Motor Learning Concepts Applied to Activity-Based Intervention With Adults With Hemiplegia

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This paper presents a framework for the integration of motor learning research findings with a neurodevelopmental treatment perspective. The importance of activity-based intervention is emphasized, and a strategy for activity synthesis is presented. Clinical problems seen in persons with hemiplegia are used to clarify concepts and illustrate therapeutic interventions.

The therapeutic value of activity has long been a philosophical assumption of the occupational therapy profession (Meyer, 1922; Willard & Spackman, 1947). Therapists still disagree, however, on the use of purposeful activity to improve motor function in persons with hemiplegia (Bissel & Mailloux, 1981; Clopton, 1981; Eliason & Gohl-Giese, 1979; Gohl-Giese & Eliason, 1986).

Motor learning research lends compelling support to the importance of task-related intervention for the improvement of motor control. The present article describes motor learning theories' support for the use of activity-based intervention to improve the motor performance of persons with hemiplegia. It further describes how motor learning concepts can be linked with the neurodevelopmental treatment perspective and presents a model for the synthesis of therapeutic activities for persons with hemiplegia.

Motor Problems and Motor Programs

Current research in motor learning has strong roots in theories initially proposed by Bernstein (1967), who emphasized a task-oriented view of motor performance and introduced the concept that purposeful movement is organized to solve motor problems. Motor problems are challenges to the neuromuscular system that arise from interaction with the external environment, such as maintaining balance when one's center of gravity is displaced (Lee, 1989; Manning, 1972) or determining the appropriate timing and sequence of muscle contractions to perform a given task (Bourbonnais & Vanden Noven, 1989).

Bernstein (1967) proposed the degrees of freedom problem, which refers to the number of individual components of a movement that are free to vary and thus need to be controlled. The steering of an automobile illustrates this concept (Turvey, Fitch, & Tuller, 1982). A car's steering wheel controls one degree of freedom, that is, movement to the left and right. Driving would be an extremely complex process if the four wheels of the automobile were free to vary individually. Instead of operating all four wheels together with one steering wheel, the driver would have to control four different steering wheels. Furthermore, the driver would constantly have to account for the possibility that certain combinations of the wheels' movements would block the car from moving at all.

The number of components that are free to vary during normal human movement is much greater than that for a hypothetical automobile with four steering wheels. The degrees of freedom of limb movements are commonly viewed as the number of planes through which a specified joint is free to move (Norkin & Levangie, 1983; Soderberg, 1986). In an upper extremity, the shoulder has three degrees of freedom; the elbow, an additional one degree of freedom; the wrist, an additional...
two degrees of freedom; two degrees of freedom at each of the metacarpophalangeal joints; and one degree of freedom at each of the interphalangeal joints (Norkin & Levangie, 1983).

Bernstein (1967) suggested that persons reduce the degrees of freedom by creating dependencies or linkages among muscular activities at various joints. This is analogous to the way the four wheels of an automobile are linked to respond to a driver's handling of the steering wheel. Various names are used to describe this linking strategy: coordinative structures (Turvey et al., 1982), muscle linkages (Bernstein, 1967), function generators (Greene, 1969), synergies (Bernstein, 1967), and action plans (Newell, 1978).

Muscle linkages are apparent in the kinesiology of all normal movements. For illustration purposes, normal shoulder abduction can be viewed as an example. As the deltoid, or prime mover, contracts, the supraspinatus and other rotator cuff muscles contract simultaneously to seat the humerus in the glenoid fossa. In addition, neural signals to the abductors and upward rotators of the scapula allow for normal scapulohumeral rhythm (Cailliet, 1980; Kapandji, 1970) to occur.

From this perspective, motor control is a person's ability to coordinate kinematic linkages that will limit degrees of freedom (Bernstein, 1967). Persons who are beginning to learn a new sport have not yet developed the ability to control the degrees of freedom in an efficient manner (Fowler & Turvey, 1978). One compensatory strategy is to curtail degrees of freedom by immobilizing some joints. An example of this strategy is a person's tendency to co-contract all the flexors and extensors of his or her trunk when attempting to ski or ice skate for the first time (Lemkuhl & Smith, 1985). A similar maladaptive strategy is seen in the person with hemiplegia who does not disassociate his or her pelvis from the lumbar spine or his or her scapula from the thorax.

