Motor Behavior Research: Implications for Therapeutic Approaches to Central Nervous System Dysfunction

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Key Words: motor control • neurodevelopmental therapy

This article reviews the models and theories of motor behavior that are the foundation for the traditional approaches to central nervous system (CNS) dysfunction and presents a new theoretical model and approach that are beginning to influence practice. Reflex, hierarchical, and systems models of motor control and developmental and motor learning theories are discussed. The relationships of these models and theories to past, present, and future treatment approaches to CNS dysfunction are explored. The assumptions and limitations of the muscle reeducation, neurodevelopmental, and motor relearning approaches are discussed. A contemporary task-oriented approach based on the systems model is proposed and contrasted with traditional neurodevelopmental approaches.

Theoretical models of motor behavior serve as a foundation for treatment approaches to central nervous system (CNS) dysfunction. The assumptions of each model guide the focus of and provide a rationale for each treatment approach used with clients who have motor control problems. For example, the assumptions of the traditional approaches to CNS dysfunction are based on reflex or hierarchical models of motor control and traditional motor development and learning theories.

Contemporary motor behavior research reflects a major shift from reflex and hierarchical models to systems models of motor control (Abernethy & Sparrow, 1992; Horak, 1991). Similar changes are seen in the contemporary motor development and motor learning literature (Higgins, 1991; Thelem & Ulrich, 1991). As models and theories of motor behavior change, the assumptions of the traditional approaches must be reexamined (Crutchfield & Barnes, 1993; Gordon, 1987; Lister, 1991; Rothstein, 1991). This article discusses and critiques the models and theories of motor behavior that are the foundation for the traditional approaches to CNS dysfunction and describes a new theoretical model and approach that are beginning to influence practice.

Figure 1 illustrates the relationships of models and theories of motor behavior to approaches to managing CNS dysfunction. The upper half of the illustration depicts selected models and theories of motor behavior and their historical evolution. Arrows between the reflex, hierarchical, and systems models reflect two major shifts in the motor behavior literature. Traditional and contemporary theories of motor development and motor learning have been influenced by these three models. The lower half of the illustration shows changes in the major approaches to managing CNS dysfunction over time. The arrows heading downward indicate what we think are the models and theories that have influenced these various approaches. The neurodevelopmental approach is presently the dominant approach to managing CNS dysfunction in occupational therapy; the motor relearning program is having some influence on clinical practice; and the contemporary task-oriented approach will probably have a major effect in the future. Each of the boxes in Figure 1 is discussed below.

Models of Motor Control

Reflex Model

The reflex model of motor control originated with the works of Sherrington (1906), who regarded the CNS as a black box in which specific sensory input would elicit reflexes or stereotyped motor output (see Figure 2). In addition, the sensory feedback from the motor output could trigger other reflexes or stereotyped movements. This model suggested that human movement was the summation or combination of reflexes. Sherrington...
MODELS:

- REFLEX
- HIERARCHICAL
- SYSTEMS

THEORIES:

- TRADITIONAL MOTOR DEVELOPMENT & LEARNING
- CONTEMPORARY MOTOR DEVELOPMENT & LEARNING

CNS TREATMENT APPROACHES:

- MUSCLE REEDUCATION
- NEURO-DEVELOPMENTAL
- MOTOR RELearning PROGRAMME
- CONTEMPORARY TASK-ORIENTED

Figure 1. Models and theories of motor behavior and their relationship to approaches to central nervous system (CNS) dysfunction. On the bottom are notable publications and conferences that have had major influences on approaches to CNS dysfunction. NUSTEP = Northwestern University Special Therapeutic Exercise Project, NDT = neurodevelopmental treatment, PNF = proprioceptive neuromuscular facilitation.

(1906) and Magnus (1926) conducted experiments on anesthetized animals whose neural structures above the midbrain had been removed. The findings of these studies supported a reflex or peripheral model of motor control.

The influence of the reflex model of motor control on practice is evident in a number of areas. Assessments that focus on reflex testing, as well as treatment approaches that use sensory stimuli to elicit normal motor responses, are consistent with this model. Rood (1954) based many of her treatment techniques on the neurophysiological research of her time. For example, brushing, stretch pressure, and tapping are based on research by Eldred and Hagbarth (1954), who demonstrated that stimulation applied over a muscle facilitated that muscle and inhibited its antagonist. The decision to splint or not to splint a spastic hand may depend on whether the splint is believed to inhibit or facilitate certain muscles. The rationale for using vibration and the tonic labyrinthine inverted position is also based on reflex model ideas. Clearly, the reflex model of motor control has had a major effect on the neurodevelopmental approaches.

