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Applying principles of motor learning and control to upper extremity rehabilitation

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Abstract

The purpose of this article is to provide a brief review of the principles of motor control and learning. Different models of motor control from historical to contemporary are presented with emphasis on the systems model. Concepts of motor learning including skill acquisition, measurement of learning, and methods to promote skill acquisition by examining the many facets of practice scheduling and use of feedback are provided. A fictional client case is introduced and threaded throughout the article to facilitate understanding of these concepts and how they can be applied to clinical practice.

Keywords

Motor Learning; Motor Control; Hand; Upper extremity; Rehabilitation

The challenge of achieving hand and arm skill given neurological disease or injury may be met by weaving key concepts of motor learning and control into treatment protocols. However, in order to effectively integrate these concepts into hand rehabilitation programs, motor learning and motor control strategies need to be better understood. The purpose of this review is to outline key principles of motor learning and motor control that can be used to foster skill acquisition in upper extremity (UE) rehabilitation. To illustrate the application of these principles for individuals with neurological conditions, we will consider the case of “Joan”, a 38 year old female who sustained a traumatic brain injury that led to left UE hemiplegia (see Table 1).

MOTOR LEARNING AND CONTROL

The attainment of motor skills involves a process of motor learning¹ whose principles integrate information from psychology, neurology, physical education, and rehabilitation

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research. Together these disciplines shape our understanding of how individuals progress from novice to skilled motor performance throughout the lifespan. Infants learning to reach and grasp use the perceptions they have of their own body and abilities to secure objects of various shapes and sizes. Older adults must often accommodate to the gradual loss of strength and sensory changes that occur with aging, to modify how they perform manipulation tasks. Individuals with neurological conditions that affect UE function may need to *relearn* previously acquired motor skills with an altered number and quality of resources available to them.

Systems Model

Motor control theories provide a framework to guide the interpretation of how learning or re-learning movement occurs. Perspectives in motor control are based on evolving models of the nervous system and represent the paradigm shifts that have taken place throughout history. Historically, when the concepts of an existing paradigm begin to limit the way movement and behavior are interpreted, new paradigms are developed.² For example, in the early 1900's voluntary movement was thought to occur through reflex linkages.³ This paradigm led to numerous theories of motor control that have been replaced as knowledge of the nervous system expands. Although the assumptions associated with varied motor control theories differ, most current theories have incorporated a Systems view of distributed control of the nervous system. A Systems model suggests that movement results from the interaction of multiple systems working in synchrony to solve a motor problem.⁴ The advantage of the Systems model is that it can account for the flexibility and adaptability of motor behavior in a variety of environmental conditions. Functional goals as well as environmental and task constraints play a major role in determining movement.⁵ This frame of reference provides a foundation for developing intervention strategies based on task goals that are aimed at improving motor skills.

To exemplify how movement problem are solved, consider our case, **Joan**, as she attempts to don a shirt while sitting at the edge of the bed. To be successful, she must learn how to solve this motor problem with the constraints imposed by her brain injury. A Systems model of control suggests multiple factors, both internal and external to **Joan**, need consideration when she performs this functional movement. Internal factors may include strength, flexibility, coordination, pain level, motivation, cognition, autonomic function, and sitting balance at a minimum. External factors may include the type of shirt, firmness of the bed, the type of floor surface, the availability of assistive devices, and outside distractions. In order to complete the task of upper body dressing all available systems must work together to produce a single strategy.

Degrees of Freedom Problem

Producing a single optimal strategy for movement presents a significant problem to the nervous system. Nikolai Bernstein, a nineteenth century Russian neurophysiologist who challenged the contemporary reflex theories of movement that dominated his field, pioneered the concept of multiple systems working together to create movement. He argued that to perform smooth and efficient voluntary movement one must overcome the *degrees of freedom problem*.⁴ Bernstein recognized that when multiple systems interact, there are vast movement options (degrees of freedom) available *to perform the same action*. For example, **Joan** could reach for a cup on a table in front of her by flexing her shoulder and extending her elbow *or* she could keep her arm close to her body and flex at the trunk to bring her hand to the cup. This redundancy takes place at multiple levels within the CNS. For example, muscles can fire in different ways to control particular movement patterns or joint motions. In addition, many different kinematic/movement patterns can be executed to accomplish one specific outcome or action. A healthy individual can don a shirt by initiating the action with

one arm or the other or even both arms at once— each strategy accomplishes the same dressing goal.