Regulatory Conditions in the Environment

Environmental demands play a critical role in the determination of how people organize purposeful movements. In a given task, some environmental features will influence a person's choice of motor strategies. These environmental features are referred to as regulatory conditions. When one reaches for a glass of water, the size, shape, weight, and location of the glass as well as the nature of the sitting or standing surface are regulatory conditions. Nonregulatory conditions, such as the color of the glass or table, are irrelevant in terms of the movement organization required for achievement of the task goal (Gentile, 1972, 1987). A major concern in the occupational therapy process is the manipulation of a task's regulatory conditions to facilitate performance and encourage the development of specific skills.

One classification scheme for activities is based on features of regulatory conditions in the environment as they vary along two dimensions. First, the supporting surfaces and task objects may be either stationary or in motion. Second, the regulatory conditions may vary between one performance of the task to the next or remain unchanged between trials (Gentile, 1972, 1987).

The use of repetitive practice as a strategy for learning is effective only with closed tasks, or activities in which the regulatory conditions are stationary and do not vary over time. Most daily activities, however, require persons to adapt to changing regulatory conditions in different situations and at different times. For example, motor requirements for drinking beverages will vary depending on the type of mug, cup, or glass that is used as well as on how much the container is filled. Independent dressing requires that a person master the donning of clothing of varying fabrics, dimensions, and styles.

Tasks in which the regulatory conditions are in motion during task performance and that vary unpredictably during trials may be referred to as open tasks (Gentile, 1972, 1987). These activities require the appropriate timing of movements as well as spatial anticipation of where the relevant objects will be moving. For example, when sitting in a moving train, the passenger must maintain balance when the supporting surface is moving unpredictably. When crossing a street, one must anticipate the speed and rhythm of both pedestrians and oncoming traffic. When playing most ball games, one must predict the speed and direction of the ball in order to position oneself in the right place at the right time. Research has shown that the skills required for successful open-task performance cannot be learned through repetitive practice in a stationary environment (Higgins & Spaeth, 1972).

A major distinction of highly skilled performance in any task is the ability to perform the skill in a number of different ways, according to variations in environmental demands (Summers, 1989). Often in rehabilitation therapy, patients are asked to perform one or two movement patterns repetitively, with the goal of improving motor performance. Persons with hemiplegia need opportunities to practice skills in situations with varying regulatory conditions so that they can develop motor schemata that are versatile enough to meet the situations they will encounter in their daily lives.

Open- and Closed-Loop Modes of Motor Control

Closed-loop and open-loop systems are engineering concepts that are useful in describing how normal movement is controlled (Adams, 1971; Keele, 1982; Kelso, 1982; Trombly, 1989). A closed-loop, or feedback, system is dependent on the recognition and correction of errors in performance.

Figure 1 illustrates a closed-loop model of motor control (Keele, 1982). A movement generator in the cen-
Central nervous system sends efferent output to appropriate muscles. Kinesthetic and other feedback is received by a comparison center, which compares the feedback with previously stored sensory information associated with that motor activity. The comparison center then notifies the movement generator as to which corrections need to be made. Feedback mechanisms are useful when performing exploratory movements in unfamiliar environments. If all movement was dependent on the detection and correction of errors, however, human motor behavior would be extremely slow and inefficient.

In an open-loop, or feed-forward, system, instructions for action are prepared in advance and carried out without modification from feedback. All parameters of the movement are specified in the motor command, and the movement is carried out to completion without alteration. Open-loop control of movement is accomplished through the use of motor programs, which are sets of prestructured commands that execute movement without requiring peripheral feedback (Brooks, 1986; Rosenbaum, 1985; Summers, 1989).

