

## Possible Factors Mediating Lateralization Effect in Limb Positioning Movements and Hemispheric Specialization

Kuniyasu IMANAKA,<sup>1</sup> Sho NISHIZAWA<sup>1</sup> and Masaki YAMAUCHI<sup>2</sup>

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### Abstract

Several influential factors mediating possible cerebral hemispheric specialization in limb positioning movements were reviewed. One important factor may be cognitive strategies employed by subjects in encoding available parameters during a given task. The difference between proximal and distal muscle groups for a task is also shown to be a crucial factor. Lateralization effects seem to appear in the distal parts while possible interhemispheric interference/conflict could occur in the proximal parts. The hemispace should also be considered as an important factor causing lateralization effects. These factors are suggested to be critically important to study motor control in limb positioning movements with respect to hemispheric specialization.

### Introduction

Hemispheric specialization has been studied in neuropsychologic research. Sperry, Gazzaniga and co-workers (see Gazzaniga, 1983; Sperry, 1982, for reviews) have conducted a long series of studies on split-brain patients and have shown much evidence for the asymmetrical nature of each cerebral hemisphere. It is now accepted that the left hemisphere is predominantly involved with verbal-related tasks, logic, and calculation and that the right hemisphere is primarily specialized for nonverbal spatial analysis (Dean, 1986; Spirduso, 1978; Weinstein, 1978). The left hemisphere has also been shown to be better prepared to process information in an analytic, logical or sequential fashion

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<sup>1</sup> Department of Health and Physical Education, Faculty of Liberal Arts, Nagasaki University, 1-14 Bunkyo-cho, Nagasaki 852, Japan.

<sup>2</sup> Department of Health and Physical Education, Faculty of Education, Nagasaki University, 1-14 Bunkyo-cho, Nagasaki 852, Japan.

while the right hemisphere has been shown to be best suited to processing information of a more holistic and simultaneous nature (Dean, 1986).

Although such a division of hemispheric functions may be normal for right-handed people, it is not always so for left-handers. Rasmussen and Milner (1977) reported from a study of hemispheric dominance of language that 96 % of 140 right-handers had left hemispheric dominance while among 112 non-right-handers, 70% had left hemispheric dominance, 15% had clear right hemispheric dominance and another 15% showed bilateral organization. Sex differences have also frequently been reported in cognitive functioning particularly with respect to visual and auditory spatial abilities (Harris, 1978). In particular, it has been found that females are less lateralized in visual and auditory spatial abilities than males (McGlone, 1980). Such sex differences in the lateralization of visual and auditory spatial abilities have often been attributed to sex differences in hemispheric specialization (Levy & Levy, 1978).

It has also been found that laterality or a dominant side in various human behavior tends to shift during long (Geffen, Bradshaw, & Wallace, 1971; Johnson, 1977; Marzi & Berlucchi, 1977) and short (Hellige, 1976; Streitfeld, 1985; Taylor & Heilman, 1980) periods of time. Musical discrimination is generally specialized in the right hemisphere for the musical layman while the left hemisphere excels for the same tasks in trained musicians (Johnson, 1977). Face recognition is usually assumed to show right hemisphere advantage (Geffen et al., 1971), while familiar famous faces are specialized in the left hemisphere (Marzi & Berlucchi, 1977). These are examples of long-term shifts. As an example of short-term shift, the transfer of initial right hemisphere superiority to the left hemisphere within a single experiment has been shown for key tapping (Taylor & Heilman, 1980), visual and tactual length discrimination (Streitfeld, 1985), and same-name letter pairs (Hellige, 1976) tasks. From these laterality shift findings, hemispheric specialization is not absolutely but rather relatively defined as superiority to the other hemisphere (Bradshaw, 1989).

These asymmetrical functions of the cerebral hemispheres have often been investigated on visual and auditory information processing, with much less research effort directed towards examining the possible lateralization of motor functions (e.g., Bianki, 1984; Kimura & Archibald, 1974; Taylor & Heilman, 1980; Todor & Doane, 1977, 1978). However, research in hemispheric specialization has been rapidly expanding into research areas of the motor domain. In this study we deal with issues regarding lateralization effects on motor functions. First, we will review literature on left and right hemi-

sphere specialization for motor functions, and then review primary factors mediating lateralization effects on motor tasks. In particular, we discuss critical factors responsible for lateralization effects on limb positioning movement, which have frequently been used in studies investigating motor memory (e.g., Imanaka, 1989; Walsh, Russell, & Imanaka, 1980; Walsh, Russell, Imanaka, & James, 1979; Wrisberg & Winter, 1985).

### **Left Hemispheric Specialization for Motor Functions**

Some evidence has been presented for the superiority of the left hemisphere in the performance of sequential motor tasks. Wyke (1967, 1971a, 1971b) examined right and left hand performance in manual tapping and tracing tasks in right-handed patients with cerebral lesions. Wyke found that left hemisphere damage caused a bilateral deficit whereas right hemisphere damage caused a contralateral deficit only, despite the anatomical connection of distal musculature in either side of the body to the contralateral cerebral hemisphere (Brinkman & Kuypers, 1972, 1973; Haaxma & Kuypers, 1975; Kuypers, 1978, 1982; Moll & Kuypers, 1977, 1980). Similar findings were reported by Kimura and Archibald (1974) who examined the performance of manual sequencing tasks, such as finger flexion and copying hand movements, in right-handed patients with either right or left hemisphere damage. Kimura and Archibald found a bilateral deficit only in the left hemisphere-damaged group, suggesting that the bilateral deficit was not due to a disorder caused by anatomical damage but due to a disorder of left hemisphere control for sequential movements. This finding of left hemisphere dominance in sequential motor tasks has been corroborated by other studies in which brain-injured patients were tested for finger (Kimura, 1977; Roy & Elfeki, 1979) and oral (Mateer & Kimura, 1977) movements.