Bernstein⁴ has suggested that a key function of the CNS is to control redundancy by minimizing the degrees of freedom or the number of independent movement elements employed. The resolution to the degrees of freedom problem will vary depending on the characteristics of the learner as well as the components of the task and environment. For **Joan**, shoulder pain may increase the likelihood of co-contraction to stabilize her body against undesired movement as she attempt to don the shirt. Her impulsivity and lack of insight might make her less likely to appropriately restrain the degrees of freedom during her initial attempts at dressing. Thus, during the early stages of learning how to dress her upper body, **Joan** may produce very simple movements and limit the amount of joint motion by holding some joints stiffly via muscle co-contraction.⁶ This action decreases the degrees of freedom allowing for greater success. As the task is learned, **Joan's** muscle co-activation may decrease. As her skill improves, she may exhibit greater fluidity, reflecting the ability of the CNS to use multiple motor resources to accomplish select tasks.

Dominant Theories

The question of how specific movement patterns are selected out of the vast number of options available has a major influence on how therapists intervene. Many theories have developed describing how multiple systems might come together to produce a functional movement. However, two distinct classes of theory have dominated the discussion for more than forty years. The first focuses on central control of movement instructions (e.g., Motor Program Theory [MPT]) and the second on dynamic self-organization of multiple sub-systems around a meaningful goal (e.g., Dynamic Pattern or Dynamical Systems Theory [DST]).

Motor Program Theory initially suggested that some form of neural storage of motor plans took place⁷ and that these motor plans were retrieved as needed to achieve motor goals. Three major issues arose around the ability of MPT to adequately explain voluntary movement; a storage problem, a novelty problem, and the problem of motor equivalence. The storage problem is the result of the huge repertoire of human movements. Where are the motor plans for the movements stored? It would seem there would need to be an infinite storage capacity in the nervous system to contain all the plans necessary for the variety of movement available. The second issue, the novelty problem, addresses the ability to plan new actions. How is there a program for a movement that has never been performed before? Finally, there is the issue of motor equivalence --the same action can be accomplished using different patterns of coordination. How is this possible if the action is the result of a program?

Some of the issues outlined above in MPT have been addressed with the generalized motor program (GMP) theory proposed by Schmidt.^{8,9} In his work, Schmidt argues that motor programs do not have to be specified for every action. Rather, there are generalized programs that contain rules for a large class of similar actions. This minimizes the storage needs, accounts for novelty (new actions are merely versions of other actions previously performed and, therefore, part of an existing class of movements), and explains motor equivalence by arguing that rules of a GMP are not muscle specific; rather there are *invariant features* that the program specifies, including timing and force coordination. These invariants help define classes of movement and minimize the absolute amount of information that must be stored.

Conversely, DST proposes that rather than a sequence of motor steps that are “stored”; movement is an emergent property¹⁰ occurring as the neuromuscular system interacts with

the environment; an online adaptation specific to the task at hand.¹¹ In DST, physical movement is constrained by characteristics of the individual (size, cognition, motivation, etc.), environment (light, gravity, etc.), and task (goals, rules, etc.).¹² Although the CNS is still necessary for initiating movement and monitoring ongoing movement for error, it is just one subsystem responsible for the eventual motor output. An assumption of DST is that while certain movement patterns are preferred they are not obligatory and, therefore, new patterns of movement can emerge when there is a shift somewhere in the system.¹³ This is an attractive idea when working with patients as changes in their body structure (e.g., hemiparesis of one arm) would represent a “shift in a sub-system” allowing for a new adaptive motor pattern to emerge. Providing opportunities in clinic and home programs for the emergence of new patterns would exemplify use of the DST perspective.

It is not clear whether one theory will prevail or a compromise of these two theories will evolve that better answers how movement occurs. Bernstein⁴ suggested that the *outcome* of a movement is represented in a motor plan (e.g., aiming a ball toward a target), and distributed at different levels of the CNS. This is a concept that many theories have adopted. Although the specific organization of motor plans is not known, flexible neural representations of the dynamic and distributed processes through which the nervous system can solve motor problems seem to exist.^{14–16} A motor program has evolved into an abstract representation of a movement that centrally organizes and controls the degrees of freedom.¹⁷ Learning comes from an interaction and strengthening among multiple systems and there may be strong neural connections between related systems that can be crudely viewed as representations. This internal representation needs to be matched to the external environment and functional movement likely emerges as a result of this interaction.

SKILL ACQUISITION

Skilled actions are those that demonstrate *consistency, flexibility and efficiency*. *Consistency* refers to the repeatability of performance – is the individual able to perform the task consistently over a period of trials conducted over a number of sessions? For example, can **Joan** sit for a sustained period, repeatedly? *Flexibility* (transferability) refers to the ability to adapt and modify task performance based on changing environments or conditions. For instance, can **Joan** maintain her sitting balance on various surfaces when buttoning her shirt? *Efficiency* usually pertains to the capabilities of the cardiovascular and musculoskeletal systems. Can **Joan** maintain a sustained sitting position without becoming exhausted or does an extended period of sitting limit her activity for the rest of the day? It is important to realize that performance of an activity indicates that one has attained that skill; however, within any motor task people can possess various levels of skill.