Figure 2 illustrates an open-loop model of motor control. Motor centers send efferent output to muscles without requiring proprioceptive or other peripheral feedback. Simultaneously, the motor center sends a copy of the motor command, or efferent copy, to an internal monitoring system. Based on previous learning, the monitoring system detects errors in the plan before the movement has been executed, and corrections are made in the motor program before any errors are made. Open-loop control requires that a person's central nervous system be able to predict the consequences of a movement and compensate to avoid errors, rather than awaiting the consequences and reacting to them. Normal postural control is maintained with a feed-forward mechanism (Nashner & McCollum, 1985) and is most efficiently learned or relearned in the context of task performance (Carr & Shepherd, 1987a, 1987b).

Motor Memory

Motor memory is stored sensory information that is associated with a motor activity and that reminds a person what specific movements should feel like. All persons have memory traces (Smyth, 1984; Stelmach, 1982), or efference copies (Jones, 1974), for movements they perform frequently and skillfully.

Findings from studies examining how persons with normal movement recall specific discrete arm movements after short intervals (Smyth, 1984) indicate that subjects recall a movement most efficiently when they have had an opportunity to actively control all aspects of the initial movement. This includes the preliminary planning and initiation of the movement, its execution, and its termination (Jones, 1974; Kelso, 1977; Smyth, 1984). Roy and Diewert (1975) proposed that the encoding strategy used to store the sensory information associated with a given movement will determine how successfully that movement can be remembered. Active planning, execution, and termination of a movement sequence enable a person to code the movement-related kinesthetic and visual information most efficiently.

Two other factors have been found to influence the ability to encode motor memory traces. The first factor is the context in which the movement is initially produced. If a movement sequence is performed as part of a specific task performance, it is encoded more efficiently than if the movement is learned outside of an environmental context (Smyth, 1984). The second factor is that due to differences in cognitive style, persons may vary in which type of motor training will best enable them to develop...
encoding strategies for motor memory traces (Anshel & Ortiz, 1986). These findings clearly support the use of meaningful activities in occupational therapy intervention designed to assist patients in improving motor control.

**Application of Motor Learning Concepts to Clinical Intervention With Adult Hemiplegia**

When viewed from the perspective of motor learning concepts, some major problems in adult hemiplegia are (a) ineffective or absent motor programs, which leave the person with an unmanageable number of degrees of freedom to control; (b) impaired motor memory; (c) impaired feedback mechanisms; (d) and impaired feed-forward mechanisms.

Persons with ineffective or absent motor programs have lost the coordinate structures that previously guided their functional movements. Normally, when a person wants to reach forward to grasp an object, the central nervous system calls forth a movement pattern that includes scapular abduction and upward rotation as well as shoulder flexion. Additionally, wrist extensors contract to establish optimal mechanical efficiency for the finger flexors (Norkin & Levangie, 1983; Soderberg, 1986). Persons with hemiplegia cannot rely on an automatic generation of these complex muscle linkages, and each attempt at movement presents the challenge of coordinating an unmanageable number of degrees of freedom.

Impairments in motor memory limit a person's ability to remember what functional postural alignment or movement should feel like or to remember newly relearned motor sequences for future use (Bobath, 1979). Many occupational therapists use neurodevelopmental positioning and handling techniques to provide patients with reminders about postural alignment and functional movement patterns. The patient's ability to establish memory traces of relearned movement sequences will be maximized if the movement is performed in an environmental context (Smyth, 1984) and if the patient is challenged by the therapist to actively plan, initiate, execute, and terminate the motor sequence (Carr & Shepherd, 1987a; Roy & Diewert, 1975).

Impaired feedback is a common problem in persons with hemiplegia who have deficits in proprioceptive sensation, motor memory, or both. Knowledge of performance and the ability to correct errors that have occurred are critical components in the learning of new motor skills (Sachs, 1980; Schmidt, 1988). Therapists can assist persons with hemiplegia by helping them gain insights about the effectiveness of the movement components they choose for accomplishing specific tasks (Brooks, 1983, 1986).

Persons with hemiplegia who have impaired feed-forward mechanisms are unable to plan which postural adjustments will supplement an intended movement. To perform the simple act of standing up, persons must posturally set themselves in several ways. Both feet must be positioned on the floor in an appropriate base of support. Perpendicular angles are established at the ankle, knee, and hip joints, and the pelvis is tilted anteriorly to free the lumbar spine for forward movement (Carr & Shepherd, 1987a; Davies, 1985; Kovich & Bermann, 1988).