In normal subjects a number of studies using sequential or temporal motor tasks, such as key-depression using a finger (Roy & Elfeki, 1979; Nachshon & Carman, 1975), finger lifting (Edwards & Elliott, 1987), manual typing (Hicks, Provenzano, & Rybstein, 1975), and finger tapping (Cremer & Ashton, 1981; Dalen & Hugdahl, 1987; Elliott, 1985; Elliott, Weeks, & Jones, 1986; Hammond, Bolton, Plant, & Manning, 1988; Lomas & Kimura, 1976; Todor & Doane, 1978; Todor & Kyprie, 1980; Todor, Kyprie, & Price, 1982; Podbros & Wyke, 1988), have all demonstrated right hand superiority over the left primarily in movement speed (or frequency) and/or consistency. These studies have suggested that there is left hemisphere dominance over the con-

trol of sequential motor tasks in normal subjects as well as in brain-injured or split-brain patients.

Left hemisphere control for sequential motor tasks has also been evident in experiments using the dual task paradigm (Dalen & Hugdahl, 1987; Hicks et al., 1975; Lomas & Kimura, 1976), in which subjects are required to perform a sequential manual motor task during a concurrent verbal/nonverbal task. Hicks et al. (1975), for example, examined performance in sequential manual typing with or without concurrent vocal rehearsal. Results showed that even left hand performance was interfered with by a concurrent verbal task, although right hand performance was more interfered with by a concurrent verbal task. Lomas and Kimura (1976) and Dalen and Hugdahl (1987) also found similar interference effects by a concurrent vocalization task on tapping performance. These studies suggest that the interference caused by a concurrent verbal task to performance of a sequential motor task may result from intrahemispheric competition between the two concurrent tasks. The left hemisphere is hypothesized to mediate both the sequential motor task and concurrent verbal task, thereby causing intrahemispheric competition between the two tasks.

### **Right Hemispheric Specialization for Motor Functions**

In contrast to a number of studies regarding left hemisphere dominance for sequential motor functions, relatively few studies have been carried out to investigate the role of the right hemisphere in motor performance (e.g., Carnahan & Elliott, 1987; Carson, 1989; Grünwald, Grünwald-Zuberbier, Hömberg, & Schuhmacher, 1984; Nachshon & Carmon, 1975; Nishizawa & Saslow, 1987; Roy & MacKenzie, 1978). Kimura and Vanderwolf (1970) tested the performance of a finger flexion task for both right-handed and left-handed subjects. The subjects were asked to flex a single finger or pairs of fingers at the middle joint. Kimura and Vanderwolf found that the designated finger flexions were performed better by the left hand than the right hand, with left hand superiority being most consistent for the right-handed subjects. This finding was replicated by Ingram (1975), who examined hand posturing and finger spacing performances in children.

Hermelin and O'Connor (1971) also demonstrated a left hand/finger advantage for reading Braille both in right-handed blind and normal subjects. Braille dot patterns are hypothesized to be analysed more efficiently by the right hemisphere than the left because of their spatial-configurational design,

although the Braille patterns are symbols of alphabet letters. Harris (1980) proposed a slightly different interpretation for left hand superiority in Braille reading. Harris argued that the left hand advantage for reading Braille patterns is primarily due to the haptic perceptual systems responsible for reading Braille patterns rather than the spatial configurational design of Braille dot patterns. Tactual perception is assumed to necessarily require integration from separate points in time and space because skin space-resolution power is relatively poor. This assumption indicates that the nature of tactual perception is spatial or right-hemispheric. Harris has inferred from this assumption that the haptic perceptual systems working in reading Braille patterns should be more efficient in the right hemisphere than in the left.

Furthermore, similar left hand superiority over the right hand has been found in various spatial tasks, such as finger spatial discrimination (Nachshon & Carmon, 1975; Nishizawa, 1987; Nishizawa & Saslow, 1987), hand positioning movements guided by a visible target light (MacKenzie, Sivak, & Elliott, 1988), and ballistic finger pointing movements to a visual target light (Guiard, Diaz, & Beaubaton, 1983). The findings from these studies are all consistent with the widely acknowledged notion of right hemisphere specialization for processing spatial information (Gazzaniga, 1983; Sperry, 1982).

### **Lateralization Effects in Positioning Movements**

For the positioning tasks on a short-term memory paradigm, in which subjects are asked to reproduce standard or criterion movements with a short retention interval, only three studies have shown a left limb advantage (i.e., right hemisphere dominance) for the accuracy of movement reproduction. Studies examining the reproduction performance of finger (Colley, 1984; Roy & MacKenzie, 1978) or foot (Carnahan & Elliott, 1987) positioning tasks have shown a typical left side superiority over the right in their performance. However, in all studies dealing with *arm* positioning movements within a short-term memory paradigm (Carson, Elliott, Goodman, & Dickinson, 1990; Roy & MacKenzie, 1978; Wallace, 1977; Wrisberg & Winter, 1985) evidence for a left limb advantage has not been found. Only within a long-term memory paradigm, an experiment by Kurian, Sharma, and Santhakumari (1989) has alone demonstrated a left arm advantage for the reproduction of elbow flexion to predetermined angular positions which subjects had learned during a 5-min acquisition session prior to the test (reproduction) session.

