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Functional Training and Advanced Rehabilitation

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OBJECTIVES **After completion of this chapter, the physical therapist should be able to do the following:**

- Define and discuss the importance of proprioception in the neuromuscular control process.
- Define and discuss the different levels of motor control by the central nervous system and the neural pathways responsible for transmission of afferent and efferent information at each level.
- Apply a systematic functional evaluation designed to provoke symptoms.
- Demonstrate consistency between functional and clinical testing information (combinatorial power).
- Apply a 3-step model designed to promote the practical systematic thinking required for effective therapeutic exercise prescription and progression.
- Define and discuss objectives of a functional neuromuscular rehabilitation program.
- Develop a rehabilitation program that uses various exercise techniques for development of neuromuscular control.

Function and Functional Rehabilitation

The basic goal in rehabilitation is to restore and enhance function within the environment and to perform specific activities of daily living (ADL). The entire rehabilitation process should be focused on improving the functional status of the patient. The concept of functional training is not new, nor is it limited to function related to sports. By definition, *function* means having a purpose or duty. Therefore, *functional* can be defined as performing a practical or intended function or duty. Function should be considered in terms of a spectrum because ADL encompass many different tasks for many different people. What is functional to one person may not be functional to another. It is widely accepted that to perform a specific activity better, one must practice that activity. Therefore, the functional exercise progression for return to ADL can best be defined as breaking the specific activities down into a hierarchy and then performing them in a sequence that allows acquisition or reacquisition of that skill. It is important to note that although people develop different levels of skill, function, and motor control, certain fundamental tasks are common to nearly all individuals (barring pathologic conditions and disability). Lifestyle, habits, injury, and other factors can erode the fundamental components of movement without obvious alterations in higher-level function and skill. Ongoing higher-level function is a testament to the compensatory power of the neurologic system. Imperfect function and skill create stress in other body systems. Fundamental elements can first be observed during the developmental progression of posture and motor control. The sequence of developmental progression can also give insight into the original acquisition of skill. The ability to assess retention or loss of fundamental movement patterns is therefore a way to enhance rehabilitation. The rehabilitation process starts with a 2-part appraisal that creates perspective by viewing both ends of the functional spectrum:

- The current level of function (ADL, work, and sports/recreation) relative to the patient's needs and goals.
- The ability to demonstrate the fundamental movement patterns that represent the foundation of function and basic motor control.

Objectives of Functional Rehabilitation

The overall objective of a functional exercise program is to return patients to their preinjury level as quickly and as safely as possible by resolving or reducing the measurable dysfunction within fundamental and functional movement patterns. Specific training activities are designed to restore both dynamic joint stability and ADL skills.[1] To accomplish this objective, a basic tenet of exercise physiology is used. The SAID (specific adaptations to imposed demands) principle states that the body will adapt to the stress and strain placed on it.[2] Athletes cannot succeed if they have not been prepared to meet all the demands of their specific activity.[2] Reactive neuromuscular training (RNT) helps bridge the gap from traditional rehabilitation via proprioceptive and balance training to promote a more functional return to activity.[2] The SAID principle provides constructive stress, and RNT creates opportunities for input and integration. The main objective of the RNT program is to facilitate the unconscious process of interpreting and integrating the peripheral sensations received by the central nervous system (CNS) into appropriate motor responses. This approach is enhanced by the unique clinical focus on pathologic orthopedic and neurologic states and their functional representation. This special focus forces the clinician to consider evaluation of human movement as a complex multisystem interaction and the logical starting point for exercise prescription. Sometimes this will require a breakdown of the supporting mobility and stability within a pattern. Regardless of the specific nature of the corrective needs, all the functional exercises follow a simple but very specific path. First, the functional exercise program is driven by a functional screening or assessment that produces a baseline of movement. The process of screening and assessment will rate and rank patterns. It will provide valuable information about dysfunction in movement patterns such as asymmetry, difficulty with movement, and pain. Screening and assessment will therefore identify faulty movement patterns that should not be exercised or trained until corrected. Second, the functional framework will assist in making the best possible choices for corrective categories and exercises. No single exercise is best for a movement problem, but there is an appropriate category of corrective exercises to choose from. Third, following the initial session of corrective exercises, the movement pattern should be rechecked for changes against the original baseline. Fourth, once an obvious change is noted in the key pattern, the screening or assessment is repeated to survey other changes in movement and identify the next priority. By working on the most fundamental pattern, it is possible to see other positive changes. Therefore, these 4 steps provide the framework that makes corrective exercise successful:

- The screening and assessment direct the clinician to the most fundamental movement dysfunction.
- One or 2 of the most practical corrective exercises from the appropriate category should be chosen and applied.
- Once the exercise has been taught and is being performed correctly, check for improvement in the dysfunctional basic movement pattern as revealed by specific tests in the screening or assessment.