Stages of Skill Acquisition

In the early part of **Joan's** recovery, her movements may be poorly controlled and her movement goals may be simple and limited. For example, **Joan** may knock over cups when attempting to grasp or may need to focus on donning a pullover shirt rather than one that requires fastening. As she begins to recover **Joan** may exhibit a larger repertoire of movements and move with less effort or greater efficiency. These attributes exemplify **Joan's** progression through stages of skill acquisition. As clinicians, we must determine where individuals are struggling along the learning continuum so we can target our interventions appropriately. Although various stages of learning have been proposed, a two-stage model proposed by Gentile¹⁸ introduces key components for clinicians to consider when designing intervention strategies.

In Gentile's model, there are two objectives for the *initial* stage of learning: (1) to learn the basic movement pattern needed to achieve the goal; and (2) to identify components of the

environment important to the task. Gentile further classifies environmental characteristics into regulatory and non-regulatory features. Regulatory features of the environment include all aspects necessary for successful performance of the task. Thus, when donning a shirt while sitting at the edge of the bed, **Joan** must consider the texture of the shirt, the size of the openings for the arms and the head, the buttons and button holes, the firmness of the bed, the height of the bed, the surface of the floor, and presence or absence of bed rails to use for support. Non-regulatory features are those aspects of the environment that are present – and may even be distracting – but are not integral to performance of the task. In our example, the color of the shirt, presence of a roommate, and sound in the hallway are all non-regulatory features. Even though the features may alter the way the movement ultimately is produced **Joan** does not need to attend to these characteristics to put on her shirt.

When they are in the initial stage of learning individuals should be encouraged to actively explore the environment through trial and error. This stage is a period in which the basic dynamics of movements are experienced and new strategies are tested within the limits of patient safety. It is often considered a cognitive stage as performers must solve a series of problems experienced as they try various movements. It is important to note that even those with cognitive deficits should be provided with opportunities to strategize ways to complete a movement without over instruction. Therapists can aide learning by structuring the environment to maximize regulatory features and minimize non-regulatory features as individuals actively search for appropriate movement strategies.

Once a coordinative pattern develops that allows for some degree of success, and the performer is able to distinguish between regulatory and non-regulatory features of the environment, the later stage of learning begins. During this phase of refinement the focus switches from “what to do” to “how to do” the movement better.¹⁷ Thus, this *later* stage of learning is characterized by a less cognitive process of consolidation in order to improve motor efficiency and movement flexibility (e.g. the ability to perform the task under different conditions).

It is important to remember that learning is not linear. Instead motor performance follows the ‘power law of learning’ with large improvements noted during early practice and smaller rates of improvement displayed as practice continues.¹⁹ We often see periods of great improvement followed by plateaus or even regression in our patients. During these periods it is possible that, while performance appears worse, *learning is still occurring*. During the off periods individuals may be fatigued or have decreased attention or they may be attempting new strategies to perform the task. However, evidence suggests that memory consolidation for long-term storage continues during performance plateaus and plateaus are followed by new periods of observable improvement.²⁰

Explicit vs. Implicit Learning Processes

Gentile²¹ has suggested that motor skill learning involves two parallel yet distinct learning processes, *explicit and implicit*, complementing the stages of learning discussed above. Although these two processes change at different rates, and appear to take place in different stages, they overlap during skill learning. During *explicit learning* the performer's focus is on attainment of the goal as in the initial stage of learning. In an attempt at early success, the performer develops a “map” between their body structure and the conditions within the environment.

Initially, **Joan** must understand the movements she can make with her limited ROM and strength to determine how her body can achieve the goal of sitting in bed or transitioning from sit to stand. She must attend to changes in her movement's shape/structure and its relationship to external conditions and demands as she attempts to problem-solve through

tasks. The therapist may need to provide simple, relevant cues to assist with problem solving due to **Joan's** attention deficits. Whenever movement patterns can be consciously adapted by the performer they are considered to be regulated by *explicit* processes.²² However, success at achieving a task goal does not necessarily imply that movement performance is efficient.