When standing, people automatically change the configuration of their bases of support in anticipation of the direction toward which they expect to shift their body weight. If they plan to shift forward, as in bowling or throwing, they will establish an anterior–posterior base of support. If they plan to shift to the left or right, as in a tennis swing, they will establish a medial–lateral base of support. Persons with hemiplegia often assume postural support bases that are inappropriate to the activity in which they are preparing to engage.

Prior to the onset of motor activities, widespread changes may be observed in the muscular organization of persons with intact central nervous systems (Brunia, Haagh, & Scheirs, 1985). These feed-forward adjustments prepare the person for performing the selected activity and also preclude performance of other movement patterns. Postural sets, then, are one way in which a person can reduce the degrees of freedom, or number of decisions that need to be made, when executing a movement pattern. Postural adjustments occur simultaneously with the plan to move. During efficient task performance, persons predict how movements will affect their centers of gravity. Well-organized postural adjustments prevent major displacements in the center of gravity through a feed-forward mode of control.

Postural adjustments can be learned only in the context of task performance (Carr & Shepherd, 1987a, 1987b). Neurodevelopmental treatment handling strategies can provide patients with the feeling of what a normal postural adjustment should be. The ability to respond to displacements that are applied by a therapist, however, requires different skills than does the ability to generate appropriate postural adjustments when initiating an activity involving weight shift. It is most appropriate, therefore, for therapists to apply handling while a patient engages in actual tasks instead of during artificial displacements that are imposed on the patient.

The characteristic limb synergies demonstrated by persons with hemiplegia have been documented by Brunstrom (1970) and Twitchell (1951). Although some theorists view these abnormal movement constellations as direct results of cerebrovascular accident or head trauma, others (Bobath, 1979; Carr & Shepherd, 1987a, 1987b; Davies, 1985) believe they are compensatory strategies that persons with hemiplegia develop as they attempt to move. Neurodevelopmental treatment practitioners have identified several blocks to normal movement in children and adults with neurological dysfunction (Bly, 1983). Some blocks that serve as obstacles to movement in adults with hemiplegia are (a) an inability
to disassociate the scapula from the thorax (Cailliet, 1980; Ryerson & Levit, 1987) or the pelvis from the lumbar spine (Kovich & Bermann, 1988), (b) weakness of specific muscles (Bouwbronnais & Vandennovren, 1989; Davies, 1990), (c) an inability to counteract gravitational forces (Boehme, 1988), (d) abnormalities in muscle tone (Davies, 1985; Eggers, 1984), and (e) incorrect timing of components within a movement pattern (Carr & Shepherd, 1987a). When a person attempts to move and encounters these blocks, the natural reaction is to compensate with whatever motor strategies are available.

Carr and Shepherd (1987a, 1987b) applied traditional occupational therapy concepts along with motor learning principles in a motor relearning program. In the program, evaluation is administered in the context of task performance. The therapist analyzes the patient's performance of a specific task and compares it with the normal kinesiology associated with that task. As in the neurodevelopmental treatment approach, a major focus of this analysis is to identify the blocks to normal kinesiology. In the case of a person with hemiplegia who is trying to reach forward to grasp for a cup, he or she may tend to use the entire shoulder girdle as one tightly bound unit, instead of disassociating the scapula from the thorax or the humerus from the scapula.

Intervention strategies are directly determined from this task analysis. In the above example, the therapist will direct the patient's attention to the lack of mobility between structures at the shoulder girdle. The patient will then practice reaching forward in a variety of contexts while the therapist provides verbal and visual instructions as well as manual guidance. The manual guidance strategies suggested by Carr and Shepherd (1987a, 1987b) can be complemented with neurodevelopmental handling techniques to biomechanically mobilize the scapula and constrain inappropriate movements.

The next step in the motor relearning program is for the patient to directly practice the original task. Finally, the task is attempted in a variety of contexts. The cup may be placed in a sink, on a counter, or on a dishwasher rack. In each situation, the patient is an active participant in determining which movement variations will be most effective for accomplishing the goal. The goal of the program is to teach persons with hemiplegia to develop problem-solving strategies rather than to train them to perform specific motor skills.