The limitations of the reflex model have been shown in a number of studies. Deafferented animals have demonstrated coordinated movement without sensory input (Polis & Bizzi, 1979; Taub, 1976). Lashley (1917) reported the case of a human with severe lower extremity sensory loss who had minimal problems with coordinated movement. Thus, sensory input is not necessary for all types of motor behavior. In addition, the reflex model cannot account for preprogrammed instructions or anticipatory control of movement, key components of the hierarchical model. In conclusion, the reflex model of motor control has significant limitations and is an inadequate model for explaining motor control.

Some concepts similar to those of the reflex model have been proposed by other investigators. Thorndike (1927) stated that rewarded responses tend to be repeated, whereas unrewarded responses or punished responses tend not to be repeated. The principles of behavior modification evolved from his work. Adams (1971) proposed a closed-loop model of motor behavior that emphasizes the role of peripheral sensory feedback in controlling movement. This model extends the reflex model because it adds a reference of correctness that can detect discrepancies between planned and actual movements. This closed-loop model allows adjustments to movements as they occur so that the intended movements are achieved. Although the closed-loop model expands the role for the CNS in movement control, it still suggests that the movement is controlled peripherally.

Hierarchical Model

One of the earliest hierarchical models of motor control was proposed by Jackson and Taylor (1932). In this mod-
el, movements are believed to be controlled centrally from the top down. The highest level of the nervous system controls the middle level, and the middle level controls the lowest level (see Figure 3, left side). Recent hierarchical models (Keele, 1968; Schmidt, 1988) have suggested that control of movement originates centrally with the executive selecting, planning, and initiating a motor program to respond to specific input (see Figure 3, right side). The motor program contains the instructions for the effector, which carries them out without the possibility of modification if something goes wrong. The output is the movement that can be observed (Schmidt, 1988). In clients with normal CNS function, the higher levels control the lower levels. In clients with CNS dysfunction, however, loss of higher level voluntary control results in the release of lower level reflexes. In the latter case, primitive reflexes, spasticity, and abnormal movement patterns dominate movement control.

The hierarchical model incorporates an open-loop system of control rather than a closed-loop system. An open-loop system sends preprogrammed instructions to an effector that does not use feedback to carry out the movement (Schmidt, 1988). Feedforward or anticipatory control is used for rapid movements because there is insufficient time for sensory feedback to influence the outcome of the movement. Feedforward is information that is sent ahead to prepare the system for sensory feedback or for a future motor command (Schmidt, 1988). For example, when a standing person raises an arm, the center of gravity shifts, thus postural adjustments must occur before the movement is initiated in order to maintain balance.

Many postural adjustments that were thought to be equilibrium reactions in response to sensory input have
been shown to be anticipatory adjustments prior to self-initiated limb movements (Belen'kii, Gurfinke1, & Palt'sev, 1967; Cordo & Nashner, 1982; Horak, Anderson, Esselman, & Lynch, 1984). For example, Belen'kii et al. (1967) demonstrated that in a reaching task, electromyographic (EMG) activity occurred in the opposite leg about 60 msec before any EMG activity in the arm; thus, the subjects made postural adjustments in anticipation of changes in their centers of gravity. In the hierarchical model of motor control, these types of behavior are thought to be part of the motor program.

Assessments of CNS dysfunction that focus on evaluating abnormal movement patterns and muscle tone are consistent with the hierarchical model because those problems are assumed to result from loss of higher level control. Similarly, treatment approaches that focus on inhibiting spasticity and abnormal movement patterns, facilitating a balance of tone between agonist and antagonist muscle groups, and eliciting a variety of selected movement patterns are consistent with the hierarchical model. Clearly, the neurodevelopmental approaches are influenced by this model.

The hierarchical model does not clearly answer several key questions generated by motor control research. First, how can treadmill locomotion of cats with transected spinal cords (Grillner, 1975; Shik & Orlovskii, 1976) be explained when the cats have no control of higher centers? Second, if voluntary and reflex levels are so distinct, why do so many voluntary movements appear similar to reflexive movements (e.g., throwing a baseball is similar to the asymmetrical tonic neck reflex) and why can reflex movements be modified volitionally by prior instruction (Hammond, 1956)?

