Movement Laterality and Its Relationship to Hemispheric Specialization

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Hypothesized relationships between asymmetric brain processes and movement-related asymmetries are reviewed. Theories that attribute asymmetric preference and performance to hemisphere dominance have been superseded by more complex ideas: motor-specific and more global hemispheric specializations are considered to influence movement organization. Environmentally conditioned preferences and their relationship to preferential asymmetric movements are also addressed. The literature suggests that laterality may be dynamic, because task requirements have been shown to override asymmetric brain influences. This observation of the nature of laterality may result in a more flexible approach to the reeducation of preference and performance in brain-injured patients.

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Functional asymmetries of the brain are the most popular explanation of movement lateralities (i.e., the preferred, consistent use of an asymmetric movement in the performance of an asymmetric action). Right preferences for the hand, foot, and eye have been attributed to left-hemisphere dominance and/or genetics (Annett, 1985; Levy & Nagylaki, 1972). Other preferential movement asymmetries of the head (Coryell & Michel, 1978; Turkewitz, Gordon, & Birch, 1965), lower limb (Vanden-Abeele, 1980), and rotational preferences (Lund, 1930) have had limited consideration as explanations for left-hemisphere dominance of motor control. Rather than clarify the concepts of preference and performance, many motor-control theorists have implicitly linked these asymmetries in a unidimensional approach to the brain and behavior (Heuer, 1987).

This paper reviews hypotheses that link functional asymmetries of the brain with motor control and with the manifest movement lateralities or performance asymmetries (i.e., measured differences in performance between the two hands doing the same task). These hypotheses, which are implicit in many remediation and educational protocols, emphasize the tentative understanding of interrelationships between functional and structural asymmetries of the brain and movement behaviors. Laterality and movement problems are also discussed to show how brain asymmetries may influence task organization. The relationship is hypothesized to be dynamic in order to accommodate the varying demands of the changing environment. Brain damage could limit this flexibility.

Motor Dominance and Handedness

Early explanations of the relationship between motor control and handedness focused on left-hemisphere dominance. At the turn of this century, Hugo Liepmann, a German neurologist, hypothesized that left-hemisphere dominance for speech was a function of the superiority of that hemisphere “for movement made without objects, purely from memory” (Liepmann, 1908/1980, p. 49). In right-handed persons, the plans for both right- and left-hand movement sequences were thought to be stored in the left hemisphere. The left hand was thought to receive messages from the left hemisphere via the corpus callosum.

Liepmann (1908/1980) found that approximately 50% of the right-hemiplegic patients that he studied had left-hand apraxia. From this he reasoned that the left hemisphere (in right-handed persons) influences the movement of both sides of the body, especially the limbs. In contrast to the right-hemiplegic patients, the left-hemiplegic patients performed well with the right hand (with the exception of a few left-handed...
patients). Liepmann concluded that motor control was determined in the hemisphere contralateral to the dominant hand.

Orton (1937) hypothesized that "the whole control of speech, reading and writing in one half of the brain bears an intimate relation to the development of unilateral manual skill in the individual" (p. 27). This early theory still influences remedial approaches to the treatment of children with severe brain damage and learning disabilities. Right homolateral dominance of the right hand, foot, and eye was considered essential for optimal development of language skills in the left hemisphere (McBurney & Dunn, 1976). Implicit was the idea that right-sidedness was a manifestation of the integrity and control of the dominant left hemisphere.

Geschwind (1975) further developed the idea of a relationship between language dominance and handedness. Like Liepmann (1908/1980), he noted cases of left-hand apraxia in right-hemiplegic patients and proposed that the hemisphere contralateral to the dominant hand was specialized for motor planning. Unlike Liepmann, however, Geschwind interpreted the relationship between language and the motor centers as one of proximity, with asymmetric control of movement dependent on left hemisphere language dominance.

Geschwind (1975) noted a problem with his own hypothesis. Right-hemiplegic patients with severe comprehension problems were still able to perform axial movements. Consequently, Geschwind postulated that the right hemisphere had a special ability to comprehend axial commands; this caused him to shift from his 1975 model to a model in which handedness had a multidimensional basis (Healey, Liederman, & Geschwind, 1986).

The unidimensional models (Geschwind, 1975; Liepmann, 1908/1980; Orton, 1937) were the first approximations to understand the relationship between asymmetric brain organization and motor control and to include movement asymmetries. These models assumed a hierarchical style of motor control in which the left hemisphere was dominant for motor planning as a result of its relationship with language areas of the brain or through a motor dominance of the left hemisphere. These models assumed a direct structural influence of a functional brain asymmetry on the contralateral limb (i.e., left hemisphere and right hand). The strict association between brain asymmetries and behavior was not upheld by the following: blood flow studies of voluntary movements (Roland, 1984, 1985); electrophysiological studies that looked at footedness as well as handedness (Boschert & Deoke, 1986); behavioral studies that showed varying reaction time proficiencies for the left and right hands (Larkin, 1986; Nakamura & Saito, 1974); a study that showed superior proficiency of the left (nondominant) hand with certain tasks (Roy & MacKenzie, 1978); and studies that showed changing proficiencies as a function of experience and task demands (Larkin, 1986; Provins & Glencross, 1968).