During extended practice in the later stages of learning, **Joan's** motor control strategies should be refined, indicating the predominance of implicit processes. Implicit learning will occur over a gradual period of time as she learns to unconsciously merge successive movements, couple simultaneous components and regulate intersegmental force dynamics inherent in specific tasks.²¹ Intersegmental force dynamics incorporate active forces produced through muscle contraction and passive forces such as motion-dependent torques (joint movement obtained without muscle contraction) that occur naturally in the environment or as a result of movement. The variability typically observed in young children and novel performers as they learn particular motor skills allows them to develop a range of force production patterns.²¹ Although explicit processes dominate the early stages and implicit processes in the later stages, it is important to understand that both processes are present throughout (re)learning. **Joan** may not be able to perform the most basic component of dressing without some change in force dynamics and gradation. Likewise, as her skill improves, new conditions will be confronted and conscious attention will be allocated as necessary.

Measurement of Motor Learning

Motor learning is measured by analyzing performance in three distinct ways: acquisition, retention and transfer of skills.²³ *Acquisition* is the initial practice or performance of a new skill (or new control aspect of a previously learned motor skill). For **Joan**, this means the practice of reaching with her left hemiparetic arm toward an object of interest as she incorporates the components of sequencing, balance control, strength, and movement efficiency. *Retention* is the ability to demonstrate attainment of the goal or improvement in some aspect, following a short or long time delay in which the task is not practiced. This means that **Joan** would be able to reach to grasp objects while sitting at the edge of the bed at the end of one treatment session and again at the beginning of a new session on a different day without further practice or cueing. If she is successful, she demonstrates that she has *retained* the ability to reach to grasp objects from a static sitting position. *Transfer* requires the performance of a task similar in movement yet different from the original task practiced in the acquisition phase (e.g., altered force or timing). For example, **Joan** would display transfer if she could reach to grasp objects placed at different parts of the workspace at a quick pace from a seated position on chairs of different height. Acceptable performance of a motor skill within a single session (or series of sessions) does not demonstrate that the skill has been learned. A skill is not considered truly learned until retention and/or transfer of that particular skill is demonstrated. It is imperative when determining a client's level of independence that we consider whether we have measured *performance* at a point in time or *learning* of the skill so that it can be performed in the environments and under the conditions necessary for the client to be successful.

Classification of Motor Skills

Three useful classification systems for motor skills include defining the:

- (1) size of the movement – gross or fine motor skills;
- (2) beginning and end points – discrete or continuous; and

- (3) characterizing the stability of the environment in which the task is being performed – open or closed. These three classification schemes can be used to organize and plan task practice.

Fine and gross motor skills are familiar to therapists. Fine motor skills are those that use small muscles of the hands, and mouth for manipulation and speech. Gross motor skills *use* the larger muscles of the trunk and extremities. Both small and large muscles may be included in various upper extremity tasks for **Joan** such as stabilizing the trunk while reaching in standing.

Movements classified as discrete or continuous may be controlled by different mechanisms.²⁴ Discrete movements have a defined beginning and end point. Common examples are turning on a light, pushing a button, raising your hand in class, slipping on a shoe, and goal-directed reaching. Continuous or rhythmic motions are those with no clear start or end. Walking, playing the drums, swimming, and driving all represent continuous tasks. The distinction between these classes of movements is often difficult to discern. Is continuous motion a series of discrete movements or, conversely, are rhythmic movements functional units while discrete are merely abbreviated rhythmic motions?²⁵ As movements fall along a continuum between these classes, the term serial movements has been proposed to account for movements that are continuous but with clear discrete components.¹⁷ Piano playing, keyboard typing, and buttoning a blouse could be considered serial movements.

Finally, skills can be classified as open or closed based on the temporal and spatial features of the environment where a task is performed.²² A closed skill is one in which the performer can start and stop at any time because the regulatory features of the environment remain constant. Examples include sitting on a chair in a quiet room while performing hand exercises, dressing, and many activities of daily living. Open skills require the performer to conform to changes in the environment for success. Predictive abilities are essential. For example, catching a ball requires you to move your hands in time with the movement of the ball to make contact. Similarly, when reaching out to shake someone's hand – you must conform to the other person's speed and hand position to be successful. As clinicians, we frequently start with closed skills because we are working in a patient's room, therapy gym or clinic, but we must move to environments that are progressively more open to provide a challenge and optimize an individual's independence.

PROMOTING SKILL ACQUISITION

Practice

We know that to gain expertise a skill must be rehearsed repeatedly.²³ However, there are many variables to consider when structuring the way practice should ensue including the amount, the type, and the schedule. As presented above, the best practice design should not simply promote immediate performance effects, but ensure long-term learning by promoting retention and transfer of skill.