This concept is called the *functional continuum.* Most patients seek care because of an obvious source of pain or dysfunction. What is not obvious is the true cause of the pain or dysfunction, ascertainment of which is the purpose of functional movement assessment (see Chapter 17). By looking at movement as a whole, all the compensations and conscious sources of pain and dysfunction can be highlighted and addressed. Patients fall into one of four phases on a functional continuum (Table 19-1).

Table 19-1 **Four Phases of the Functional Continuum**

Phase	Description
Subconscious dysfunction	This is the initial phase when most patients are first seen by the clinician. Patients are totally unaware of their true dysfunction (it is in their subconscious) or are convinced that the problem lies elsewhere.
Conscious dysfunction	This is what happens after a movement assessment is performed. Patients are now aware of their true dysfunction (it is in their conscious), and they can start to address the real cause.
Conscious function	This phase is entered once patients can perform the correct functional pattern, but it is not automatic (it is functional only with conscious control). They still need conscious effort to perform a good pattern of movement.
Subconscious function	The final stage occurs when patients can perform a functional pattern automatically (it is in their subconscious control) without having to think about the correction.

Table 19-2 Three Rs of Treatment Phases

R	Description
Reset	Most problems require resetting of the complete system to break them out of their dysfunctional phase. By just jumping to exercises, the results can be less than optimal. Types of treatments that would be considered a "reset" include joint mobilization, soft-tissue mobilization, and various soft-tissue techniques.
Reinforce	Once the system has been reset, many dysfunctions will need support or reinforcement while proper patterns are being introduced. Types of reinforcement devices include taping, bracing, orthotics, postural devices, and static and dynamic stretching.
Reload	The last phase of treatment is the exercise implementation or reload phase, in which the new software is loaded into the central nervous system and a true functional pattern of motion can be reprogrammed.

Exercise prescription choices must continually represent the specialized training of the clinician through a consistent and centralized focus on human function and consideration of the fundamentals that make function possible. Exercise applied at any given therapeutic level must refine movement, not simply create general exertion in the hope of increased tolerance of movement.[3] Moore and Durstine state, "Unfortunately, exercise training to optimize functional capacity has not been well studied in the context of most chronic diseases or disabilities. As a result, many exercise professionals have used clinical experience to develop their own methods for prescribing exercise."[4] Experience, self-critique, and specialization produce seasoned clinicians with intuitive evaluation abilities and innovations in exercise that are sometimes difficult to follow and even harder to ascertain; however, common characteristics do exist. Clinical experts use parallel (simultaneous) consideration of all factors influencing functional movement. RNT as a treatment philosophy is inclusive and adaptable and has the ability to address a variety of clinical situations. It should also be understood that a clinical philosophy is designed to serve, not to be served. The treatment design demonstrates specific attention to the parts (clinical measurements and isolated details) with continual consideration of the whole (restoration of function).[3] Moore and Durstine follow their previous statement by acknowledging that "Experience is an acceptable way to guide exercise management, but a systematic approach would be better."[4] We use the 3 "Rs" as a way to understand the type of treatment phases that a patient will undergo (Table 19-2).

The Three-Phase Model for Prescription of Exercise

This chapter demonstrates a practical model designed to promote the systematic thinking required for effective prescription of therapeutic exercise and progression at each phase of rehabilitation.[3] The approach is a serial (consecutive) step-by-step method that will, with practice and experience, lead to parallel thinking and multilevel problem solving. The intended purpose of this method is to reduce arbitrary trial-and-error attempts at prescribing effective exercise and lessen protocol-based thinking. It will give the novice clinician a framework that will guide but not confine clinical exercise prescription. It will provide experienced clinicians with a system to observe their particular strengths and weaknesses in dosage and design of exercise. Inexperienced and experienced clinicians alike will