The study by Roy and MacKenzie (1978), which involved both bilateral

finger (thumb) and arm positioning tasks, showed a clear left hand advantage for finger positioning tasks, but no lateralization effects on the arm positioning tasks. This discrepancy between the finger and arm in the appearance of left hand advantage has later been attempted to be explained by several researchers. Carnahan and Elliott (1987) have explained such non-lateralized performance found in the arm positioning tasks in terms of a ceiling effect. The ceiling effect is inferred to be derived from somewhat easy motor control involved in the arm positioning tasks, relative to the foot positioning task for which Carnahan and Elliott demonstrated a typical left limb advantage. Nishizawa and Saslow (1987) have suggested that a possible factor which could reveal possible lateralization effects on manual performance is a large number of trial repetitions. Roy and MacKenzie employed only six trials per condition and consequently failed to show a significant lateralization effect. In contrast, Nishizawa and Saslow carried out 56 trials measuring the kinesthetic threshold for manual spatial discrimination, thereby demonstrating a clear left hand superiority in the spatial discrimination threshold. These explanations, however, fail to provide any convincing empirical evidence for the discrepancy between the finger and arm positioning tasks in the appearance of left side advantage.

Carson (1989) has argued that lateralization effects are mediated by two types of processes. One is associated with peripheral feedback involving information about spatial complexity inherent in a task. The other is related to the programming of movement or resultant output variability. Carson suggests that the degree to which the two types of processes are responsible for a task is highly dependent upon the task structure. Likewise Hammond et al. (1988) and Todor and Kyprie (1980) have stated that the right hand is superior to the left hand in motor systems and consequently that the output variability of the left hand appears greater than that of the right hand. Accordingly, in the Roy and MacKenzie (1978) study, a possible left hand advantage for the arm positioning tasks might have been masked because left hand performance could suffer more from output variability than is mediated by peripheral feedback for processing spatial complexity. Even in these terms, however, the discrepancy between the finger and arm positioning tasks in the appearance of lateralization effects cannot be well explained.

### **Effects of Cognitive Strategies on Lateralization**

An important factor for mediating the lateralization effect seems to be a differential use of the subject's approach or strategy to a given task. Colley (1984) suggests that the nature of a motor task can be changed by a subject trying to encode specific parameters available during the task by using a different strategy, in which the subject processes either temporal/sequential information or spatial information selectively. Evidence for such a view has been provided by Nishizawa (1987). He examined the threshold of either the kinesthetic spatial or weight discrimination ability of right-handed subjects, using an experimenter-defined thumb movement with a weight connected to the thumb via a pulley system. The subject's task consisted of successive presentation on each trial of a standard angle of the thumb position with a standard weight followed by a combination of test angle and weight. Two groups of subjects were tested on a different requirement of their judgments but in exactly the same task procedures. One group was asked to judge whether the test angle was larger or smaller than the standard angle, while the second group was asked to judge whether the test weight was heavier or lighter than the standard weight. Despite the subjects of both groups executing exactly the same movements, only the spatial group showed a clear left hand superiority over the right hand in their discrimination threshold. No lateralization effects were found for the weight discrimination group. Nishizawa concluded that the spatial judgment is mediated by the right hemisphere while weight judgment is bilateral.

On the basis of this finding and Colley's proposition mentioned above, subject strategies or approaches to the encoding of parameters involved in a motor task seem important in determining which cerebral hemisphere is primarily responsible for the processing of relevant information available from the task. In particular, the nature of a motor task such as arm positioning which has both a spatial and sequential nature, is dependent upon whether the subject strategies are focused on the temporal and sequential parameters (e.g., the use of timing or counting strategy) or on the spatial components (e.g., the use of starting and end positions) of the task.

### **Lateralization Effects on Distal and Proximal Musculature**

A most fundamental and crucial factor related to lateralization effect may be the anatomical connections between the hemispheres and limbs to be

used for a task. In research on motor tasks involving finger and hand movements, performance on one side of the body is generally assumed to be served by the motor cortex of the contralateral cerebral hemisphere (e.g., Brinkman & Kuypers, 1972, 1973; Kuypers, 1978, 1982). However, it has been reported that the more proximal muscle groups, such as those in the upper arm, are also controlled by the ipsilateral cerebral hemisphere (Brinkman & Kuypers, 1972, 1973; Di Stefano, Morelli, Marzi, & Berlucchi, 1980; Gazzaniga, Bogen, & Sperry, 1967; Zaidel & Sperry, 1977). In this regard, Wiley (1975, cited in Spirduso, 1978) reported a case study of a patient with a left hemispherectomy. The right hand and fingers of the patient were paralyzed but the right arm was controllable. This finding suggests that the distal musculature may be primarily controlled contralaterally while the proximal musculature is controlled bilaterally. In contrast, Todor et al. (1982) have shown that lateral differences in hand/arm tapping tasks are observed equally for movements around both proximal and distal joints, suggesting that either contralateral or ipsilateral pathways are available and the type of movement control required by the task may well determine which pathway is used. A more recent study (Trope, Fishman, Gur, Sussman, & Gur, 1987) has reported that the thumb and index finger are efficiently controlled by means of the ipsilateral pathways as well as the contralateral pathways, with the contralateral control being more responsible for movements of these fingers than ipsilateral control. For ring and little fingers, only contralateral pathways are found to be responsible for movement control. Trope et al. suggest that each finger may differ in the degree of control which occurs via ipsilateral pathways.