Amount of Practice

It is well supported that the best way to improve at any skill is to practice, practice and do more practice. The more time devoted on task the more opportunity an individual has to improve their capabilities. This is readily observed by thinking about the development of reaching abilities in children. It takes a number of years for a child to be able to perform a reach to grasp that is similar to how it is performed in adults.^{26,27} During those years many movements are made as the child initially tries to get a hand to the mouth or bat at a toy and eventually attempts to pick up a cup of water to drink or throw a ball. During practice not all of the attempts and combinations of movements are successful but each attempt provides the

child with information about both what to do, and what not to do in order to achieve the goal.

In rehabilitation, the underlying principle, more practice is better, is readily observed when interpreting the literature on constraint-induced movement therapy (CIMT). In this rehabilitation paradigm, initially designed for adults post-stroke, the unaffected arm is restrained, requiring the individual to use the affected arm to complete numerous repetitions of various tasks that challenge the system.²⁸⁻³⁴ Results from this type of rehabilitation program have been promising showing that intense structured practice leads to improvements in function³⁵, quality of movement, timing, and even changes in the neuro substrates of the brain.³⁶⁻³⁹ which correspond to improved movement capabilities⁴⁰

Whole vs. Part Practice

Should a motor task be practiced in its entirety (whole) or should it be broken into separate parts? The answer is not an easy one and is multi-factorial involving an in-depth understanding of the movement in question. To decide if part practice may be beneficial the task must be analyzed based on the number of segments as well as the degree that those segments are interdependent on one another.¹⁷ In continuous motor tasks, the current portion of a movement is dependent on the movement just completed and, therefore, these tasks are best practiced in their entirety. Sequences of movements that will be coupled, such as a dance routine or reaching to grasp a cup and lifting it to drink may lend themselves to be divided, practiced, and then combined for whole practice since there are segments that are clearly separated from one another. This *part* practice can be beneficial if used properly since a learner can perform pieces of the movement and have some degree of success providing increased motivation to learn the skill. However, deciding how to divide a task is often a difficult decision for a therapist. For example, it may be easy to see how **Joan** can practice the reach to grasp of the cup then separately practice the movement of bringing the cup to her mouth, however it is more difficult to separate the reach from the grasp since there is a temporal relationship between reach and grasp.⁴¹ Artificially breaking apart a task that does not lend itself to part practice may not benefit motor learning and may even hinder the process.

While it appears clear that more practice is better, how practice sessions should be structured to ensure optimal learning is less clear. Should a lot of practice be performed at once (massed) or should rest breaks be sprinkled throughout (distributed)? Should only one task be practiced (constant) or should different tasks or variations of the singular task be introduced (variable)?

The concepts of massed and distributed practice define different ways that practice can be undertaken. For example, if you wanted to work with **Joan** on left hand control you may decide to perform 30 trials of inserting a key into a lock and turning during the treatment session, but should **Joan** practice all 30 trials at once? Massed practice requires all the trials to be performed in a manner that minimizes the amount of rest between trials so there is more time on task than there is spent during rest.²³ Distributed practice divides repetitions into smaller chunks to allow for rest between trials (e.g., 5 trials now, 5 in 10 minutes, etc.). Clinically, there is no empirical evidence to support that either of these schedules lead to superior motor skill learning, however, depending on the goal of the practice session and the individual's capabilities (strength, endurance, cognition, ability to focus on task), incorporating either a massed or distributed schedule may lead to better learning and should be taken into account when designing a treatment intervention.

Constant vs. Variable Practice

Performance of only one task exactly the same way time after time is termed constant practice. Using our earlier example this would involve **Joan** inserting the same key into the same lock from the same start position every attempt. While this may improve **Joan's** ability to perform this particular task, the literature to date has found there may be a reduced ability to retain and transfer a skill following constant practice.^{42–45} For transfer of skill to occur, study results have suggested that variable practice may be more effective. Variable practice involves performing variations of the task or completely different tasks throughout a treatment session. For **Joan** this would mean using different keys, which require varying degrees of force to undo a lock. Variability could also be introduced by placing locks in different locations, which would require changes in the starting hand posture. What is not clearly understood is how much variation should be present to encourage optimal learning?

Three categories are used to describe variability and practice order --blocked, random and serial.⁴⁶ In the key and lock example the intervention is designed so that **Joan** will engage in 30 practice trials inserting three different shaped keys with slightly different fingertip force demands (Key A, Key B, and Key C) into the same lock. A blocked schedule would require that all practice be completed under one condition before moving on to the next. For example, 10 trials are performed consecutively with Key A, then 10 with Key B and finally 10 with Key C. A random schedule maximizes variability. As with blocked, **Joan** will complete 30 trials, ensuring 10 trials with each key, but each key is practiced in a random order. If blocked and random practice schedules are considered as the anchors on a continuum, a serial schedule is somewhere in between. A serial schedule requires a sequence to be followed until all 30 trials (10 on each condition) are completed (e.g., ABC, ABC, ABC ...10 times).