One of the most important challenges to the hierarchical model was raised by the Soviet physiologist Bernstein (1967). He questioned how the many degrees of freedom of the body could be regulated systematically in varying contexts by the CNS. The degrees-of-freedom problem, as it has become known, refers to the large number of joints, planes of motion within each joint, muscles that control each joint, and single motor units within each muscle that need to be controlled separately to perform a motor task. Bernstein (1967) considered the hierarchical model to be uneconomical and unlikely explanation of how the motor system worked. He questioned how the CNS could control the many degrees of freedom of each movement without specifying the details of the muscle activation pattern. If the CNS does specify the details, each motor program would be extremely complex. To perform the numerous tasks that humans perform in everyday life, an extremely large number of programs would be needed, and to perform a given task in varied contexts would require an infinitely large number of programs. Several studies (Marteniuk, MacKenzie, & Jeannerod, 1987; Mathiowetz, 1992) have demonstrated that small changes in environmental context can result in unique movement patterns during simple reaching tasks. Thus, the environment plays a larger role in motor control than the hierarchical model suggests and an unlimited number of motor programs seem to be necessary to respond to varied contexts. Does the brain have unlimited storage capacity to accommodate all of the motor programs? The inability of the hierarchical model to answer these questions adequately has caused an increasing number of researchers to explore a systems model of motor control as an alternative explanation.

**Systems Model**

In the past 25 years, a new model of motor control has emerged that is based on systems or dynamical systems theory (Giuliani, 1991; Horak, 1991; Thelen, 1989; Thelen & Ulrich, 1991). This hierarchical (Crutchfield & Barnes, 1993; Horak, 1991) model represents a major change from the hierarchical models. It focuses on the interaction of a person with the environment. Task performance emerges from the unique characteristics of a person’s multiple systems interacting with unique task and environmental constraints (Newell, 1986). From this perspective, functional tasks and the environmental context are used to organize behavior. With use or modification of personal and environmental constraints, a person finds the optimal strategy to perform functional tasks.

In the systems model, the nervous system is only one system among many that influence motor behavior. The nervous system itself is organized heterarchically such higher centers interact with the lower centers but do not control them. Closed-loop and open-loop systems work cooperatively and both feedback and feedforward control are used to achieve task goals. The CNS interacts with multiple personal and environmental systems as a person attempts to achieve a goal. From this perspective, motor development is due to changes in multiple systems, not just maturation of the CNS.

When there is CNS damage, the person attempts to compensate for the lesion in order to achieve functional goals. Recovery from brain damage is a process of discovering what remains to perform tasks. From a systems perspective, the apparent use of abnormal patterns is evidence of attempts to use remaining systems to complete tasks. For example, clients with weak shoulder flexion will flex their elbows when trying to raise their arms, because that shortens the lever arm and makes shoulder flexion easier. Thus, muscle weakness is one factor contributing to abnormal flexor patterns seen in many clients with CNS damage.

The systems model has evolved from the ecological approach to perception and action and from the study of complex systems in biology, physics, and mathematics. The ecological approach to perception and action has been influenced greatly by Gibson’s (1956, 1979) ecological psychology, and Bernstein’s (1967) physiology of ac-
tion approach. The ecological approach emphasizes the study of the person–environment interaction during everyday, functional tasks and the close linkage between perception and action.

Gibson recognized the role of functional goals and the environment in the relationship between perception and action. He stated that direct perception involves the active search for affordances (1977), or the functional utility of an object, by a person with unique personal characteristics (Warren, 1984). Thus, Gibson’s concept of affordances explains the close relationship between perception and action in terms of what the information available in the environment means to a person.

The ecological approach also has been influenced by the 1997 translation of the writings of Bernstein. His ideas challenged the feasibility of hierarchical models of motor control by raising the problem of degrees of freedom that was discussed above. Bernstein also recognized the importance of the environment and personal characteristics other than the CNS in motor behavior. He suggested that the role a particular muscle plays in a movement depends on the context or circumstances in which it is used and termed this concept context-conditioned variability (Bernstein, 1967; Turvey, Shaw, & Mace, 1978). Bernstein (1967) identified three potential sources of variation in muscle function: anatomical (variations dependent on body position), mechanical (variations dependent on how forces are applied), and physiological (variations dependent on higher and lower levels of neural control). Nonmuscular factors (e.g., gravity, inertia) were also considered major influences on motor behavior (Bernstein, 1967).

Turvey (1977) and Reed (1982) synthesized the theoretical ideas originated by Gibson (1966, 1979) and Bernstein (1967) and proposed a more coherent theory coupling perception and action. Turvey (1977) used the concept of coordinative structures as a solution to the problem of degrees of freedom. Coordinative structures were defined as a group of muscles spanning several joints that are constrained to act as a single functional unit. Studies on locomotion have provided particularly strong evidence supporting coordinative structures (Grimmer, 1975; Shik & Orlovskii, 1976). The invariant features in locomotion, which those authors identified as coordinative structures, reduced the number of variables that needed to be controlled by the executive or higher centers of the brain.