Several of the therapeutic guidelines in the motor relearning program are inherent to the use of purposeful activities in occupational therapy practice (Cynkin, 1979; DiJoseph, 1982; Fidler & Fidler, 1978, Hinogosa, Sabari, & Rosenfeld, 1983). Therapists must select motor tasks with goals that are clear, relevant, and worthwhile in the eyes of the patient. The selected tasks must be reasonably hard, yet attainable. A major role of the therapist is to structure regulatory conditions in the environment so that the above criteria are met by each activity.

Application to Activity Synthesis in Occupational Therapy

Occupational therapy's emphasis on the therapeutic use of purposeful activities provides occupational therapists with the unique ability to develop therapeutic tasks that incorporate motor learning concepts. Activity synthesis is the creative design of an activity that suits the needs of an individual patient and his or her therapeutic program (Mosey, 1981).

Figure 3 illustrates a model that occupational therapists can use to include motor learning concepts when synthesizing therapeutic activities. Using this model, occupational therapists develop therapeutic activities by considering which task requirements are most appropriate for each patient and which regulatory conditions in the environment may be adapted to best elicit the selected task requirements. Successful performance of functional activities requires the person to remember and generate efficient, appropriate motor programs as well as to selectively use feedback and feed-forward mechanisms to guide performance. Because these subskills are theoretical constructs that are difficult to assess behaviorally, it is useful to consider the following task requirements when planning intervention.

![Figure 3. Strategy for synthesizing therapeutic activity.](http://ajot.aota.org/pdfaccess.ashx?url=/data/journals/ajot/930282/ on 11/30/2018 Terms of Use: http://AOTA.org/terms)
Postural set. All tasks require that persons posturally set themselves in preparation for performance, including establishing an appropriate base of support, shifting one's center of gravity, and choosing postural alignments that will allow for stability in some body segments and mobility in others. Many persons with hemiplegia fail to succeed in motor tasks because they choose inappropriate postural sets. Failure to rotate the pelvis into an anterior tilt in preparation for forward reach will prevent a person from achieving necessary mobility in the hips, trunk, and scapula. Faced with these constraints, many persons with hemiplegia choose ineffective compensatory strategies in their neck and arms. Failure to establish a medial-lateral base of support when activity requires weight shift or reach to the side will impair a person's balance when performing that task. In dressing tasks such as putting on socks or slacks from a sitting position, if the person does not preset the pelvis in a posteriorly tilted position, he or she will find it virtually impossible to achieve the degree of hip and knee flexion required. Therapists can assist persons with hemiplegia to appreciate the importance of postural sets. By focusing on the postural set aspects of each activity presented, patients can develop their own problem-solving strategies for choosing appropriate postural sets for future activities they wish to perform.

Postural adjustments. Performance of appropriate postural adjustments is another universal task requirement. Advocates of neurodevelopmental treatment identified the importance of righting responses and equilibrium reactions during movement (Bobath, 1971; Manning, 1972). Although righting and equilibrium reactions have traditionally been defined as muscular contractions that occur in response to shifts in one's body alignment or center of gravity, motor learning theory indicates they are adjustments rather than responses (Keshner, 1981). As people prepare to move, they anticipate how their centers of gravity will shift. If the central nervous system predicts an anterior weight shift, posterior musculature is recruited in an equilibrium adjustment that will prevent the body's center of gravity from falling in front of its base of support. When postural adjustment mechanisms are impaired in persons with hemiplegia, the slightest limb movement may cause postural insecurity or loss of balance.

Trajectories of body parts. Task performance requires movement of the eyes, head, trunk, and limbs in paths, or trajectories, that will efficiently contribute to accomplishment of the task goal. Because persons with hemiplegia often move in patterns that are biomechanically inefficient, the therapist should have a clear idea of the variety of movement pathways that will be appropriate for accomplishment of the selected activity. If the activity is standing up from a chair, the therapist will encourage the patient to flex at the hips, instead of at the trunk, and may cue the patient to move the head and neck in a trajectory that will complement the total effort rather than inhibit it (Davies, 1985; Eggers, 1984). Limbs may be most effectively used in a closed kinematic chain, as in supporting body weight, or in an open kinematic chain, as in moving freely in space (Davies, 1985; Norkin & Levangie, 1983; Ryerson & Levit, 1987).