Box 19-1 **Three-Phase Rehabilitation Model**

1. Proprioception and kinesthesia
2. Dynamic stability
3. Reactive neuromuscular control

develop practical insight by applying the model and observing the interaction of the systems that produce human movement. The focus is specifically geared to orthopedic rehabilitation and the clinical problem-solving strategies used to develop an exercise prescription through an outcome-based goal-setting process. All considerations for therapeutic exercise prescription will give equal importance to conventional orthopedic exercise standards (biomechanical and physiologic parameters) and neurophysiologic strategies (motor learning, proprioceptive feedback, and synergistic recruitment principles). This 3-phase model (Box 19-1) will create a mechanism that necessitates interaction between orthopedic exercise approaches and optimal neurophysiologic techniques. It includes a 4-principle foundation that demonstrates the hierarchy and interaction of the founding concepts used in rehabilitation (both orthopedic and neurologic). For all practical purposes, these 4 categories help demonstrate the efficient and effective continuity necessary for formulation of a treatment plan and prompt the clinician to maintain an inclusive, open-minded clinical approach.

This chapter is written with the clinic-based practitioner in mind. It will help the clinician formulate an exercise philosophy. Some clinicians will discover reasons for success that were intuitive and therefore hard to communicate to other professionals. Others will discover a missing step in the therapeutic exercise design process. Much of the confusion and frustration encountered by rehabilitation specialists is because of the vast variety of treatment options afforded by ever-improving technology and accessibility to emerging research evidence. To effectively use the wealth of current information and what the future has yet to bestow, clinicians must adopt an operational framework or personal philosophy about therapeutic exercise. If a clinical exercise philosophy is based on technology, equipment, or protocols, the scope of problem solving is strictly confined. It would continually change because no universal standard or gauge exists. However, a philosophy based solely on the structure and function of the human body will keep the focus (Box 19-2) uncorrupted and centralized. Technologic developments can enhance the effectiveness of exercise only as long as the technology, system, or protocol remains true to a holistic functional standard. Known functional standards should serve as governing factors that improve the clinical consistency of the clinician and rehabilitation team for prescription and progression of training methods. The 4 principles for exercise prescription are based on human movement and the systems on which it is constructed (Box 19-2). The intent of these 4 distinct categories is to break down and reconstruct the factors that influence functional movement and to stimulate inductive reasoning, deductive reasoning, and the critical thinking needed

Box 19-2 **Four Principles for Prescription of Exercise**

Functional evaluation and assessment in relation to dysfunction (disability) and impairment
Identification and management of motor control
Identification and management of osteokinematic and arthrokinematic limitations
Identification of current movement patterns followed by facilitation and integration of synergistic movement patterns

to develop a therapeutic exercise progression. It is hoped that these factors will serve the intended purpose of organization and clarity, thereby giving due respect to the many insightful clinicians who have provided the foundation and substance for construction of this practical framework.[3]

Proprioception, Receptors, and Neuromuscular Control

Success in skilled performance depends on how effectively an individual detects, perceives, and uses relevant sensory information. Knowing exactly where our limbs are in space and how much muscular effort is required to perform a particular action is critical for successful performance of all activities requiring intricate coordination of the various body parts. Fortunately, information about the position and movement of various body parts is available from peripheral receptors located in and around articular structures and the surrounding musculature. A detailed discussion of proprioception and neuromuscular control is also presented in Chapter 9.

Joints: Support and Sensory Function

In a normal healthy joint, both static and dynamic stabilizers provide support. The role of capsuloligamentous tissues in the dynamic restraint of joints has been well established in the literature.[5-15] Although the primary role of these structures is mechanical in nature by providing structural support and stabilization to the joint, the capsuloligamentous tissues also play an important sensory role by detecting joint position and motion.[8,16-18] Sensory afferent feedback from receptors in the capsuloligamentous structures projects directly to the reflex and cortical pathways, thereby mediating reactive muscle activity for dynamic restraint.[5,6,8,17,19] The efferent motor response that ensues from the sensory information is called *neuromuscular control.* Sensory information is sent to the CNS to be processed, and appropriate motor strategies are executed.