Typical arm positioning tasks (e.g., Carson et al., 1990; Roy & MacKenzie, 1978) involve both distal and proximal parts of the body. The proximal musculature is generally controlled via both ipsilateral and contralateral pathways, although the distal musculature is primarily controlled contralaterally. The positioning movements executed by each arm, which involve both proximal and distal musculature, should accordingly be controlled via both the ipsilateral and contralateral pathways. Therefore, even though the positioning task is strongly characterized by either a sequential or spatial nature, lateralization effects are not expected to appear in the performance. This is because the positioning performance should be mediated equally by both hemispheres via both pathways, irrespective of whether the left or right arm is used. It should be noted here that the lateralized hemispheric functions do not mean absolute functions of information processing but relative superiority of each hemi-



sphere to the other in specific information processing (see Gazzaniga, 1983; Sperry, 1982). One hemisphere might therefore process specific information, even though it may be more efficiently processed by the other hemisphere. In contrast to the arm positioning task, the finger positioning or finger tapping task has frequently shown a clear lateralization effect. This is probably because the finger used for the task is innervated contralaterally and the contralateral hemisphere confers lateralized functions which can contribute either efficiently or inefficiently to the task.

### **A Model for Lateralization Effects and Interhemispheric Conflict**

In conjunction with the notion of unilateral-bilateral innervation of distal and proximal musculature, a number of researchers (Cook, 1986; Passingham, 1981; Sperry, 1974) have proposed an interesting view regarding the hemispheric specialization for speech. On the basis of the neurophysiological finding that the central organs, such as the vocal cords, tongue, and jaw, are innervated from both hemispheres, Passingham (1981) has argued that it is most efficient for a single hemisphere to mediate complex sequential programming for human vocalization and it is least efficient for the two hemispheres to provide each side of the central organs with respective programs prepared by each hemisphere. Passingham's view for cerebral speech dominance is also based on earlier studies using stammerers. Jones (1966) reported that there was a substantial bilateral representation of the speech mechanisms in his four stammering patients, using Wada's (1949, 1960) amytal injection test, which is a neurophysiological test for determining the dominant hemisphere for language. Curry and Gregory (1969) also found that 55% of their stuttering subjects showed left ear advantage (i.e., the right hemisphere advantage) for the dichotic listening test (e.g., Kimura, 1961, 1967) with verbal material. This test is used to determine the dominant hemisphere for language and usually shows in right-handed people a typical right ear advantage (i.e., the left hemisphere advantage) for listening to verbal material. Curry and Gregory suggested that this stuttering was less firmly represented in the left hemisphere (*viz.*, represented more bilaterally). These findings by Curry and Gregory, as well as by Jones, are consistent with Passingham's view accounting for a single hemisphere, rather than both hemispheres, being specialized for speech.

The notion which Passingham (1981) argues has recently been supported and extended by Cook (1986) into a more general concept. Cook's view for

hemispheric motor control has been developed, again, on the basis of the neurophysiological findings indicating the contralateral neural control for distal parts of the body and bilateral control for the *midline* organs of speech. Cook has stated that:

There is consequently a far greater potential for hemispheric conflict, interference and disagreements in the control of organs located on the midline of the body than on the far periphery where there is at least a strong predominance of neural control from the contralateral hemisphere. Control of speech by only one hemisphere may be a simple means of avoiding confusion. (pp. 15–16)

It is accordingly assumed that the lateralization effects are expected to appear most clearly in the performance of a motor task only involving distal musculature, whereas in the performance of a task involving central organs or proximal musculature possible lateralization effects seem to be weakened or rather masked. Conversely, the effect of either interaction or conflict between hemispheres is expected to appear in the performance of tasks primarily involving central organs or proximal musculature, whereas any inter-hemispheric interaction or conflict may be not expected to occur in the distal parts.

### **Anatomical Connectivity versus Hemispace-Hemisphere Relationship**

In contrast to the general notion, as reviewed so far, that the asymmetries are mediated more or less by the anatomical limb-hemisphere connections, Heilman and his co-workers (Heilman & Valenstein, 1979; Heilman & Van Den Abell, 1979) have proposed that laterality effects could be attributed not only to the anatomical connections between each hemisphere and the sensory-motor (input-output) channels but also to some hemispheric mechanisms involved in the perception of, and action upon, stimuli arising in the contralateral hemispatial field or hemispace. It is postulated that the hemispace refers to the external space to the left or right of the midline of the body, regardless of where the eyes are fixated or which limb is used (e.g., Heilman & Valenstein, 1979). Each hemispace is assumed to represent a perceptual field for attending to stimuli and a behavioral field for acting on stimuli (Bowers & Heilman, 1980). Thus, one of hemispheric functions is hypothesized as the specialization of each hemisphere for perceiving, attending to, and/or acting (intending) on stimuli in the contralateral hemispace. This hypothesis has been supported by evidence from a number of experiments testing right-

handed normal subjects and brain-damaged patients performing various tasks, such as a tactual/visual line bisection (Bowers & Heilman, 1980; Heilman, Bowers, & Watson, 1984; Heilman & Valenstein, 1979; Reuter-Lorenz & Posner, 1990) and manual simple/choice reaction time tasks in which a visual stimulus is presented in lateralized visual fields (Bowers, Heilman, & Abell, 1981; Heilman & Van Den Abell, 1979; Verfaellie, Bowers, & Heilman, 1988).