Other task requirements. The speed with which a movement sequence is performed and the speed changes required of specific body parts are often critical to successful task performance. In addition, incorrect timing of muscle activation may be as disruptive to a movement pattern as the inability to elicit that muscle contraction. In many persons with hemiplegia who move in an abnormal flexor synergy pattern (Brunnstrom, 1970), the problem with the external rotators of the shoulder is not that they do not contract, but that their activation is elicited at the wrong time in the forward reach sequence.

The presence of gravity and other forces during functional tasks requires the elicitation of concentric, eccentric, and isometric contractions. Many persons with hemiplegia require therapeutic intervention to assist them in recruiting appropriate types of contractions in muscles at the right time during a motor sequence.

Finally, it is important to consider if an activity is a closed or open task (Gentile, 1972, 1987). If it is truly a closed task, then repetitive practice with consistent goal objects is a suitable intervention strategy. If, however, the activity is an open task, regulatory conditions in the therapeutic environment must be varied during and between treatment sessions.

The remaining components of the strategy illustrated in Figure 3 represent regulatory conditions that can be manipulated to influence the task requirements.

Regulatory Conditions

Supporting structures. Supporting structures can vary in several ways. The shape and weight of a seat, standing support, or bolster will directly influence which postural adjustments will be most effective for task performance. The base of support may be wide or narrow, and it may be established along a continuum from a medial-lateral direction to an anterior-posterior direction. The degree of support may be easily adapted through the provision of appropriate amounts of back support, lateral support, or both. Finally, the therapist may choose a supporting structure that is stationary, as in a stable seat or standing surface, or moveable, as in a therapy ball or tilt board or an office chair on wheels.

The therapist. The therapist may also be viewed as a regulatory condition to a patient's task performance. Occupational therapists vary their handling, or manual guidance, in several ways. The location may be proximal or distal and it may be directed toward specific "key points of
control" (Bobath, 1979, p. 60). The degree of handling may be graded from significant support and guidance to mild cuing. The nature of the handling itself may also vary. At one moment, the therapist may choose primarily passive movement. At another moment, the major purpose will be to limit inappropriate or extraneous movements. Still another type of handling is when the therapist guides the patient's movement along a specified trajectory. In addition to handling, the therapist may provide verbal instruction, visual demonstration, and feedback.

**The goal objects.** The goal objects, or tools, with which the patient will interact can be adapted according to size, shape, weight, and texture (Hopkins & Tiffany, 1988; Trombly, 1989). Their position in relation to the patient will significantly influence which movement patterns and postural adjustments will be required for task performance (Hinojosa et al., 1983). In many ball activities and computer games, goal objects are moving during task performance. This requires the patient to anticipate the speed and direction of the object's movement and introduces the demands of open-task performance (Gentile, 1987).

**Other objects in the environment.** Other objects in the environment may introduce additional regulatory conditions. For example, if the activity goal is independent wheelchair mobility, the presence of obstacles or other moving persons will place demands on the patient's spatial and temporal planning in an open-task context (Gentile, 1972, 1987).

All of the above regulatory conditions will influence the task requirements of a person with hemiplegia as he or she attempts to accomplish an activity goal. Choices of activity goals are infinite and are determined by the patient's expressed interests and current capacities. Activities used in occupational therapy intervention with persons with hemiplegia may be as simple as wiping a countertop with a sponge or as complex as creating a craft project. Therapists should not overlook the fact that basic tasks of daily living, such as removing a sock or getting out of bed, can be powerful therapeutic activities when presented in terms of the above described model for activity synthesis. Small components of a larger activity, such as getting necessary crafts or cooking supplies from a shelf or setting up materials on a game board, can provide important opportunities for therapeutic intervention. The ultimate goal in using a motor learning approach in occupational therapy is to assist persons with hemiplegia to develop their own strategies for effective movement in relation to objects and structures in their environments.

**References**