The ability to predict what task will be performed from trial to trial differs depending upon the type of practice schedule, with blocked having the highest and random the lowest degree of predictability. The effect of different practice schedules on learning is termed contextual interference.⁴⁷ Briefly, during blocked practice there is low interference or disruption in memory as a person practices multiple trials repeatedly. However, in random practice there is high interference because trials are interrupted by other tasks. Study results have shown that while higher contextual interference (random practice) may lead to poor performance it frequently leads to better learning (as measured with retention and transfer tests) compared to blocked practice.⁴⁸ This may occur because in random practice the skill must be reconstructed on each attempt, allowing an individual to practice a variety of strategies. This benefit appears to be lost when learning very complex tasks or in individuals with significant neurological impairments.⁴⁹ For example, **Joan's** difficulty with multi-step commands and trouble focusing on tasks may make random practice ineffective. Furthermore, blocked practice may be best because of the increased chance for success during practice providing motivation to continue with practice.

The Role of Mental Practice

Mental practice involves cognitive rehearsal and imagining of a motor action with the goal of improving performance but without the production of overt physical movement^{23,50–52} Research has demonstrated that, depending on the task, improvements in motor skill can occur with mental practice alone, however, when mental practice is combined with physical practice the improvement in skill is magnified.^{51,52} It is hypothesized that mental practice is successful in helping improve skill because, when performed, the neural processes involved in imagining the movement are very similar to those required for physical performance.^{41,53–55} Further, although there is no overt movement with mental practice, EMG studies have demonstrated that low level muscle activity (submovement activity)

occurs. Thus, if **Joan** was to use mental practice to work on dressing she should be instructed that it is not relaxing meditation. Instead, **Joan** should visualize herself going through the steps are dressing, concentrating on the movements required and “feeling” how their imagined body is moving.

Specificity and Location of Practice

Task-specific or task-oriented practice⁵⁶ is an approach to rehabilitation that focuses on performance of functional tasks that are meaningful to the individual. In order for this type of practice to be successful, a therapist must be able to accurately assess their patient and identify their limitations and deficits. It becomes the job of the therapist to accurately arrange the environment to provide the proper affordances so that the task, or a modified version of the task, can successfully be completed by the performer. An affordance is the reciprocal relationship or “fit” between a performer and the environment⁵⁷ and can drive the composition of the movement. For example, when working on reach to grasp with **Joan**, if the goal for the session is to have her modulate the force of her grasp, then following principles of task-oriented practice, **Joan** might be asked to reach and grasp a Styrofoam cup instead of a glass. This task-oriented regiment differs from a therapeutic approach that is typically more impairment based whereas the latter regiment may use therapeutic exercise (i.e., repetitive squeezing activity) out of the reach to grasp context as a means to achieve the goal.

While task oriented treatments may appear simple, setting the environment to target the movements you desire your patient to practice is quite difficult and time consuming. If your environment is not set properly the performer may not be successful and thus may become frustrated and not have the drive to want to continue to practice. Further, it is important to ensure the activity performed is challenging and meaningful to the individual as to not be perceived as boring or useless. Lastly, it is important to note that task-specific practice may be only one portion of your therapeutic intervention. Therapeutic exercise and other modes of treatment may also be required, such as range-of-motion activities or joint mobilization, to allow the patient to have the tools available to successfully complete a particular task-oriented activity.

Practice which leads to optimal learning depends on the task being learned and the characteristics of the learner (e.g., age, stage of learning). The best practice design will not simply promote immediate performance effects, but more importantly will promote long-term learning.

THE ROLE OF FEEDBACK

Feedback refers to information an individual receives pertaining to the performance of a task. It is generated from two sources. The first is referred to as internal or task-intrinsic, which is information about the movement gained through interpretation of sensory, visual and auditory experiences.^{17,23} The second is external feedback, commonly referred to as augmented feedback since this information is primarily used to enhance task-intrinsic feedback.^{17,23} However, sometimes external feedback may have a more important role and serve as a replacement if impairment is present in a sensory system. Augmented task-related feedback can come in many forms such as verbal, visual (demonstration), or physical (manual guidance). Use of augmented feedback can greatly enhance a person's ability to learn a task, but when and how should it be provided? Here we will explore the types of augmented feedback available and discuss the content, timing and frequency of this feedback and its role in enhancing learning (see Table 2).