Fitch, Tuller, and Turvey (1982) suggested that perceptual information—information from the environment—could modulate the coordinative structures without intervention from the executive. Perceptual information might be exteroceptive (i.e., information about the environment), proprioceptive (i.e., information about where the limbs are in relation to each other), or exoproprorceptive (i.e., information about where a person is relative to the layout of the environment) (Lee, 1978). Reed (1982) suggested that postures and movements were modulated as needed by updated perceptual information to achieve the functional goal. Thus, postures and movements were not triggered by external stimulation or central commands as suggested by the reflex and hierarchical models, but were coordinative structures capable of adapting to changing circumstances. In this way, the study of motor behavior or action evolved into the study of how perceptual information is used to modulate actions (Reed, 1982). Proponents of this view have looked to systems theory to explain the complex person–environment interactions.

In mathematics and the sciences, a new paradigm based on interest in complex, dynamical (nonlinear) systems has emerged (Gleick, 1987); these ideas are now being used to study and explain motor behavior (Giuliani, 1991; Thelen, 1989; Thelen & Ulrich, 1991). Dynamical systems theories propose that order and pattern emerge from the interaction and cooperation of many systems and that self-organization is evident in all phenomena (Thelen & Ulrich, 1991). Motor behavior then may be described as movement patterns that emerge from the interaction of multiple personal systems and performance contexts to achieve a functional goal. The concept of self-organization or emergence of movement patterns is not compatible with the assumptions of the reflex and hierarchical models. Self-organization is evident in the relatively stable patterns of motor behavior seen in many tasks despite the many degrees of freedom (Thelen & Ulrich, 1991). Dynamical systems then provide a solution to the degrees-of-freedom problem.

Thelen (1989) suggested that when personal subsystems interact in the environmental context to achieve a functional goal, the original degrees of freedom are compressed into one or several collective variables. The movement patterns that emerge for a given task in a given context are stable and are the preferred means of achieving the functional goal because they require the least amount of energy and are the most efficient (Kamm, Thelen, & Jensen, 1990). This pattern is referred to as an attractor “because the system falls into the pattern easily and returns to that pattern even when perturbed or interrupted” (Kamm et al., 1990, p. 770).

Like the ecological approach to perception and action, systems models emphasize the reciprocity between the person and the environment. The environment provides the context for the emergence of unique movement patterns and may be described in terms of subsystems involved in motor behavior.

Explanations of changes in motor behavior differ for the systems model and the earlier models. Thelen (1989) stated that an important characteristic of systems theories is that the shift from one attractor state (stable movement patterns) to another is marked by discrete, discontinuous transitions. These transitions in motor behavior occur as a result of changes in only one or a few personal
or environmental systems or subsystems (control parameters) (Davis & Burton, 1991). Thus, systems or subsystems themselves are subject to change. The systems model is hierarchical, however, because there is no inherent ordering of systems or subsystems in terms of importance or influence on motor behavior.

A proposed systems model of motor control using occupational therapy terminology (see Figure 4) illustrates the interaction between the personal characteristics, or systems of the person, and the performance context, or systems of the environment. Occupational performance (i.e., activities of daily living, work, and play and leisure) emerges from the interaction between personal characteristics (cognitive, psychosocial, and sensorimotor) and performance contexts (physical, socioeconomic, and cultural). Changes in any one of these systems can affect occupational performance and, consequently, role performance. In some cases, one primary factor might determine occupational performance. In most cases, occupational performance emerges from the interaction of many systems.

The subsystems that influence occupational performance may be framed in occupational therapy terminology. Strength, endurance, range of motion, coordination, sensory awareness, postural control, and perceptual skills are generally associated with the sensorimotor system. The psychosocial system includes a person's interests, values, self-concept, social interactions, and self-management skills that could affect occupational performance. Orientation, attention span, memory, and problem-solving skills are components of the cognitive system. The performance context includes physical, socioeconomic, and cultural characteristics of the task itself and the broader environment. The physical environment system includes objects, the natural and built environment, and the sensory environment, which could limit or enhance task performance. Societal beliefs, values, customs, and expectations are components of the cultural system that also could affect performance. Finally, the socioeconomic system includes family, friends, community and financial resources, and social supports that could influence choice and involvement in activities. These examples should clarify how components of each system are related to occupational performance.

In addition, any occupational performance affects the environment in which it occurs and the person performing. For example, a client with a closed head injury who has just become independent in dressing frees his spouse to spend more time with their children before they leave for school. Objects in the bedroom need to be accessible to enable that independence. Thus, the occupational performance of dressing affects the social and

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**Figure 4.** A systems model of motor control using occupational therapy terminology, emphasizing that occupational performance emerges from an interaction of personal characteristics and performance contexts. In addition, any occupational performance affects the environment and the person in return.
physical environment. It also affects the person. The performance of dressing gives the client the opportunity to solve problems, to discover optimal strategies for performing tasks, and to feel less dependent on his spouse. This influences the client’s cognitive, motor, and psychosocial abilities. This part of the model is downplayed to emphasize that occupational performance emerges from the interaction of the person and the environment.