The contribution of the hemisphere-hemisphere relationship for the asymmetries in perceptual-motor performance has also been shown in a series of experiments by Bradshaw and his co-workers (Bradshaw, Bradshaw, Nathan, Nettleton, & Wilson, 1986; Bradshaw, Bradshaw, & Nettleton, 1988, 1989; Bradshaw, Nathan, Nettleton, Wilson, & Pierson, 1987; Bradshaw, Nettleton, Nathan, & Wilson, 1983, 1985; Bradshaw, Spataro, Harris, Nettleton, & Bradshaw, 1988), who have examined left and right hand performance of right-handed normal subjects in various bisection tasks. In these tasks the subjects were asked to bisect either a horizontal line, rod, or the gap of two lights presented in either the left or right hemisphere. These studies with bisection tasks have generally shown a leftward error in bisecting a line/rod or gap (i.e., determining the midpoint of the line/rod or gap), suggesting that right-handed subjects tend to judge the extent of a line/rod or gap less than the actual size in the left hemisphere, irrespective of whether the left or right hand is used. Bradshaw and his co-workers have interpreted this leftward error in terms of the hemisphere-hemisphere relationship with a greater capacity for processing spatial information in the right hemisphere. The greater processing capacity is assumed to cause an overestimation of perceived stimuli or extent and accordingly to cause subjects to judge the extent of a line/rod or gap to be less than the actual size in compensation for overestimation. Bradshaw et al. (1985, 1986, 1987) have also found that the hemispatial asymmetry in bisection performance is larger with the central fixation of the subject's gaze (i.e., the side of the visual field is consistent with the hemispatial side) than with free scanning of the line/rod or gap. Bradshaw et al. have suggested that the hemisphere-hemisphere relationship rather than anatomical connectivities may be much more responsible for the asymmetry observed in bisection performance, although both hemispatial and anatomical pathway factors may contribute to it.

Similar findings have also been reported in studies with different tasks. With a vibrotactile reaction time task (Bradshaw, Bradshaw, Pierson-Savage, & Nettleton, 1988; Bradshaw, Nathan, Nettleton, Pierson, & Wilson, 1983), a right side advantage rather than a right hand advantage (viz., faster responses

in the right hemispace than in the left hemispace for either hand) has been evident. Furthermore, Pierson, Bradshaw, and Nettleton (1983) have shown, by conducting experiments using an auditory task, a strong right side advantage for listening to paired word stimuli given through loudspeakers. Specifically, Pierson et al. have shown that the right side advantage is obtained with loudspeakers as actual sound sources located in front and back of the subject and a dummy loudspeaker (i.e., no sound is emitted) located to the right rather than the left of the subject. Pierson et al. have suggested that it is the perceived location of a sound source, rather than the actual position or the ear of entry, that may determine the right side advantage for auditory perception of verbal stimuli.

The interpretation by Pierson et al. (1983) is consistent with those made in early studies by Morais (1978) and by Morais, Cary, Vanhaelen, and Bertelson (1980) but is inconsistent with the conventional anatomical pathway model developed by Kimura (1976). Although Kimura found a right *ear* advantage for a dichotic listening task, in the Pierson et al. study the right *side* advantage has been observed even when the subjects receive auditory stimuli through both ears, with a dummy loudspeaker being located to the right of the subjects. Thus, the anatomical pathway model fails to account for the right side advantage, whereas the hemispacial account can fully explain both the right ear advantage and right side advantage. Pierson et al. have found, however, that the right side advantage is lost with a 90° head turn to either the left or right, thereby concluding that the hemispacial factor alone cannot generate any lateral asymmetries and that the observed asymmetries are due to both hemispacial factor and anatomical pathway factor.

These findings from studies on the hemisphere-hemispace relationship suggest that lateralization effects of visual, auditory and tactual motor tasks can be interpreted not only by the conventional notion of anatomical connections between receptors/effectors and contralateral hemisphere but also by the notion of a hemisphere-hemispace relationship, which may relate to attention/intention functions in the brain. This also suggests that a number of previously reported findings about lateralization effects on various modality tasks should be carefully re-examined to see whether the outcomes had been confounded by the hemispacial effect.

### Conclusion

We reviewed, in this study, literature concerning cerebral hemispheric specialization of motor functions. In particular, we referred to issues relating to several influential factors mediating possible lateralization effects in the performance of arm positioning movements. One important factor may be the cognitive strategies which subjects use to selectively encode parameters available from a given task or by which performers simply approach a given task. The primary use of either cerebral hemisphere in information processing for a given task may partly depend upon such cognitive strategies as well as the apparent spatial or sequential nature of the task. The proximal-distal location of the muscle groups to be used for the task may be an extremely influential factor. It seems that lateralization effects tend to appear in motor performance requiring distal parts, such as fingers and hands, while possible interhemispheric conflict/interference may occur in motor tasks involving the proximal limbs, such as the arm. Furthermore, the hemispace, within which perception and action take place, appears to influence the occurrence of either lateralization effects mediated by each hemispheric specialization or interference effects due to interhemispheric integration and/or conflicts. We conclude that the control of an arm positioning movement may well be influenced by, at least, all the critical factors mentioned in this study. We also suggest that the arm positioning movements are unlikely to produce any lateralization effects but may generate some interhemispheric interference /conflict.