Physiology of Proprioception

Sherrington[18] first described the term *proprioception* in the early 1900s when he noted the presence of receptors in the joint capsular structures that were primarily reflexive in nature. Since that time, mechanoreceptors have been morphohistologically identified around articular structures in both animal and human models. In addition, the well-described muscle spindle and Golgi tendon organs are powerful mechanoreceptors. Mechanoreceptors are specialized end-organs that function as biologic transducers for conversion of the mechanical energy of physical deformation (elongation, compression, and pressure) into action nerve potentials yielding proprioceptive information.[10] Although receptor discharge varies according to the intensity of the distortion, mechanoreceptors can also be described in terms of their discharge rates. Quickly adapting receptors cease discharging shortly after the onset of a stimulus, whereas slowly adapting receptors continue to discharge while the stimulus is present.[8,10,20] Around a healthy joint, quickly adapting receptors are responsible for providing conscious and unconscious kinesthetic sensations in response to joint movement or acceleration, whereas slowly adapting mechanoreceptors provide continuous feedback and thus proprioceptive information related to joint position[10,20,21] (see Chapter 9 for examples of quickly and slowly adapting receptors).

Once stimulated, mechanoreceptors are able to adapt. With constant stimulation, the frequency of the neural impulses decreases. The functional implication is that mechanoreceptors detect change and rates of change, as opposed to steady-state conditions.[22] This input is then analyzed in the CNS to determine joint position and movement.[23] The status of the musculoskeletal structures is sent to the CNS so that information about static versus dynamic conditions, equilibrium versus disequilibrium, or biomechanical stress and strain relationships can be evaluated.[24,25] Once processed and evaluated, this proprioceptive information becomes capable of influencing muscle tone, motor execution programs, and cognitive somatic perceptions or kinesthetic awareness.[26] Proprioceptive information also protects the joint from damage caused by movement exceeding the normal physiologic range of motion (ROM) and helps determine the appropriate balance of synergistic and antagonistic forces. All this information helps in generating a somatosensory image within the CNS. Therefore, the soft tissues surrounding a joint serve a double purpose: they provide biomechanical support to the bony partners making up the joint by keeping them in relative anatomic alignment, and through an extensive afferent neurologic network, they provide valuable proprioceptive information.

Central Nervous System: Integration of Motor Control

The response of the CNS falls into 3 categories or levels of motor control: spinal reflexes, brainstem processing, and cognitive cerebral cortex program planning. The goal of the rehabilitation process is to retrain the altered afferent pathways and thereby enhance the neuromuscular control system. To accomplish this goal, the objective of the rehabilitation program should be to hyperstimulate the joint and muscle receptors to encourage maximal afferent discharge to the respective CNS levels.[21,27-30]

First-Level Response: Muscle

When faced with an unexpected load, the first reflexive muscle response is a burst of electromyographic activity that occurs between 30 and 50 milliseconds. The afferent fibers of both the muscle spindle and the Golgi tendon organ mechanoreceptors synapse with the spinal interneurons and produce a reflexive facilitation or inhibition of the motor neurons.[28,30,31] The monosynaptic stretch reflex is one of the most rapid reflexes underlying limb control. The stretch reflex occurs at an unconscious level and is not affected by extrinsic factors. These responses can occur simultaneously to control limb position and posture. Because they can occur at the same time, are in parallel, are subconscious, and are not subject to cortical interference, they do not require attention and are thus automatic.

At this level of motor control, activities to encourage short-loop reflex joint stabilization should dominate.[15,21,27,30] These activities are characterized by sudden alterations in joint position that require reflex muscle stabilization. With sudden alterations or perturbations, both the articular and muscular mechanoreceptors will be stimulated to produce reflex stabilization. Rhythmic stabilization exercises encourage monosynaptic cocontraction of the musculature, thereby producing dynamic neuromuscular stabilization.[32] These exercises serve to build a foundation for dynamic stability.

Second-Level Response: Brainstem

The second level of motor control interaction is at the level of the brainstem.[25,28,33] At this level, afferent mechanoreceptors interact with the vestibular system and visual input from the eyes to control or facilitate postural stability and equilibrium of the body.[21,25,27-29] Afferent mechanoreceptor input also works in concert with the muscle spindle complex by inhibiting antagonistic muscle activity under conditions of rapid lengthening and periarticular distortion, both of which accompany postural disruption.[26,30] In conditions of disequilibrium in which simultaneous neural input exists, a neural pattern is generated that affects the muscular stabilizers and thereby returns equilibrium to the body's center of gravity.[28] Therefore, balance is influenced by the same peripheral afferent mechanism that mediates joint proprioception and is at least partially dependent on an individual's inherent ability to integrate joint position sense with neuromuscular control.[34]

