioning movements using right-handed subjects at different levels of psychological processes. The psychological process level for the arm positioning movement was altered by changing subject requirements during the test of a criterion movement. After completing a criterion movement, subjects were asked to duplicate the movement at a length equal to, half, or double the original. The psychological processes involved in estimating either half or double the length of a criterion movement are assumed to be more complex than those involved in estimating a length equal to that of the criterion movement. Therefore, we propose that lateral differences are more likely to appear in estimating either half or double the length of a criterion movement than in estimating an equal length.

Method

Subjects

Subjects were fifteen male undergraduate students, aged 18 to 22, from Nagasaki University. They were strongly right-handed, as determined by the H.N. Handedness Inventory (Hatta and Nakatsuka, 1975).

Apparatus

The apparatus consisted of two boxes (20 cm × 50 cm × 10 cm), each of which opened at the front (subject side) and at the back (experimenter side). A horizontal linear 50 cm metal track was mounted inside each box and a vertical handle-plate (18 cm × 12 cm) was attached on a small carriage which could move freely in a left-to-right direction along the track. The two boxes were mounted on a table side by side on a parallel plane in front of the subject; one to the left of the subject, the other to the right. This allowed the subject to make linear arm positioning movements by moving the handle-plates with either the left or the right hand within the left or right box.

The starting position for the arm positioning movements was 5 cm to the right or left of the midline of the body. Both the start and end positions of the linear arm movements were measured to the nearest millimeter using a photo-sensor attached to the small carriage. Electric signals from the photo-sensor were converted to digital data and stored in an NEC PC-9801 computer.

During the experiment, the subject put on a set of headphones, which emitted white noise and tone signals indicating either the time for hand placement on the handle-plate, or the time for making a linear movement as a criterion or test trial. The entire experimental procedure was preprogrammed on the NEC PC-9801 computer.

Task

Each subject was blindfolded and asked to sit in front of the apparatus. A task consisted of a criterion movement, a retention interval, and a test movement. Both the criterion and test movements in a trial were made with the same arm. The subject was required to make a constrained criterion movement 12 cm in length and then asked to make the movement at a length of 6, 12, or 24 cm. The length of criterion movement was set at 12 cm, so that the distances of test movement (6, 12, 24 cm) would fall within an appropriate movement range. This particular distance was reported to be reliable for both cues of distance and location (Imanaka et al., 1995b; Roy and Kelso, 1977). Because the 6-cm and 24-cm test movements were half or double the length of the criterion movement, the information processing needed for the performance of the task should involve complex psychological processes (e.g., inferential thought; Hatta, 1977) which mediate in the imaging of half or double the length of the criterion movement. By adopting such complex psychological processes in processing information during the task, the hemispheric functional asymmetries are predicted to become more apparent (Hatta, 1977).

A block of six trials, consisting of all probable combinations of the two experimental variables, arm (left and right) and reproduction movement length (6, 12, and 24 cm), was repeated six times. The order of the six trials within a block was randomized. A trial started with the emission of white noise and, 5 sec later, a preparatory tone signal was used to ready the subject for the performance of the criterion movement. Then, after 3 sec, a starting tone signal was used. A preparatory tone signal for the next test movement was emitted after a 10-sec retention interval. Then, after 3 sec, a tone signal was used to indicate that the test movement should be performed. Ten sec later, the white noise was eliminated to indicate the completion of the trial sequence. The inter-trial interval was 10 sec.

Procedure

On entering the laboratory, each subject was seated comfortably in front of the positioning apparatus, and then told the purpose and procedure of the experiment. Then, each subject was asked to put on the headphones and a blindfold, and to keep both hands on his lap.