Hemispheric Specialization and Motor Asymmetries

Semmes (1968) proposed that specializations from both the right and left hemispheres contribute differentially to the organization of movement. Testing brain-injured patients on cutaneous and simple motor tasks, Semmes found that lesions in the sensorimotor cortex of the left hemisphere produced greater deficits in the contralateral hand than did lesions in the right sensorimotor cortex. However, greater deficits were observed in the contralateral hand when there was damage to the nonsensorimotor areas of the right hemisphere. Semmes extrapolated that the right sensorimotor cortex was more diffusely organized and the left sensorimotor cortex more focally organized.

The focal representation of elementary units in the sensorimotor cortex was considered to provide proximity and convergence of input, which resulted in more precise coding and finer control of output. Semmes (1968) postulated that this organization would be more suitable for the production of fine movements used for manipulative skills and speech. She did not expand on how the more diffuse organization of the nondominant hand was behaviorally manifest. Nevertheless, the idea that asymmetric control of movement may be distributed across both hemispheres generated further consideration that a number of elemental asymmetric motor-related processes may contribute to the emergent laterality of the limbs.

Evolving Views

More complex relationships between asymmetric brain organization, motor control, and manifest movement asymmetries are evolving. Kimura, working with both impaired and normally functioning persons, has demonstrated special asymmetric motor control functions in the left hemisphere (Kimura, 1977, 1982; Kimura & Archibald, 1974). Additionally, other right- and left-hemisphere specializations may have influenced shifts in hand use in response to verbal and nonverbal biases (Hampson & Kimura, 1984). Sexual dimorphism specifically related to motor control has added to the complexity (Kimura, 1987; Leonard, Jones, & Milner, 1988).

Evidence of motor specialization in the left and possibly the right hemispheres was supported by a number of experiments. For example, subjects with either left- or right-hemisphere damage performed equally well on a hand posture task, but the subjects
with left-hemisphere damage were markedly impaired on the ipsilateral and contralateral hand when copying a movement sequence that combined the hand postures (Kimura & Archibald, 1974). Perseverative movement errors also differentiated subjects with left-hemisphere damage from those with right-hemisphere damage (Kimura, 1977). The impaired control function was considered to be a movement selection process, which is particularly relevant to speech and manipulation (Kimura, 1977, 1982).

Demonstrations that movement responses with the left and the right hand vary when task demands are loaded in favor of the underlying functional asymmetries (i.e., visual-spatial versus verbal) indicated that specific hemispheric specializations from the right and left can differentially affect task performance (Hampson & Kimura, 1984). Both general-hemispheric and motor-specific specializations contributed to asymmetry in movement organization. These findings may explain some of the variability in the expression of movement preference and performance on different task demands.

Right-Hemisphere Contributions

Ideas about asymmetric motor processes in the right hemisphere were considered to be of less importance than those about the left hemisphere. Stockmeyer’s (1980) hypothesis that the left hemisphere was specialized for changing position and the right hemisphere was specialized for holding postures accommodated the often-noted motor impersistence in adults with right-hemisphere damage (Fisher, 1956; Kertesz, Nicholson, Cancelliere, Kassa, & Black, 1985; Stockmeyer).

Other motor-related deficits considered characteristic of persons with right-hemisphere damage include difficulties in drawing, copying, and constructing visual or spatial representations (LeDoux, 1984). Hemineglect, disorientation, and problems with maze negotiation in patients with brain damage are also considered to reflect a general specialization of the right inferior parietal lobule for orienting to the environment (LeDoux). Concerning speech production, there are controversial reports of a relationship between prosody and right-hemisphere damage (Ross, 1988; Ryalls, 1988). A more systematic and detailed analysis of motor problems in patients with right-hemisphere damage may add to our limited understanding of the contribution of this hemisphere to the organization of movements.

Additional Model Complexities

Theories of asymmetric control of movement are not supported by blood flow studies, which have established symmetric and asymmetric flow patterns that vary in response to the organization of different motor tasks (Roland, 1984, 1985; Roland, Meyer, Shibasaki, Yamamoto, & Thompson, 1982). Although blood flow asymmetry in the brain’s sensorimotor and globus pallidus areas was related to contralateral arm and hand movement (Roland et al.), the prevalence of symmetric activations in supplementary and premotor areas during unimanual movements suggested distributed control of movement. Roland et al. proposed bihemispheric development specification of motor programs.