Role performance is included in Figure 4 because it seems a natural extension of the model. However, it is also deemphasized because we believe its inclusion gives the model broader applications than are intended for this article. Because the systems model may be viewed in a more general way as it relates to occupational performance and role performance, this model may have applications to all areas of practice and to occupational therapy theory development. Similarly, it may serve as a foundation for a model of motor behavior in movement science. These possibilities are not explored further in this article.

Motor Development and Learning Theories

Traditional and Contemporary Developmental Theories

The traditional neuromaturational theory of motor development (Gesell, 1954; McGraw, 1945) has influenced the neurodevelopmental approaches to CNS dysfunction in various ways. The traditional theory suggested that changes in motor development were due to maturation of the nervous system, that is, changes in neural structures caused changes in motor function (Gesell, 1954). This theory implied that the environment played a minimal role in motor development. The heavy emphasis on neural maturation to explain changes in motor development had often been overlooked by occupational therapists; the theory implied that a child’s experiences and therapist’s interventions have little effect on motor development.

Developmental sequences were also an integral part of traditional developmental theory. Gesell (1954) proposed that development must progress through a particular sequence. Although he acknowledged that the rate of development of children was variable, he believed that the sequence was invariant and followed a particular direction: cephalocaudal sequence and proximal to distal sequence. Halverson (1931) added the ulnar to radial sequence in the development of prehension. Other developmental sequences have been described in terms of higher and lower centers of the CNS. In these sequences, higher centers gradually gain control over lower centers and regulate voluntary movement as the nervous system develops.

When traditional neuromaturational theory and its developmental levels are used as a guide in therapy, it is assumed that treatment must start at the client’s current developmental level. Developmental and reflex testing serve as primary assessment tools (Bobath, 1978; Fiori­tino, 1973; Knott & Voss, 1968; Rood, 1954). For treatment, it is assumed that a client must master the current developmental level before progressing to the next level (Rood, 1954). The normal developmental sequence becomes the organizing framework for therapy. Because most clients are at the lower levels of the developmental sequence, there is often little time for practice of higher-level functional tasks in therapy. If clients master the developmental sequence, these motor skills are assumed to generalize to task performance. There is also great concern that working on specific functional tasks would result in splinter skills that would not generalize and might interfere with a child’s progression through the developmental sequence. As a result, the development of movement skills has been emphasized at the expense of functional performance. Some of these concepts are still used in practice; others have been modified (see the paragraph below on contemporary developmental theories).

Traditional developmental theories have also been used to explain motor problems seen in adults with CNS damage. It is believed that CNS dysfunction frees lower centers from higher level control, resulting in a release of primitive reflexes and abnormal muscle tone (Bobath, 1978). Neurodevelopmental approaches focus on a progression through the developmental sequence, inhibition of primitive reflexes and spasticity, and facilitation of higher level control.

Traditional neuromaturational theory has many limitations. Contemporary theories of motor development suggest that changes over time are due to multiple factors or systems. Maturation of the nervous system is certainly one factor but there are others. For example, Thelen, Fisher, and Ridley-Johnson (1984) clearly demonstrated that the disappearance of the stepping reflex at about 4 to 6 weeks of age is due to multiple factors both internal and external to the child. Characteristics of the child (e.g., strength of leg muscles, weight of the legs, and level of arousal) and the environment (e.g., varying effects of gravity) contributed to these changes. Contemporary theories also suggest that normal development does not follow a rigid sequence (Touwen, 1976). In fact, children follow variable developmental sequences due to their unique personal characteristics and environmental contexts. Finally, the behaviors seen after CNS damage result from attempts to use the remaining resources to achieve occupational performance. For example, the flexor pattern of spasticity commonly seen after a stroke is due to various factors in addition to spasticity (e.g., inability to recruit appropriate muscles, weakness, soft tissue tightness, and perceptual deficits). If these traditional developmental theories are no longer sufficient as a guide for working with children with CNS dysfunction, then they are certainly not appropriate as a guide for working with adults (VanSant, 1991b).
Traditional and Contemporary Motor Learning Theories

Motor learning theories, like the developmental theories, have evolved over time. The traditional view of motor learning was that change in performance during practice reflected learning. Thus, any variable that enhanced performance during practice was considered important for improving motor learning. Research based on this assumption indicated that blocked practice (repetition of the same task) was better than random practice, physical and verbal guidance during practice was beneficial, and progression from part to the whole task was desirable for motor learning (Schmidt, 1988). Feedback that was more frequent, more immediate, more accurate, and more informationally rich was reported to be more effective in enhancing motor learning (Salmoni, Schmidt, & Walter, 1984). Some of the treatment approaches to CNS dysfunction incorporated this traditional view of motor learning. In muscle reeducation (Kottke, 1971), the repeated contraction of a specific isolated muscle is promoted to develop motor engrams. In some neurodevelopmental approaches, the repeated practice of specific movement patterns and tasks is promoted (Brunstrom, 1970; Knott & Voss, 1968).