The handle-plate was placed at a starting position (a position displaced either to the left or right, 5 cm from the midline of the subject's body), and the stopping block was positioned 12 cm from the starting position, to either the left or right. The position where the block was placed marked the end position of the criterion movement. Each subject was then told which hand to use in the trial. On hearing the preparatory tone, each subject was required to hold the handle-plate with the instructed hand. Following the next tone, emitted 3 sec later, each subject moved the handle-plate until it hit the stopping block. This movement was the criterion movement. After completing the criterion movement, each subject was to return his hand to his lap. During the 10-sec retention interval, the handle-plate was returned to its original starting position and the block was removed. Then, each subject was verbally informed to repeat the movement at a length equal to, half or double the criterion movement, as estimated by each subject. On hearing the next preparatory tone, emitted at the end of a 10-sec retention interval, each subject held the handle-plate with the hand used in the criterion movement, and then, when the starting tone signaled 3 sec later, performed the test movement. The subjects were instructed to judge criterion movements using only kinesthesis and proprioceptive senses, and to avoid using any alternate cues such as number counting during positioning movement.

Prior to the experimental trials, a practice session of six trials, which consisted of all of the combinations of the two experimental variables, was held to familiarize the subject with the experimental apparatus and procedure.

Experimental design

Two independent variables, arm (left and right) and test movement length (6, 12, and 24 cm), were analyzed using a factorial design, both variables being within-subject factors. Three dependent variables, constant error (CE), variable error (VE), and absolute error (AE), were used. CE is the algebraic error between the

Table 1 Means and standard deviations (mm) of CE, VE, and AE for each estimation condition (n=15)

	CE			VE			AE		
Estimation	Half	Same	Double	Half	Same	Double	Half	Same	Double
Left arm									
Mean	1.5	4.3	5.9	8.5	9.8	21.1	9.7	10.4	24.7
SD	8.1	6.2	20.3	3.4	2.4	5.8	3.4	3.2	9.0
Right arm									
Mean	5.9	10.6	11.8	7.5	12.2	20.4	9.8	15.1	27.7
SD	7.6	10.6	23.6	2.3	4.6	7.9	4.8	8.8	12.7

reproduced response and correct response, indicating the response bias-either an undershooting (negative CE) or an overshooting (positive CE). VE is a measure of the standard deviation of CE scores, indicating response variability. AE, which is the absolute value of CE scores, indicates overall accuracy (See Schmidt 1988).

Both the mean CE and AE scores were calculated by averaging six trial scores in each condition per subject. VE scores were calculated on the basis of six trial scores of CE.

Results

Two-way analyses of variance (ANOVAs) were used to analyze the main effect for each independent variable and the interactions between the two independent variables on the CE, the VE and the AE. Table 1 shows the means and standard deviations of the CE, VE, and AE scores.

Constant error

The mean CE score for the left arm was smaller than that for the right. ANOVA of the CE scores showed a significant main effect only for the arm ($F_{1,14}$=8.68, p<.01), but not for the length of the test movement. The interaction between arm and the length of the test movement was also not significant. In all length test movement conditions, the mean CE scores for both the left and right arm conditions were positive (overshooting). The overall mean CE score (calculated on the basis of all of the data from three test movement length conditions) for the right arm was 9.5 mm (SD=16.0 mm), which was significantly different from zero[1] (t=3.94, df=44, p<.01), while the mean CE for the left arm was 4.4 mm (SD=13.5 mm), which was not significantly different from zero[1] (t=1.98, df=44, p>.05).

These results indicate that in right-handed subjects, error in the left arm was smaller (more accurate) than in the right arm, with only the movement produced with the right arm indicating an overshooting. These results, of no significant effect of the length of test movements on test performance for both the left and right arm, suggest that the levels of psychological processes may not influence the appearance of laterality effects assessed in terms of CE.

Variable error

Analysis of VE scores showed a significant main effect only for the length of the test movement ($F_{2,28}$=45.59, p<.001), unlike the results in CE. Neither the main effect for arm nor the interaction between arm and the length of the test movement was significant. The overall mean VE scores were 8.0 (SD=3.0), 11.0 (SD=4.0), and 20.7 (SD=7.0) mm for half, the same, and double the criterion length, respectively. Multiple comparisons, using Scheffé's test, showed significant differences between half and double the criterion length (mean difference=12.7 mm, $F_{2,58}$=45.81, p<.001), and between the same and double the criterion length (mean difference=9.7 mm, $F_{2,58}$=26.62, p<.001), but not between half and the same criterion length (mean difference=3.0 mm, $F_{2,58}$=2.59, p>.05).