Evidence of anatomical asymmetries in the cortex (LeMay, 1977) and in the globus pallidus (Kooistra & Heilman, 1988) were also postulated to reflect asymmetric brain influences in the organization of movement. Functional relationships of these structural asymmetries have not been elaborated. In addition to these structural asymmetries, which are static, the biochemical asymmetries in the thalamus (Oke, Keller, Mefford, & Adams, 1978), in the nigrostriatal system, and in Brodmann’s Area 4 (Glick, Ross, & Hough, 1982) provide a basis for the more dynamic emergent functional asymmetries that are conditioned at times by the constraints of the internal motor organization and at times by the constraining demands of the task and of the environment.

The extent of asymmetric subsystems distributed throughout the brain adds to the complex relationship of the movement and behavioral asymmetries. Nevertheless, thinking in terms of distributed and multiple asymmetries at the neural level may help us to better understand the multiple asymmetries in behavior that we observe in persons.

The dynamic nature of movement asymmetries, which causes the performance level of each hand to be affected by unimanual or bimanual training (Larkin, 1986), requires functional asymmetric brain networks that are flexibly and dynamically linked (Kinsbourne & Hicks, 1978). Brain asymmetries may relate directly or indirectly to the performance of the limbs. A dynamic relationship would help explain the performance equivalence developed between the hands when tasks such as typing are learned (Provins & Glencross, 1968) and would explain performance variations of each hand with different training (Larkin, 1986). For example, in the right-handed person, if the right hand is trained before the left, left-hand performance is poorer. However, if the left hand is trained first, performance of both hands is improved.

Laterality and Brain Asymmetries

Lateral dominance is useful only under conditions that require a predictable asymmetric performance (such as writing). To explain the preferred asymmetric performance of tasks, several theorists have pro-
posed a multicausal approach (Dawson, 1977; Larkin, 1988; Wile, 1934), which includes sociogenetic, environmental, biological, and biomechanical factors that can influence the emergent asymmetric behavior.

A rigid relationship between brain asymmetries and preferential asymmetry is too constraining to explain the complexity of motor control that arises as a function of mixed dominance, which is found in more than 50% of the normal population (Porac & Coren, 1981).

A direct brain-behavior asymmetry becomes even less likely when preferences for footedness, eyedness, and earedness are considered. Under these circumstances, consistent laterality for the normal population is below 50% (Porac & Coren, 1981).

More problems arise when the combination of preferences into complex multilink tasks is considered. In the early part of this century, many asymmetric preferences were examined (Downey, 1927; Haefner, 1930, Lund, 1930). These preferences were related to tasks that had a predominantly distal demand (e.g., writing) as opposed to a proximal demand (e.g., sweeping). Many combinations were apparent. If multiple but discordant asymmetric limb and axial preferences are needed in a task, then a consensus must emerge in terms of biomechanical and neural demands; otherwise, performance will be degraded. For example, a right hand preference for the fine motor control that is required to release a ball may not be congruent with a clockwise rotational trunk preference that is required during the preparatory part of the throw. The degree of asymmetry combined with direction adds complexity to the teaching or relearning of tasks.

When laterality is subsumed by the task demands, there is evidence for the environmental and task demands to supersede central influences. For example, head-turning patterns to watch for traffic are firmly established by environmental conditioning; Americans who visit England must stop and think before crossing a road because they automatically check for traffic in the wrong direction. The functional brain asymmetries are not necessarily hierarchical influences from the cerebral cortex but rather from organizational processes that contribute to the efficient production of unilateral and bilateral asymmetric and symmetric movements. Laterality appears to be a dynamic, variable state that is not always centrally determined. Laterality in task performance emerges as a consensus of neural, environmental, and mechanical factors that contribute to the organization of preferential asymmetric movement.

Summary

Current models of asymmetric motor control do not explain the multiple and dynamic asymmetries that emerge at the behavioral level. A distributed model of asymmetric brain processes is needed to accommodate emergent asymmetric behavior. The model must show how discordant lateral limb and axial preferences mesh with biomechanical and environmental constraints.

Many assumptions that are based on the theory that laterality is a manifestation of left-hemisphere control mechanisms in right-handed persons have influenced the assessment and remediation of patients with brain damage and learning disabilities. Our current knowledge suggests a dynamic relationship, where task laterality is a consensus of asymmetric neural, biomechanical, and environmental constraints. Further systematic observation is needed to identify motor processes that may be affected by brain damage, particularly in the right hemisphere. In light of our limited understanding, a focus on the functional task with secondary attention to the underlying processes appears a most viable approach to remediation.

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References