Clinical Pearl

Balance activities, both with and without visual input, will enhance motor function at the brainstem level.[28,33]

It is important that these activities remain specific to the types of activities or skills that will be required of the athlete on return to sport.[35] Static balance activities should be used as a precursor to more dynamic skill activity.[35] Static balance skills can be initiated when the individual is able to bear weight on the lower extremity. The general progression of static balance activities is to move from bilateral to unilateral and from eyes open to eyes closed.[21,28,35-37] With balance training, it is important to remember that the sensory systems respond to environmental manipulation. To stimulate or facilitate the proprioceptive system, vision must be disadvantaged, which can be accomplished in several ways (Box 19-3).

Third-Level Response: Central Nervous System/Cognitive

Appreciation of joint position at the highest or cognitive level needs to be included in an RNT program. These types of activities are initiated on the cognitive level and include programming motor commands for voluntary movement. Repetitions of these movements will maximally stimulate the conversion of conscious programming to unconscious programming.[21,25,27-29,38] The term for this type of training is the *forced-use paradigm*. By making a task significantly more difficult or asking for multiple tasks, the CNS is bombarded with input. The CNS attempts to sort and process this overload information by opening additional neural pathways. When the individual goes back to a basic ADL task, the task becomes easier. This information can then be stored as a central command and ultimately be performed without continuous reference to conscious thought as a triggered response.[21,27-29,39] As with all training, the single greatest obstacle to motor learning is the conscious mind. We must get the conscious mind out of the act!

Box 19-3 Ways to Disadvantage Vision for Stimulation of the Proprioceptive System

Remove vision by either closing or blindfolding the eyes.

Destabilize vision with demanding hand and eye movements (ball toss) or by moving the visual surround.

Confuse vision with unstable visual cues that disagree with the proprioceptive and vestibular input (sway referencing).

Closed-Loop, Open-Loop, and Feed-Forward Integration

Why is a coordinated motor response important? When an unexpected load is placed on a joint, ligamentous damage occurs in 70 to 90 milliseconds unless an appropriate response ensues.[40-42] Therefore, reactive muscle activity that provides sufficient magnitude in the 40- to 80-millisecond time frame must occur after loading begins to protect the capsuloligamentous structures. The closed-loop system of CNS integration may not be fast enough to produce a response to increase muscle stiffness. There is simply no time for the system to process the information and provide feedback about the condition. Failure of the dynamic restraint system to control abnormal force will expose the static structures to excessive force. In this case, the open-loop system of anticipation becomes more important in producing the desired response. Preparatory muscle activity in anticipation of joint loading can influence the reactive muscle activation patterns. Anticipatory activation increases the sensitivity of the muscle spindles, thereby allowing the unexpected perturbations to be detected more quickly.[43]

Very quick movements are completed before feedback can be used to produce an action to alter the course of movement. Therefore, if the movement is fast enough, a mechanism such as a motor program would have to be used to control the entire action, with the movement being carried out without any feedback. Fortunately, the open-loop control system allows the motor control system to organize an entire action ahead of time. For this to occur, previous knowledge needs to be preprogrammed into the primary sensory cortex (Box 19-4).

In the open-loop system, a program that sets up some kind of neural mechanism or network that is preprogrammed organizes movement in advance. A classic example of this occurs in the body as postural adjustments are made before the intended movement. When an arm is raised into forward flexion, the first muscle groups to fire are not even in the shoulder girdle region. The first muscles to contract are those in the lower part of the back and legs (approximately 80 milliseconds pass before noticeable activity occurs in the shoulder) to provide a stable base for movement.[44] Because the shoulder muscles are linked to the rest of the body, their contraction affects posture. If no preparatory compensations in posture were made, raising the arm would shift the center of gravity forward and cause a slight loss of balance. The feed-forward motor control system takes care of this potential problem by preprogramming the appropriate postural modification first rather than requiring the body to make adjustments after the arm begins to move.

Lee[45] demonstrated that these preparatory postural adjustments are not independent of the arm movement but rather are part of the total motor pattern. When the arm movements are organized, the motor instructions are preprogrammed to adjust posture first and then move the arm. Therefore, arm movement and postural control are not separate events but instead are different parts of an integrated action that raises the arm while maintaining balance. Lee showed that these electromyographic preparatory postural adjustments

Box 19-4 Preprogrammed Information Needed for an Open-Loop System to Work

The particular muscles that are needed to produce an action.
The order in which these muscles need to be activated.
The relative forces of the various muscle contractions.
The relative timing and sequencing of these actions.
The duration of the respective contractions.

disappear when the individual leans against some type of support before raising the arm. The motor control system recognizes that advance preparation for postural control is not needed when the body is supported against the wall.