Types of Augmented Feedback

Verbal augmented feedback is provided as either knowledge of results or knowledge of performance.¹⁷ Knowledge of results is information related to the outcome and in most cases is redundant information because by the time a task is completed the performer is usually aware if they were successful. Knowledge of performance pertains to information regarding execution of the task and typically relates to the type or quality of the movement. Although it is usually redundant information, knowledge of results may be useful at any time during the learning process but is particularly useful in the earlier stages because it can serve as a motivator (e.g., great job, you opened your hand).⁵⁸ Knowledge of performance is best used in the later stages after the goal of the movement is realized and now the information provided about varying aspects of the movement can be more readily understood by the performer.

Composition of the Augmented Feedback

Feedback can be delivered many ways. With regards to knowledge of performance the therapist can provide *descriptive* information regarding the past movement (e.g. you moved your hand too soon) or *prescriptive* information offering a possible solution to be used for the next attempt (e.g. next time move your hand as you extend your elbow). If used in the traditional sense, these are both passive methods of providing information (the learner is being told what happened or what to do next). A better way to use these tools may be to engage the patient-learner in a dialogue by asking leading questions so that they become an active participant in trying to solve the movement problem (e.g. what do you think happened on the last attempt? What will you do differently on the next attempt?). Active learning is thought to be crucial because it emphasizes the process of continuing to solve new and different motor problems as they arise, rather than just being provided with the solution. For example, when working with **Joan** to improve her dressing abilities we may ask her how she intends to get her left arm through the shirtsleeve. This approach would require **Joan** to assess the situation and her ability to ultimately formulate and execute a motor plan, rather than just being provided with a solution.

In addition, depending on the learner and the stage of learning he or she is in, the therapist must decide what type of feedback to provide such as:

- 1) whether the information given should be *general* (about the movement itself) or *specific* (about a particular portion of a movement);
- 2) *qualitative* (that was faster than last time) or *quantitative* (that was 3 seconds faster than last time),
- 3) comprised of information related to an *internal focus of attention* (lift your arm to shoulder height and extend your elbow) or *external focus of attention* (reach to turn on the light switch); and
- 4) whether information should be provided regarding the *correctness of the movement* or on the *errors*.^{17,59}

Overall, it appears that individuals in the early stage of learning, such as **Joan** in the early phase of rehabilitation, would do better with prescriptive or active-engaging feedback that is more general and qualitative in nature with an external focus on what was done correctly.

Frequency of Augmented Feedback

Feedback can be provided concurrently during a task or it can be provided after a task is performed (terminal). While the goal of concurrent feedback is to have an immediate effect on the movement being performed, studies have suggested that concurrent feedback may

actually hinder retention and transfer because the performer or the individual performing the task, becomes reliant on that feedback to complete the task successfully.⁶⁰ This is an important consideration for hand therapists. So, how much feedback should be provided?

Studies in healthy populations are suggesting that less feedback is best. This does not suggest that no feedback should be provided. Augmented feedback can enhance learning but it has also been found that too much can hinder learning.⁶¹ Our patients naturally become dependent on feedback when it is provided to them. Feedback that is more frequent encourages passive rather than active participation and can reduce the patient's ability to perform those skills. Thus, the amount of feedback should be reduced as therapy progresses. This can be done by (1) using an intermittent schedule of when feedback is given that consists of summary or average information regarding a selection of previous attempts; (2) using a faded schedule that initially provides a lot and then is reduced as practice continues; (3) setting up boundaries (bandwidth) where feedback will be given only if an error is too large or too small; or (4) allowing the performer to have some control and decision-making over when and what type of assistance is provided during task practice.¹⁷ The frequency of feedback is dependent on the stage of the learner and the learner themselves.

Before Task Performance – Modeling

Modeling “refers to the process of reproducing actions that have been executed by another individual”.⁶² These demonstrations are powerful sources of information given prior to task performance that provide the observer with the general movement pattern and the goal of the movement as well as information about the way submovements are coordinated and related to one another that are otherwise difficult to put into words. Studies indicate that the learner readily adopts the demonstrated strategies (whether effective or ineffective) for use to perform a motor skill.^{63,64} Thus, the model that will demonstrate the movement must be carefully chosen.

The type of model used has been found to influence motivation, and therefore subsequent learning. While mastery or expert models provide important strategies for the learner these strategies may be so advanced that they are unusable for the learner. In these cases, a less skilled model, or even better, a less-skilled peer model (someone with similar physical characteristics) maybe more beneficial because the learner can notice correct and incorrect aspects of the movement and strategies the model used to correct for errors. Thus, in the case of **Joan**, the therapist serving as the model for how to put a shirt on may not provide **Joan** with the most useful information, it may be best to have a peer (such as another patient) perform this activity for **Joan** to watch and problem solve through.