These results indicate that the longer test movements showed larger VE scores and that there were no differences between the left and the right arm for all movement length conditions. Results indicating that VE increased as the length of the test movements increased support findings by other investigators (Walsh et al., 1980).

Absolute error

Analysis of AE scores showed a significant main effect only for the length of test movements ($F_{2,28}$=29.96, p<.001) but not for arm used. The overall mean AE scores were 9.8 (SD=4.2), 12.8 (SD=7.1), and 27.4 (SD=11.8) mm for half, the same, and double the criterion length, respectively. Multiple comparisons, using Scheffé's test, showed significant differences between half and double the criterion length (mean difference=17.6 mm, $F_{2,58}$=49.93, p<.001), and between

[1] This was tested by using a *t* test calculated between the right arm condition and a hypothetical condition in which the mean CE score was assumed to be 0 mm and the SD was assumed to be the same as that of the right arm condition.

the same and double the length of the criterion movement (mean difference=14.6mm, $F_{2,58}$=34.23, p<.001), but not between half and the same length as the criterion length (mean difference=3.0 mm). Results of AE scores showed a typical movement length effect (Salmoni and Sullivan, 1976), meaning that AE increases with the length of the criterion movement. Interaction between the arm used and the length of the test movement was not found to be significant.

Discussion

The primary objective of this study was to see whether the hypothesis of psychological processes (Hatta, 1977, 1978) accounts for lateral differences in arm positioning movements. A prediction from Hatta's hypothesis tested in this study was that left-side advantage appears only for arm positioning tasks involving relatively high-level, complex psychological processes but not for those involving relatively simple psychological processes. The results did not fully support the prediction. A typical left-side advantage (in terms of CE) appeared for all estimated lengths, indicating that the right cerebral hemisphere is dominant in the performance of arm positioning movement, irrespective of the length involved. Such lateral dominance in arm positioning movement is consistent with the report of Kurian et al. (1989), in which a long-term memory paradigm was used in a simple reproduction task.

Although tests on the typical left-side advantage yielded results generally consistent with previous findings for spatial motor tasks (Carnahan and Elliott, 1987; Nishizawa, 1991; Nishizawa and Saslow, 1987), these were inconsistent with predicted outcomes. The CE scores showed a typical left-side advantage in movements estimated at equal lengths as well as at other estimated lengths. The left-side advantage found in movements produced at half and double the criterion length can be interpreted in terms of relatively complex, high-level psychological processes. In contrast, left-side advantage in reproducing a movement estimated to be the same length as that of the preceding criterion movement should not appear, if information processing is relatively simple. Our results, nevertheless, showed a clear left-side advantage for this condition. It is therefore possible that relatively complex psychological processes are needed even for estimating the same length.

When a subject makes a criterion movement, he may use a specific strategy for estimating or imagining all possible lengths, so that he can accurately perform the movement at specified lengths. As stated, subjects were told which length to produce during a 10-sec retention interval. In such conditions, even when the subject is asked to reproduce the same length as that of the preceding criterion movement, the psychological processes are probably more complex than when the subject is simply asked to reproduce the same length (e.g., Kurian et al., 1989), in the absence of other choices. The typical left-side advantage found in estimating various lengths can thus be interpreted in terms of complex psychological processes.

In contrast, other studies (Roy and MacKenzie, 1978; Wallace, 1977; Wrisberg and Winter, 1985) have shown no lateral differences in simple reproduction tests where subjects were asked to reproduce the same length as that of a criterion movement. This seems probable because, under such simple reproduction conditions, only relatively simple psychological processes are needed for the task. This can facilitate the accurate reproduction of a positioning movement, irrespective of whether the left or right arm is used. This may have been the reason why no lateral differences were observed.

Also, lateral differences appeared in performance measured only in terms of CE scores, but not in terms of VE or AE scores. This does not mean that lateral differences in arm positioning movements appear primarily in performance measured by directional error (CE), rather than in response accuracy (AE) or variability (VE). Lateral differences in limb positioning movements have been reported in performances measured by means of either VE (Roy and MacKenzie, 1978, for finger positioning task), AE (Kurian et al., 1989), the root mean square error (Carnahan and Elliott, 1987) and CE (Colley, 1984; Roy and MacKenzie, 1978, for finger positioning task). The characteristics of lateral differences in positioning tasks should therefore be investigated to interpret lateral asymmetries or hemispheric dominance in limb positioning movements.