It is important to remember that most motor tasks are a complex blend of both open- and closed-loop operations. Therefore, both types of control are often at work simultaneously. Both feed-forward and feedback neuromuscular control can enhance dynamic stability if the sensory and motor pathways are frequently stimulated.[21] Each time a signal passes through a sequence of synapses, the synapses become more capable of transmitting the same signal.[14,46] When these pathways are "facilitated" regularly, memory of that signal is created and can be recalled to program future movements.[14,47]

Conclusion: Relationship to Rehabilitation

A rehabilitation program that addresses the need for restoring normal joint stability and proprioception cannot be constructed until one has total appreciation of both the mechanical and sensory functions of the articular structures.[27] Knowledge of the basic physiology of how these muscular and joint mechanoreceptors work together in the production of smooth, controlled coordinated motion is critical in developing a rehabilitation training program. This is because the role of the joint musculature extends well beyond absolute strength and the capacity to resist fatigue. With simple restoration of mechanical restraints or strengthening of the associated muscles, the smooth coordinated neuromuscular controlling mechanisms required for joint stability are neglected.[27] The complexity of joint motion necessitates synergy and synchrony of muscle firing patterns, thereby permitting proper joint stabilization, especially during sudden changes in joint position, which is common in functional activities. Understanding of these relationships and functional implications will allow the clinician greater variability and success in returning patients safely back to their playing environment.

Four Principles for Therapeutic Exercise Prescription

The functional exercise program follows a linear path from basic mobility to basic stability to movement patterns. Corrective exercise falls into one of the 3 basic categories: mobility, stability, and retraining of movement patterns. Mobility exercises focus on joint ROM, tissue length, and muscle flexibility. Stability exercises focus on the basic sequencing of movement. These exercises target postural control of the starting and ending positions within each movement pattern. Movement pattern retraining incorporates the use of fundamental mobility and stability into specific movement patterns to reinforce coordination and timing.

The corrective exercise progression always starts with mobility exercises. Because many poor movement patterns are associated with abnormalities in mobility, restoration of movement needs to be addressed first. Mobility exercises should be performed bilaterally to confirm limitation and asymmetry of mobility. Clinicians should never assume that they know the location or side in which mobility is restricted. Rather, both sides should always be checked and mobility cleared before advancing the exercise program. If the assessment reveals a limitation or asymmetry, it should be the primary focus of the corrective exercise program. Treatments that promote mobility can involve manual therapy, such as soft-tissue and joint mobilization and manipulation. Treatments of mobility might also include any modality that improves tissue pliability or freedom of movement. If no change in mobility is appreciated, the clinician should not proceed to stability work. Rather, all mobility problems should continue to be worked on until a measurable change is noted. Mobility does not need to become full or normal, but improvement must be noted before advancing. The clinician can proceed to a stability exercise only if the increased mobility allows the patient to get into the appropriate exercise posture and position. The stability work should reinforce the new mobility, and the new mobility makes improved stabilization possible because the new mobility provides new sensory information. If there is any question about compromised mobility, each exercise session should always return to mobility exercises before moving to stability exercises. This ensures that proper tissue length and joint alignment are available for the stabilization exercises.

When no limitation or asymmetry is present during the mobility corrective exercises, one can move directly to stability corrective exercises. Once mobility has been restored, it needs to be controlled. Stability exercises demand posture, alignment, balance, and control of forces within the newly available range and without the support of compensatory stiffness or muscle tone. Stability exercises should be considered as challenges to posture and position, rather than being conventional strength exercises.

We propose 4 principles for therapeutic exercise prescription, which we describe as the 4 "Ps" in this section. These principles serve to guide decisions for selecting, advancing, and terminating therapeutic exercise interventions. Application of these 4 principles in the appropriate sequence will allow the clinician to understand the starting point, a consistent progression, and the end point for each exercise prescription. This sequence is achieved by using functional activities and fundamental movement patterns as goals. By proceeding in this fashion, the clinician will have the ability to evaluate the whole before the parts and then discuss the parts as they apply. Table 19-3 lists and describes the principles for therapeutic exercise prescription.