## References

- Bianki, V.L. (1984). Parallel and sequential information processing in animals as a function of different hemispheres. *Neuroscience and Behavioral Physiology*, *14*, 497-501.
- Bowers, D., & Heilman, K.M. (1980). Pseudoneglect: Effects of hemispace on a tactile line bisection task. *Neuropsychologia*, *18*, 491-498.
- Bowers, D., Heilman, K.M., & Van Den Abell, T. (1981). Hemispace-VHF compatibility. *Neuropsychologia*, *19*, 757-765.
- Bradshaw, J.L. (1989). *Hemispheric specialization and psychological function*. Chichester: John Wiley & Sons.
- Bradshaw, J.L., Bradshaw, J.A., & Nettleton, N.C. (1988). Movement initiation and control: Abduction, adduction and locus of limb. *Neuropsychologia*, *26*, 701-709.
- Bradshaw, J.L., Bradshaw, J.A., & Nettleton, N.C. (1989). Direction and location of movement in kinesthetic judgements of extent. *Neuropsychologia*, *27*, 1139-1151.
- Bradshaw, J.L., Bradshaw, J.A., Nathan, G., Nettleton, N.C., & Wilson, L.E. (1986). Leftwards error in bisecting the gap between two points: Stimulus quality and hand effects. *Neuropsychologia*, *24*, 849-855.
- Bradshaw, J.L., Bradshaw, J.A., Pierson-Savage, J.M., & Nettleton, N.C. (1988). Overt and covert attention and vibrotactile reaction times: Gaze direction, spatial compatibility and hemispacial asymmetry. *Canadian Journal of Psychology*, *42*, 44-56.
- Bradshaw, J.L., Nathan, G., Nettleton, N.C., Pierson, J.M., & Wilson, L.E. (1983). Head and body hemispace to left and right III: Vibrotactile stimulation and sensory and motor components. *Perception*, *12*, 651-661.
- Bradshaw, J.L., Nathan, G., Nettleton, N.C., & Wilson, L., & Pierson, J. (1987). Why is there a left side underestimation in rod bisection? *Neuropsychologia*, *25*, 735-738.
- Bradshaw, J.L., Nettleton, N.C., Nathan, G., & Wilson, L. (1983). Head and body space to left and right, front and rear—II. Visuotactual and kinesthetic studies and left-side underestimation. *Neuropsychologia*, *21*, 475-486.
- Bradshaw, J.L., Nettleton, N.C., Nathan, G., & Wilson, L. (1985). Bisecting rods and lines: Effects of horizontal and vertical posture on left-side underestimation by normal subjects. *Neuropsychologia*, *23*, 421-425.
- Bradshaw, J.L., Spataro, J.A., Harris, M., Nettleton, N.C., & Bradshaw, J. (1988). Crossing the midline by four to eight year old children. *Neuropsychologia*, *26*, 221-235.
- Brinkman, J., & Kuypers, H.G.J.M. (1972). Splitbrain monkeys: Cerebral control of ipsilateral and contralateral arm, hand, and finger movements. *Science*, *176*, 536-539.
- Brinkman, J., & Kuypers, H.G.J.M. (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, R.G. (1989). Manual asymmetries: Feedback processing, output variability, and spatial complexity—resolving some inconsistencies. *Journal of Motor Behavior*, *21*,

- 38-47.
- Carson, R.G., 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.
- Cook, N.D. (1986). *The brain code: Mechanisms of information transfer and the role of the corpus callosum*. New York: Methuen.
- Cremer, M., & Ashton, R. (1981). Motor performance and concurrent cognitive tasks. *Journal of Motor Behavior*, *13*, 187-196.
- Curry, F.K.W., & Gregory, H.H. (1969). The performance of stutterers on dichotic listening tasks thought to reflect cerebral dominance. *Journal of Speech and Hearing Research*, *12*, 73-82.
- Dalen, K., & Hugdahl, K. (1987). Hemispheric asymmetry and left and right manual versus pedal tapping during a concurrent cognitive task. *Perceptual and Motor Skills*, *64*, 1063-1073.
- Dean, R.S. (1986). Lateralization of cerebral functions. In D. Wedding, A.M. Horton, Jr., & J. Webster (Eds.), *The neuropsychology handbook: Behavioral and clinical perspectives*, (pp. 80-102). New York: Springer.
- Di Stefano, M., Morelli, M., Marzi, C.A., & Berlucchi, G. (1980). Hemispheric control of unilateral and bilateral movements of proximal and distal parts of the arm as inferred from simple reaction time to lateralized light stimuli in man. *Experimental Brain Research*, *38*, 197-204.
- Edwards, J.M., & Elliott, D. (1987). Effect of unimanual training on contralateral motor overflow in children and adults. *Developmental Neuropsychology*, *3*, 299-309.
- Elliott, D. (1985). Manual asymmetries in the performance of sequential movement by adolescents and adults with Down syndrome. *American Journal of Mental Deficiency*, *90*, 90-97.
- Elliott, D., Weeks, D.J., & Jones, R. (1986). Lateral asymmetries in finger-tapping by adolescents and young adults with Down syndrome. *American Journal of Mental Deficiency*, *90*, 472-475.
- Gazzaniga, M.S. (1983). Right hemisphere language following brain bisection: A 20-year perspective. *American Psychologist*, *38*, 525-537.
- Gazzaniga, M.S., Bogen, J.E., & Sperry, R.W. (1967). Dyspraxia following division of the cerebral commissures. *Archives of Neurology*, *16*, 606-612.
- Geffen, G., Bradshaw, J.L., & Wallace, G. (1971). Interhemispheric effects on reaction time to verbal and nonverbal stimuli. *Journal of Experimental Psychology*, *87*, 415-422.
- Grünewald, G., Grünewald-Zuberbier, E., Hömberg, V., & Schuhmacher, H. (1984). Hemispheric asymmetry of feedback-related slow negative potential shifts in a positioning movement task. *Annals of the New York Academy of Sciences*, *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.