The contemporary view of motor learning recognizes that many of the performance changes that occur during practice are only temporary and thus do not reflect learning. Schmidt's (1988) definition of motor learning reflected this thinking: "Motor learning is a set of processes associated with practice or experience leading to relatively permanent changes in the capabilities of responding" (p. 346). Contemporary research in motor learning assesses learning with transfer or retention tests, which are given after the temporary effects of the practice or acquisition phase have been allowed to dissipate. Consequently, they are thought to reflect permanent changes in the capabilities of responding. This type of research has demonstrated that random practice is better than blocked practice (Shea & Morgan, 1979). It has also been suggested that practicing parts of fast, discrete tasks or tasks with interdependent parts is less effective than practicing the whole task (Schmidt, 1991a).

Research on the role of feedback has suggested that physical and verbal guidance improves performance during practice, but may interfere with long-term motor learning (Schmidt, 1991a). It has been demonstrated that 50% feedback (feedback after half of the trials) is better than 100% feedback (Winstein & Schmidt, 1990), faded or decreasing feedback is better than increasing feedback (Schmidt, 1991b), bandwidth knowledge of results (feedback given when a response is outside a given error range) is better than 100% feedback (Sherwood, 1988), and summary feedback after multiple trials is better than immediate feedback after every trial (Schmidt, 1991b). Most of these results are the opposites of what one might expect and are opposite to the traditional view of motor learning. For a more detailed application of contemporary motor learning principles to occupational therapy, see Sabari (1991) and Poole (1991a, 1991b).

The contemporary research on motor learning has some limitations and should be applied cautiously in therapeutic settings. Most of the research has been done on subjects without disabilities in laboratory environments. Most of the tasks studied have been brief, novel tasks. Consequently, results may not generalize to subjects with disabilities performing functional tasks in natural settings. Most of the above research has been driven from a hierarchical–motor programming model of motor control, in which motor learning was believed to result in a centrally represented, generalizable motor program.

Higgins (1991) proposed an alternative framework for understanding motor skill acquisition based on a dynamical systems model of motor control. She suggested that persons are problem solvers who use their personal characteristics or resources to interact meaningfully and adaptively with their environments. "Problems are goals that arise as a function of an encounter between the individual and the surround [environmental context], occurring under an infinite variety of conditions across a life-span. Skill is the ability to solve problems with a degree of consistency and economy" (Higgins, 1991, p. 125). An economy of effort implies that skillful persons use the optimal biomechanical and physiological solution for a problem (Bernstein, 1967). If this is so, then therapists need to provide clients with opportunities to find optimal solutions for their functional problems. For this to be successful, the personal characteristics of clients (e.g., strength, endurance, range of motion, dexterity) may need to be maximized or the task or environment or both may need to be altered.

In therapy, clients need to learn how to analyze tasks relative to their own personal capabilities and to experiment with those capabilities to solve functional problems. The goal of occupational therapy is to help clients become competent problem solvers when they interact with various functional tasks and performance contexts.

Historical Overview of Approaches to Managing CNS Dysfunction

Muscle Reeducation Approach

This approach was developed by Sister Kenny for the treatment of clients with poliomyelitis in the 1940s and 1950s (Knapp, 1955). The goal of this approach was to develop motor engrams that represented "a pathway of interneuronal linkages involving activation of certain neurons and muscles to perform a pattern of motor activity in a specific sequence of speed, strength and motion" (Kottke, 1980, p. 553). Engrams were developed by the repetition of the correct pattern of muscular performance up to three million times (Crossman, 1959). Thus, motor
Neurodevelopmental Approaches

Neurodevelopmental approaches include Rood's (1954) sensorimotor approach, Knott & Voss' (1968) Proprioceptive Neuromuscular Facilitation (PNF), Brunnstrom's (1970) Movement Therapy, and Bobath's (1978) Neurodevelopmental Treatment (NDT). All of these approaches have been influenced by reflex and hierarchical models of motor control and by traditional developmental and motor learning theories. As a result, they share the following assumptions:

- CNS is hierarchically organized with higher centers in control of lower centers
- when CNS damage occurs, abnormal reflexes or lower level movement patterns and abnormal muscle tone are released
- peripheral sensory stimuli may be used by a therapist to inhibit abnormal reflexes and spasticity and to facilitate more normal movement patterns
- repetition of movement elicited by sensory stimuli results in positive, permanent changes in the CNS
- recovery from CNS damage follows a predictable, stepwise sequence progressing from cephalo to caudal; proximal to distal; and ulnar to radial.