Table 19-3 **Four Principles for Therapeutic Exercise Prescription**

Principle	Description
Functional evaluation and assessment in relation to dysfunction (disability) and impairment	The evaluation must identify a functional problem or limitation resulting in diagnosis of a functional problem. Observation of whole movement patterns tempered by practical knowledge of key stress points and common compensatory patterns will improve the efficiency of evaluation.
Identification and management of motor control	Rehabilitation can be greatly advanced by understanding functional milestones and fundamental movements such as those demonstrated during the positions and postures paramount to growth and development. These milestones serve as key representations of functional mobility and control, as well as play a role in the initial setup and design of the exercise program.
Identification and management of osteokinematic and arthrokinematic limitations	The skills and techniques of orthopedic manual therapy are beneficial in identifying specific arthrokinematic restrictions that would limit movement or impede the motor-learning process. Management of myofascial and capsular structures will improve osteokinematic movement, as well as allow balanced muscle tone between the agonist and antagonist. It will also help the clinician understand the dynamics of the impairment.
Identification of current movement patterns followed by facilitation and integration of synergistic movement patterns	Once restrictions and limitations are managed and gross motion is restored, application of proprioceptive neuromuscular facilitation-type patterning will further improve neuromuscular function and control. Consideration of synergistic movement is the final step in restoration of function by focusing on coordination, timing, and motor learning.

Clinical Pearl

The true art of rehabilitation is to understand the whole of synergistic functional movement and the therapeutic techniques that will have the greatest positive effect on that movement in the least amount of time.

The Four Ps

The 4 Ps represent the 4 principles for therapeutic exercise: purpose, posture, position, and pattern (Table 19-4). They serve as quick reminders of the hierarchy, interaction, and application of each principle. The questions of *what*, *when*, *where*, and *how* for functional movement assessment and exercise prescription are addressed in the appropriate order (Table 19-4).

Table 19-4 Memory Cues and Primary Questions Associated with the Four Principles for Prescription of Therapeutic Exercise

Principle	Memory Cue	Memory Cue Definition	Primary Questions
Functional evaluation and assessment	Purpose	Used during both the evaluation process and the exercise prescription process to keep the clinician intently focused on the greatest single factor limiting function	"*What* functional activity is limited?" "*What* does the limitation appear to be—a mobility problem or a stability problem?" "*What* is the dysfunction or disability?" "*What* fundamental movement is limited?" "*What* is the impairment?"
Identification of motor control	Posture	Helps the clinician remember to consider a more holistic approach to exercise prescription	"*When* in the development sequence is the impairment obvious?" "*When* do the substitutions and compensations occur?" "*When* in the developmental sequence does the patient demonstrate success?" "*When* in the developmental sequence does the patient experience difficulty?" "*When* is the best possible starting point for exercise with respect to posture?"
Identification of osteokinematic and arthrokinematic limitations	Position	Describes not only the location of the anatomic structure (joint, muscle group, ligament, etc) where impairment has been identified but also the positions (with respect to movement and load) in which the greatest and least limitations occur	"*Where* is the impairment located?" "*Where* among the structures (myofascial or articular) does the impairment have its greatest effect?" "*Where* in the range of motion does the impairment affect position the greatest?" "*Where* is the most beneficial position for the exercise?"
Integration of synergistic movement patterns	Pattern	Cues the clinician to continually consider the functional movements of the human body that occur in unified patterns that occupy 3-dimensional space and cross 3 planes (frontal, sagittal, and transverse)	"*How* is the movement pattern different on bilateral comparison?" "*How* can synergistic movement, coordination, recruitment and timing be facilitated?" "*How* will this affect the limitation in movement?" "*How* will this affect function?"

Pain

Aristotle said, "We cannot learn without pain," which is very wise because pain is usually life's most powerful teacher. However, pain is simply the brain's interpretation of a neurologic signal normally associated with trauma, dysfunction, and instant and continuing damage. Pain affects motor control and greatly reduces the effectiveness of even the best corrective exercise technique.