- Haaxma, R., & Kuypers, H.G.J.M. (1975). Intrahemispheric cortical connexions and visual guidance of hand and finger movements in the rhesus monkey. *Brain*, *98*, 239-260.
- Hammond, G., Bolton, Y., Plant, Y., & Manning, J. (1988). Hand asymmetries in inter-response intervals during rapid repetitive finger tapping. *Journal of Motor Behavior*, *20*, 67-71.
- Harris, L.J. (1978). Sex differences in spatial ability: Possible environmental, genetic, and neurological factors. In M. Kinsbourne (Ed.), *Asymmetrical function of the brain* (pp. 405-522). Cambridge: Cambridge University Press.
- Harris, L.J. (1980). Which hand is the "eye" of the blind? A new look at an old question. In J. Herron (Ed.), *Neuropsychology of left-handedness* (pp. 303-329). New York: Academic Press.
- Heilman, K.M., Bowers, D., & Watson, R.T. (1984). Pseudoneglect in a patient with partial callosal disconnection. *Brain*, *107*, 519-532.
- Heilman, K.M., & Valenstein, E. (1979). Mechanisms underlying hemispatial neglect. *Annals of Neurology*, *5*, 166-170.
- Heilman, K.M., & Van Den Abell, T. (1979). Right hemispheric dominance for mediating cerebral activation. *Neuropsychologia*, *17*, 315-321.
- Hellige, J.G. (1976). Changes in same-different laterality patterns as a function of practice and stimulus quality. *Perception and Psychophysics*, *20*, 267-273.
- Hermelin, B., & O'Connor, N. (1971). Functional asymmetry in the reading of Braille. *Neuropsychologia*, *9*, 431-435.
- Hicks, R.E., Provenzano, F.J., & Rybstein, E.D. (1975). Generalized and lateralized effects of concurrent verbal rehearsal upon performance of sequential movements of the fingers by the left and right hand. *Acta Psychologica*, *39*, 119-130.
- Imanaka, K. (1989). Effect of starting position on reproduction of movement: Further evidence of interference between location and distance information. *Perceptual and Motor Skills*, *68*, 423-434.
- Ingram, D. (1975). Motor asymmetries in young children. *Neuropsychologia*, *13*, 95-102.
- Johnson, P.R. (1977). Dichotically-stimulated ear differences in musicians and non-musicians. *Cortex*, *13*, 385-389.
- Jones, R.K. (1966). Observations on stammering after localized cerebral injury. *Journal of Neurology, Neurosurgery, and Psychiatry*, *29*, 192-195.
- Kimura, D. (1961). Cerebral dominance and the perception of verbal stimuli. *Canadian Journal of Psychology*, *15*, 166-171.
- Kimura, D. (1967). Functional asymmetry of the brain in dichotic listening. *Cortex*, *3*, 163-178.
- 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., & Vanderwolf, C.H. (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, N.K., & Santhakumari, K. (1989). Left-arm dominance in active positioning. *Perceptual and Motor Skills*, *68*, 1312-1314.
- Kuypers, H.G.J.M. (1978). From motor control to conscious experience. In Buser & Rougeul-Buser (Eds.), *Cerebral correlates of conscious experience* (INSERM Symposium, No. 6, pp. 95-110). Elsevier/North-Holland Biomedical Press.
- Kuypers, H.G.J.M. (1982). A new look at the organization of the motor system. *Progress in Brain Research*, *57*, 381-403.
- Levy, J., & Levy, J.M. (1978). Human lateralization from head to foot: Sex-related factors. *Science*, *200*, 1291-1292.
- Lomas, J., & Kimura, D. (1976). Intrahemispheric interaction between speaking and sequential manual activity. *Neuropsychologia*, *14*, 23-33.
- MacKenzie, C.L., Sivak, B., & Elliott, D. (1988). Manual localization of lateralized visual targets. *Journal of Motor Behavior*, *20*, 443-457.
- Marzi, C.A., & Berlucchi, G. (1977). Right visual field superiority of accuracy of recognition of famous faces in normals. *Neuropsychologia*, *15*, 751-756.
- Mateer, C., & Kimura, D. (1977). Impairment of nonverbal oral movements in aphasia. *Brain and Language*, *4*, 262-276.
- McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. *The Behavioral and Brain Sciences*, *3*, 215-227.
- Moll, L., & Kuypers, H.G.J.M. (1977). Premotor cortical ablations in monkeys: Contralateral changes in visually guided reaching behavior. *Science*, *198*, 317-319.
- Moll, L., & Kuypers, H.G.J.M. (1980). Impaired visually guided arm, hand and finger movements. *Neurology*, *30*, 902-903.
- Morais, J. (1978). Spatial constraints on attention to speech. In J. Requin (Ed.), *Attention and performance VII* (pp. 245-260). Hillsdale, NJ: Lawrence Erlbaum.
- Morais, J., & Cary, L., Vanhaelen, H., & Bertelson, P. (1980). Postural determinants of frontal-position advantage in listening to speech. *Perception and Psychophysics*, *27*, 141-148.
- Nachshon, I., & Carmon, A. (1975). Hand preference in sequential and spatial discrimination tasks. *Cortex*, *11*, 123-131.
- Nishizawa, S. (1987). Handedness (II): Laterality of spatial and weight discrimination guided by kinesthesia. *Memoria, Seitoku Junior College of Nutrition*, *18*, 53-57.
- Nishizawa, S., & Saslow, C.A. (1987). Lateralization of kinesthetically guided spatial perception. *Cortex*, *23*, 485-494.
- Passingham, R.E. (1981). Broca's area and the origins of human vocal skill. *Philosophical Transactions of the Royal Society of London*, *B292*, 167-175.
- Pierson, J.M., Bradshaw, J.L., & Nettleton, N.C. (1983). Head and body space to left and right, front and rear - I. Unidirectional competitive auditory stimulation. *Neuropsychologia*, *21*, 463-473.
- Podbros, L.Z., & Wyke, M.A. (1988). Laterality differences for speed but not for control in sequential finger tapping. *Perceptual and Motor Skills*, *67*, 927-933.
- Rasmussen, T., & Milner, B. (1977). The role of early left-brain injury in determining