Previous studies have shown that lateralization effects are more evident in finger (e.g., Roy and MacKenzie, 1978; Nishizawa and Saslow, 1987) and foot positioning tasks (e.g., Carnahan and Elliott, 1987) than in arm positioning tasks (e.g., Roy and MacKenzie, 1978). The discrepancy between the extent of observable lateralization effects in the finger (or the foot) and the arm has been explained in several ways (e.g., Carnahan and Elliott, 1987; Nishizawa and Saslow, 1987; Brinkman and Kupers, 1972, 1973). One other important factor which results in this lateral effect is referred to as the hemispace-hemisphere relationship (Heilman et al., 1984). However, this factor was absent in the present study. At present, the discrepancy between the appearance of lateralization effects in finger and arm positioning tasks cannot be explained adequately (Imanaka et al., 1991).

In conclusion, this study shows a typical left-side advantage in the performance of arm positioning movements when relatively high-level psychological processes are needed for task performance. In contrast, other studies (Roy and MacKenzie, 1978; Wallace, 1977; Wrisberg and Winter, 1985), examining similar topics, uncovered no typical left-side advantage. This is probably because only simple psychological processes are needed to perform simple reproduction tasks. This study suggests that the level of psychological processes is a crucial factor affecting lateral differences in the performance of arm positioning movements.

References

Beaton A (1985) Left side, right side: A review of laterality research. London: Batsford Academic & Educational, 34-108

Bradshaw JL (1989) Handedness. In Bradshaw JL ed. Hemispheric specialization and psychological function. Chichester: John Wiley & Sons, 159-178

Brinkman J, Kuypers HGJM (1972) Splitbrain monkeys: Cerebral control of ipsilateral and contralateral arm, hand, and finger movements. Science 176: 536-539

Brinkman J, Kuypers HGJM (1973) Cerebral control of contralateral and ipsilateral arm, hand and finger movements in the split-brain rhesus monkey. Brain 96: 653-674

Carnahan H, Elliott D (1987) Pedal asymmetry in the reproduction of spatial locations. Cortex 23: 157-159

Carson RG, Elliott D, Goodman D, Dickinson J (1990) Manual asymmetries in the reproduction of a 3-dimensional spatial location. Neuropsychologia 28: 99-103

Colley A (1984) Spatial location judgements by right and left-handers. Cortex 20: 47-53

Edwards JM, Elliott D (1987) Effect of unimanual training on contralateral motor overflow in children and adults. Dev Neuropsychol 3: 299-309

Elliott D (1985) Manual asymmetries in the performance of sequential movement by adolescents and adults with Down syndrome. Am J Ment Defic 90: 90-97

Fujioka T (1989) On the lateral dominance in locus exploration human motor space. Jpn Psychol Res 31: 92-96

Gazzaniga MS (1983) Right hemisphere language following brain bisection: A 20-year perspective. Am Psychol 38: 525-537

Grünewald G, Grünewald-Zuberbier E, Hömberg V, Schuhmacher H (1984) Hemispheric asymmetry of feedback-related slow negative potential shifts in a positioning movement task. Ann New York Acad Sci 425: 470-476

Guiard Y, Diaz G, Beaubaton D (1983) Left-hand advantage in right-handers for spatial constant error: Preliminary evidence in a unimanual ballistic aimed movement. Neuropsychologia 21: 111-115

Haaland KY, Delaney HD (1981) Motor deficits after left or right hemisphere damage due to stroke or tumor. Neuropsychologia 19: 17-27

Hatta T (1977) Functional hemisphere asymmetries in an inferential thought task. Psychologia 20: 145-150

Hatta T (1978) Visual field differences in a mental transformation task. Neuropsychologia 16: 637-641

Hatta T, Nakatsuka Z (1975) The H.N. Inventory. In Ono S ed. Papers in celebration of 63rd birthday of Prof. K. Onishi. Osaka: Osaka City University Press, 224-247