Manual Guidance

Manual guidance is when a therapist passively moves a patient-learner in an effort to provide more appropriate proprioceptive feedback⁶⁵, but is this the best way to teach an individual how to perform a task? It goes without argument that when safety is a concern then it is important that a therapist is close by or has their “hand-on” the learner but what about when learning or relearning a skill. It has been suggested that manual guidance is, in a way, concurrent feedback. Thus, the guidance that a therapist provides becomes part of the regulatory features of the task and the participant becomes dependent on that feedback to complete the task successfully. Thus, while performance may improve, learning (as measured through retention and transfer) may be slowed since during practice the learner did not need to actively solve the motor problem over and over. So, when working with **Joan** as she tries to regain the ability to move independently from sit to stand, should the therapist practice in a manner that is always hands-off? Well, not exactly. First, as mentioned above, safety is of the utmost importance. Barring that, there are other times when manual guidance

may be needed. For example, we may keep our hands on **Joan** in order to take her through the movement she will be asked to perform to give her an idea of the movement we would like her to produce. Yet, if manual guidance is used the therapist should attempt to remove the physical assistance as soon as possible so the patient does not become dependent on this guidance.⁶⁶

SPECIAL CONSIDERATIONS FOR THE INDIVIDUAL WITH NEUROLOGICAL IMPAIRMENT

An often overlooked component of motor re-learning in our patients is the so-called slow component of learning. This aspect of learning is not experience dependent but, rather, sleep dependent. It involves the biochemical and structural changes that occur in the nervous system during different periods of sleep and is present in both sensory-perceptual and motor learning.^{67,68} Because many patients with neurological conditions have sleep disturbances, it is likely that some of the deficits in long-term skill learning arise from inadequate processing of practice.

The capacity of the brain to modify its structure or function in response to learning or brain damage is termed *plasticity*.⁶⁹ As concepts of neural plasticity have gained acceptance, the functional changes seen during learning and following recovery from brain damage are being interpreted within a Systems Theory framework. The brain's attempt to recover from injury may initially involve resolution from shock as noted by a reduction in edema. However, the majority of recovery is due to neural reorganization. The extensive research on plasticity provides strong justification to enhance motor learning and re-learning across all ages and skill levels.

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Table 1

Case Study - Joan

Joan is a 38 y/o female with no significant PMH. She is two weeks s/p a bicycle accident which resulted in a closed head injury with a right EDH (Epidural Hematoma) in the frontal and parietal region and a small EDH in the left occipital region. Joan underwent an evacuation of the right EDH via craniotomy 10 days ago. She now presents with left upper extremity (UE) hemiplegia. In addition to her other injuries, Joan sustained a right humeral fracture which was stabilized with an ORIF immediately after her injury. She is now cleared for WBAT seen in her home for an evaluation.

Joan is married, left-handed homemaker, with three children (7, 3, and 1 year old).

Cognition / Perception: She is A & O X 3. Joan follows simple motor commands consistently but struggles with multiple step commands. She is restless at times and continues to have occasional outbursts of anger and frustration. Although there is not a complete homonymous hemianopsia, Joan seems to have difficulty perceiving objects in the right visual field.

ROM and Strength (based on MMT):

Left UE; PROM is WNL, strength is 3/5 proximally, with grasp 2/5

Right UE; PROM is WNL, strength is 3+/5 throughout

Left LE; PROM is WNL, strength is 3/5 throughout with mild triceps extensor tone (1+ on Modified Ashworth scale)

Right LE PROM is WNL, strength is 4/5 throughout.

Activities of Daily Living:

Joan has difficulty with upper body dressing. She requires minimal assistance and simple verbal cues to complete. She struggles with most fasteners.

Bed mobility: Joan requires minimum assistance to roll side to side and transition from supine to short-sit at the edge of bed. Joan's movements are impulsive and poorly controlled. She indicates that she has pain upon use of her right UE.

Sitting Balance: Joan maintains her sitting balance by holding onto the mattress. Thus, she requires contact guard with static sitting balance and minimal assist for dynamic sitting balance.

Transfers: Joan transfers sit to stand with minimal assistance for balance.

Ambulation: Joan is ambulating house hold distances with a four wheeled walker and minimum assistance.

Table 2

Factors Associated with Delivery of Verbal Augmented Feedback (KR or KP)

When providing verbal augmented feedback many factors need to be accounted for when deciding on the best mode of delivery based on the targeted task and individual characteristics. These factors include:		
FACTOR	VARIABLES	
Composition of Feedback	Descriptive	Prescriptive
Mode of Delivery	Learner is a passive participant	Learner is an active participant
Timing of Feedback	Concurrent	Terminal
Frequency of Feedback	100% of the time	Less than 100% of the time
Precision of Feedback	General information	Precise information
Attentional Focus	Internal focus about movement	External focus about movement
Type of Feedback	Quantitative	Qualitative