Thus, neurophysiological rationales are used to explain normal motor behavior and the changes seen after CNS damage (Gordon, 1987).

There are a number of limitations to the neurodevelopmental approaches. First, inhibition of spasticity and abnormal reflexes does not necessarily result in normal movement and functional performance (Landa & Hunt, 1990). This fact has been most evident in clients who have had rhizotomy who continue to have movement disorders after spasticity has been surgically eliminated (Guarnieri, 1991). Clearly, inability to generate adequate force in a muscle—muscle weakness—and soft tissue contracture contribute to the movement disorders seen after CNS damage (Bourbonnais & Vanden Noven, 1989). These nonneural explanations of movement disorders are minimized for the most part by the neurodevelopmental approaches. Second, many environmental factors that affect functional performance are not emphasized due to the focus on neural explanations of motor performance (Horak, 1991). Third, clients tend to become passive recipients of treatment strategies chosen by the therapist, especially in the early stages of rehabilitation (Horak, 1991). Fourth, improvement in clients' motor control does not necessarily carry over to improvement in functional performance (Gordon, 1987; Horak, 1991). Because the criterion for successful rehabilitation today is improved functional performance, improvement in motor control is not an adequate measure of success in rehabilitation.

Motor Relearning Program

The Carr & Shepherd (1987) approach was developed to address the limitations of the neurodevelopmental approaches and in response to new ideas in the motor behavior literature. It is influenced by contemporary motor learning and skill acquisition theories and clearly rejects assumptions of the reflex model of motor control and of the traditional developmental and motor learning theories. However, this approach continues to use recent hierarchical models of motor control by emphasizing the relearning of motor programs and the role of cognition in treatment. In addition, its emphasis on the use of functional tasks and contexts in treatment draws from the systems model of motor control. Thus, this approach is viewed as a transition between the neurodevelopmental and task-oriented approaches.

A limitation of this approach is that it draws from two models of motor control that are considered incompatible by many current motor behavior theorists. In addition, the heavy cognitive emphasis used in this approach may make it difficult to use with clients having cognitive impairments. Nevertheless, Carr, Shepherd, Gordon, Gentile, and Held (1987) have made a contribution to the rehabilitation literature by critiquing current neurodevelopmental approaches and by using recent motor behavior literature to propose a new approach to treatment.

Contemporary Task-Oriented Approach

The contemporary task-oriented approach (Horak, 1991) emerges from a systems model of motor control (see Figure 1) and is influenced by contemporary developmental and motor learning and skill acquisition theories (see Figure 1). It is based on the assumption that the CNS is hierarchically organized. After CNS damage, clients' behaviors reflect their attempts to compensate for the
damage and to achieve functional performance. Thus, recovery from CNS damage is a process of discovering what remains to achieve task performance. Because each client’s personal characteristics and performance contexts are unique, the sequence of recovery will vary. Multiple factors may explain the behavioral changes seen after CNS damage as personal characteristics of clients (psychological, sensorimotor, and cognitive) interact with their performance contexts (physical, sociocultural, and economic). Moreover, functional tasks and performance context are assumed to help organize behavior (Kamm et al., 1990). Thus, varied practice is used to help clients discover optimal strategies for achieving functional performance (Higgins, 1991). More detailed evaluation and treatment strategies are being proposed (Bass Haugen & Mathiowetz, in press).

There are some limitations to this approach. Because it is still developing, evaluation and intervention strategies are still being developed and efficacy studies need to be done. It is difficult to simulate natural environments in many clinical settings. However, as therapy clinics are remodelled or new clinics are designed, more natural environments in the hospital settings can be created. In addition, it is difficult to simulate some work and leisure tasks in clinical settings. The latter two limitations suggest that therapy interventions should ideally occur in clients’ home, school, leisure, and work settings (Poole, 1991a). The increased pressure to shorten hospital stays and the increased development of community-based treatment programs should support this trend. Because this approach requires problem solving by clients, it might appear to be inappropriate for clients with cognitive impairments. However, it is argued that practice of real tasks of importance to clients should enhance occupational performance more than contrived tasks often used in clinical practice (Schmidt, 1991a).