Hayashi R, Hatta T (1978) Hemispheric differences in mental rotation task with Kanji stimuli. Psychologia 21: 210-215

Heilman KM, Bowers D, Watson RT (1984) Pseudoneglect in a patient with partial callosal disconnection. Brain 107: 519-532

Imanaka K, Abernethy B, Yamauchi M, Funase K, Nishihira Y (1995a) Hemispace asymmetries and laterality effects in arm positioning. Brain Cogn 29: 232-253

Imanaka K, Funase K, Yamauchi M (1995b) Behavioral models of motor control and short-term memory. Bull Faculty of Liberal Arts, Nagasaki Univ (Natural Science) 35: 95-123

Imanaka K, Nishizawa S, Yamauchi M (1991) Possible factors mediation lateralization effect in limb positioning movements and hemispheric specialization. Bull Faculty of Liberal Arts, Nagasaki Univ (Natural Science) 31: 695-713

Ingram D (1975) Motor asymmetries in young children. Neuropsychologia 13: 95-102

Kimura D (1977) Acquisition of a motor skill after left-hemisphere damage. Brain 100: 527-542

Kimura D, Archibald Y (1974) Motor functions of the left hemisphere. Brain 97: 337-350

Kimura D, Davidson W (1975) Right arm superiority for tapping with distal and proximal joints. J Hum Move Stud 1: 199-202

Kimura D, Vanderwolf CH (1970) The relation between hand preference and the performance of individual finger movements by left and right hands. Brain 93: 769-774

Kurian G, Sharma NK, Santhakumari K (1989) Left-arm dominance in active positioning. Percept Mot Skills 68: 1312-1314

Kuypers HGJM (1978) From motor control to conscious experience. In Buser & Rougeul-Buser eds. Cerebral correlates of conscious experience (INSERM Symposium, No. 6). Amsterdam: North-Holland Biomedical Press, 95-110

Kuypers HGJM (1982) A new look at the organization of the motor system. Prog Brain Res 57: 381-403

Nachshon I, Carmon A (1975) Hand preference in sequential and spatial discrimination tasks. Cortex 11: 123-131

Nishizawa S (1991) Different pattern of hemisphere specialization between identical kinesthetic spatial and weight discrimination tasks. Neuropsychologia 29: 305-312

Nishizawa S, Saslow CA (1987) Lateralization of kinesthetically guided spatial perception. Cortex 23: 485-494

Roy EA, Kelso JAS (1977) Movement cues in motor memory: precuing versus postcuing. J Hum Move Stud 3: 232-239

Roy EA, MacKenzie C (1978) Handedness effects in kinesthetic spatial location judgements. Cortex 14: 250-258

Salmoni AW, Sullivan SJ (1976) The intersensory integration of vision and kinesthesis for distance and location cues. J Hum Move Stud 2: 225-232

Schmidt RA (1988) Motor control and learning. 2nd ed. Human Kinetics, Illinois, 56-62

Sperry R (1982) Some effects of disconnecting the cerebral hemispheres. Science 217: 1223-1226

Todor JI, Kyprie PM (1980) Hand differences in the rate and variability of rapid tapping. J Mot Behav 12: 57-62

Todor JI, Kyprie PM, Price HL (1982) Lateral asymmetries in arm, wrist and finger movements. Cortex 18: 515-523

Wallace SA (1977) The coding of location: A test of the target hypothesis. J Mot Behav 9: 157-169

Walsh WD, Russell DG, Imanaka K (1980) Memory for movement: Interaction of location and distance cues and imagery ability. Acta Psychol 44: 117-130

Wrisberg CA, Winter TP (1985) Reproducing the end location of a positioning movement: The long and short of it. J Mot Behav 17: 242-254

Wyke M (1967) Effect of brain lesions on the rapidity of arm movement. Neurology 17: 1113-1120

Wyke M (1971) The effects of brain lesions on the learning performance of a bimanual co-ordination task. Cortex 7: 59-72

Yamamoto M, Hatta T (1980) Hemispheric asymmetries in a tactile thought task for normal subjects. Percept Mot Skills 50: 467-471

Received: October 6, 1997
Accepted: December 27, 1997

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