- lateralization of cerebral speech functions. *Annals of the New York Academy of Sciences*, 299, 355-369.
- Reuter-Lorenz, P.A., & Posner, M.I. (1990). Components of neglect from right-hemisphere damage: An analysis of line bisection. *Neuropsychologia*, 28, 327-333.
- Roy, E.A., & Elfeki, G. (1979). Hemispheric asymmetries in a finger sequencing task. In G.C. Roberts & K.M. Newell (Eds.), *Psychology of motor behavior and sport—1978* (pp. 219-228). Champaign, Ill: Human Kinetics.
- Roy, E.A., & MacKenzie, C. (1978). Handedness effects in kinesthetic spatial location judgements. *Cortex*, 14, 250-258.
- Sperry, R.W. (1974). Lateral specialization in the surgically separated hemispheres. In F.O. Schmitt & F.G. Worden (Eds.), *The neurosciences: Third study program* (pp. 5-19). Cambridge: MIT Press.
- Sperry, R. (1982). Some effects of disconnecting the cerebral hemispheres. *Science*, 217, 1223-1226.
- Spirduso, W.W. (1978). Hemispheric lateralization and orientation in compensatory and voluntary movement. In G.E. Stelmach (Ed.), *Information processing in motor control and learning* (pp. 289-309). New York: Academic Press.
- Streitfeld, B. (1985). Hemispheric advantages and shifts of laterality differences in visual and tactual modalities. *International Journal of Neuroscience*, 25, 245-254.
- Taylor, H.G., & Heilman, K.M. (1980). Left-hemisphere motor dominance in right-handers. *Cortex*, 16, 587-603.
- Todor, J.I., & Doane, T. (1977). Handedness classification: Preference versus proficiency. *Perceptual and Motor Skills*, 45, 1041-1042.
- Todor, J.I., & Doane, T. (1978). Handedness and hemispheric asymmetry in the control of movements. *Journal of Motor Behavior*, 10, 295-300.
- Todor, J.I., & Kyprie, P.M. (1980). Hand differences in the rate and variability of rapid tapping. *Journal of Motor Behavior*, 12, 57-62.
- Todor, J.I., & Kyprie, P.M., & Price, H.L. (1982). Lateral asymmetries in arm, wrist and finger movements. *Cortex*, 18, 515-523.
- Trope, I., & Fishman, B., Gur, R.C., Sussman, N.M., & Gur, R.E. (1987). Contralateral and ipsilateral control of fingers following callosotomy. *Neuropsychologia*, 25, 287-291.
- Verfaellie, M., Bowers, D., & Heilman, K.M. (1988). Hemispheric asymmetries in mediating intention, but not selective attention. *Neuropsychologia*, 26, 521-531.
- Wada, J. (1949). [A new method for the determination of the side of cerebral speech dominance: A preliminary report on the intracarotid injection of Sodium Amytal in man]. *Igaku to Seibutsugaku [Medicine and Biology]*, 14, 221-222. (Japanese)
- Wada, J., & Rasmussen, T. (1960). Intracarotid injection of sodium amytal for the lateralization of cerebral speech dominance: Experimental and clinical observations. *Journal of Neurosurgery*, 17, 266-282.
- Wallace, S.A. (1977). The coding of location: A test of the target hypothesis. *Journal of Motor Behavior*, 9, 157-169.
- Walsh, W.D., Russell, D.G., & Imanaka, K. (1980). Memory for movement: Inter-

- action of location and distance cues and imagery ability. *Acta Psychologica*, 44, 117-130.
- Walsh, W.D., Russell, D.G., & Imanaka, K., & James, B. (1979). Memory for constrained and preselected movement location and distance: Effects of starting position and length. *Journal of Motor Behavior*, 11, 201-214.
- Weinstein, S. (1978). Functional cerebral hemispheric asymmetry. In M. Kinsbourne (Ed.), *Asymmetrical function of the brain* (pp. 17-48). Cambridge: Cambridge University Press.
- Wrisberg, C.A., & Winter, T.P. (1985). Reproducing the end location of a positioning movement: The long and short of it. *Journal of Motor Behavior*, 17, 242-254.
- Wyke, M. (1967). Effect of brain lesions on the rapidity of arm movement. *Neurology*, 17, 1113-1120.
- Wyke, M. (1971a). The effects of brain lesions on the learning performance of a bimanual co-ordination task. *Cortex*, 7, 59-72.
- Wyke, M. (1971b). The effects of brain lesions on the performance of bilateral arm movement. *Neuropsychologia*, 9, 33-42.
- Zaidel, D., & Sperry, R.W. (1977). Some long-term motor effects of cerebral commissurotomy in man. *Neuropsychologia*, 15, 193-204.