Contrasting Neurodevelopmental and Contemporary Task-oriented Approaches

If a neurodevelopmental approach were used with a client with CNS dysfunction, evaluation would primarily focus on the sensorimotor and cognitive components of muscle tone, reflexes and abnormal movement patterns, postural control, sensation, perception, memory, and judgment (i.e., components thought most likely to be impaired as a result of CNS damage). Psychological components and environmental contexts would rarely be evaluated. Occupational performance areas would be evaluated secondarily, because any deficit in these areas is thought to result from impairments of the above components. Presumably, if the impairments of these components were remediated, occupational performance deficits would also be remediated (Mathiowetz, 1993). Recovery from CNS damage is assumed to follow the normal developmental sequence (Rood, 1954) or a sequence of recovery (Brunnstrom, 1970). Thus, determining a client’s stage of recovery is part of the evaluation.

Treatment using a neurodevelopmental approach focuses on remediating whatever components were identified as impaired on evaluation. Common treatment techniques include the use of various sensory stimuli to inhibit spasticity, abnormal reflexes, and abnormal movement patterns and to facilitate normal muscle tone, equilibrium responses, and movement patterns. These techniques frequently make the client a passive recipient of treatment. Often the normal developmental sequence is used as a framework for treatment, with clients expected to master lower levels before progressing to higher levels. In addition, tabletop activities and simulated tasks are used often to remediate any perceptual and cognitive deficits. If the treatment strategies are effective, any occupational performance deficits are also expected to be eliminated. If the treatment strategies are not effective, the approach becomes compensatory as clients approach discharge. In other words, clients are taught to use adaptive techniques or equipment or both to compensate for their occupational performance deficits.

If a contemporary task-oriented approach were used with clients with CNS dysfunction, evaluation would focus on occupational and role performance. Occupational therapists would collaborate with clients in determining which tasks were problematic and important to evaluate given the clients’ roles and environmental contexts. The therapists would observe clients performing selected functional tasks in varied contexts; this would provide information about the role of environmental context on performance as well as clues about the interaction of systems and subsystems that were contributing to functional deficits. Then, therapists would evaluate only those subsystems that were thought to interfere with functional performance. Because all subsystems are thought to contribute to occupational performance, nonneural factors would also be considered as potential causes of deficits in functional performance of clients with CNS dysfunction.

Treatment using a contemporary task-oriented approach focuses on helping clients find the optimal strategy for achieving functional goals. Therapists may alter task requirements or the environmental context to enhance performance (Burton & Davis, 1992; Davis & Burton, 1991). In addition, therapists may guide the remediation of subsystem deficits that interfere with functional performance. For example, if soft tissue contracture and muscle weakness interfere with function, treatment to elongate soft tissue and to strengthen weak muscles would be indicated. If the problems were lack of postural stability when standing on one leg and a bathroom environment that included a traditional tub, the physical environment could be modified to include grab bars and a bath chair to enable safe bathing. In current practice, this would be called a compensatory approach. Functional tasks in natural settings are used in treatment as much as
possible because their use is the most efficient method of enhancing functional performance. This is how a task-oriented approach to evaluation and treatment differs from a neurodevelopmental approach.

Conclusion

This article described a major shift in motor behavior research that is beginning to influence treatment approaches to CNS dysfunction. A historical overview of the models and theories of motor behavior and the traditional approaches to CNS dysfunction was presented. A task-oriented approach to CNS dysfunction based on a systems model of motor control and contemporary motor development and learning theories was introduced and contrasted with the neurodevelopmental approach.

We acknowledge that some of the neurodevelopmental approaches have started to incorporate contemporary motor behavior findings. We also recognize that some occupational therapists have always used a functional approach to treatment. Recent motor behavior research supports this focus on functional tasks. However, the proposed task-oriented approach is more than using functional tasks and is not equivalent to the functional approach as described by Jongbloed, Stacey, and Brigh- 

ton (1989). The systems model and contemporary task-oriented approach described in this article may provide a helpful conceptual framework to guide occupational therapy interventions for clients with CNS dysfunction. Research is needed to determine whether this approach is better than traditional approaches.

Abernethy and Sparrow (1992) have claimed that there has been a paradigm shift in theoretical models of motor behavior. This is true, then similar changes might be expected in therapeutic approaches to CNS dysfunction. There is beginning evidence of a major change in the physical therapy literature (Uister, 1991; Rothstein, 1991) and adapted physical education literature (Davis & Burton, 1991). We hope that this article will challenge occupational therapists to question the assumptions that guide their practice and to examine recent motor behavior literature.

Acknowledgments

The ideas for this article originated with a graduate seminar at the College of St. Catherine, St. Paul, Minnesota, and were presented with Nancy Flinn, OT, and Mary Morgan, OT, at the MOTA State Conference in Minneapolis, Minnesota in October of 1992. Undergraduate students helped develop some concepts. We thank Allen Burton, PhD; Jean Kalscheur, MS, OT; James McPherson, PhD, OT; Barbara O'Keefe, MS, OT; and Catherine Trombly, ScD, OT, for very helpful comments on an earlier draft of this manuscript.

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