Table 19-5 Three Levels of Functional Evaluation

Level	Name	Description
I	Functional activity assessment	Combined movements common to the patient's lifestyle and occupation are reproduced. They usually fit the definition of a general or specific skill.
II	Functional or fundamental movement assessment	The clinician takes what is learned through the observation of functional movements and breaks the movements down to the static and transitional postures seen in the normal developmental sequence.
III	Specific clinical measurement	Clinical measurements are used to identify and quantify specific problems that contribute to limitations in motion or control.

Purpose

The word *purpose* is simply a cue to be used during both the evaluation process and the exercise prescription process to keep the clinician intently focused on the greatest single factor limiting function. The primary questions to ask for this principle appear in Table 19-4. It is not uncommon for clinicians to attempt to resolve multiple problems with the initial exercise prescription. However, the practice of identifying the single greatest limiting factor will reduce frustration and also not overwhelm the patient. Other factors may have been identified in the evaluation, but a major limiting factor or a single weak link should stand out and be the focus of the initial therapeutic exercise intervention. Alterations in the limiting factor may produce positive changes elsewhere, which can be identified and considered before the next exercise progression.

The functional evaluation process should take on 3 distinct layers or levels (Table 19-5). Each of the 3 levels should involve qualitative observations followed by quantitative documentation when possible. Normative data are helpful, but bilateral comparison is also effective and demonstrates the functional problem to the patient at each level. Many patients think that the problem is simply symptomatic and structural in nature and have no example of dysfunction outside of pain with movement. Moffroid and Zimny suggest that "Muscle strength of the right and left sides is more similar in the proximal muscles whereas we accept a 10% to 15% difference in strength of the distal muscles. . . . With joint flexibility, we accept a 5% difference between goniometric measurements of the right and left sides."[48]

The functional activity assessment involves a reproduction of combined movements common to the patient's lifestyle and occupation. These movements usually fit the definition of a general or specific skill. The clinician must have the patient demonstrate a variety of positions and not just positions that correspond to the reproduction of symptoms.[49] Static postural assessment is included, as well as assessment of dynamic activity. The quality of control and movement is assessed. Specific measurement of bilateral differences is difficult, but demonstration and observation are helpful for the patient. The clinician should note the positions and activities that provoke symptoms, as well as the activities that illustrate poor body mechanics, poor alignment, right-left asymmetries, and inappropriate weight shifting. When the clinician has observed gross movement quality, it may be necessary to also quantify movement performance. Repetition of the activity for evaluation of endurance, reproduction of symptoms, or demonstration of rapidly declining quality will create a functional baseline for bilateral comparison and documentation.

Next is the functional or fundamental movement assessment. The clinician must take what is learned through the observation of functional movements and break the movements down into the static and transitional postures seen in the normal developmental sequence. This breakdown will reduce activities to the many underlying mobilizing and stabilizing actions and reactions that constitute the functional activity. More simply stated, the activity is broken down into a sequence of primary movements that can be observed independently. It must be noted that these movements still involve multiple joints and muscles.[49] Assessment of individual joints and muscle groups will be performed during clinical measurements. Martin notes, "The developmental sequence has provided the most consistent base for almost all approaches used by physical therapists."[48] This is a powerful statement, and because true qualitative measurements of normal movement in adult populations are limited, the clinician must look for universal similarities in movement. Changes in fundamental movements can effect significant and prompt changes in function and must therefore be considered functional as well. Because the movement patterns of most adults are habitual and specific and thus are not representative of a full or optimal movement spectrum, the clinician must first consider the nonspecific basic movement patterns common to all individuals during growth and development. The developmental sequence is predictable and universal in the first 2 years of life,[50] with individual differences seen in the rate and quality of the progression. The differences are minimal in comparison to the variations seen in the adult population with their many habits, occupations, and lifestyles. In addition to diverse movement patterns, the adult population has the consequential complicating factor of a previous medical and injury history. Each medical problem or injury has had some degree of influence on activity and movement. Thus, evaluation of functional activities alone may hide many uneconomical movement patterns, compensations, and asymmetries that when integrated into functional activities, are not readily obvious to the clinician. By using the fundamental movements of the developmental progression, the clinician can view mobility and static and dynamic stability problems in a more isolated setting. Although enormous variations in functional movement quality and quantity are seen in specific adult patient populations, most individuals have the developmental sequence in common.[50] The movements used in normal motor development are the building blocks of skill and function.[50] Many of these building blocks can be lost while the skill is maintained or retained at some level (though rarely optimal). We will refer to these movement building blocks as *fundamental movements* and consider them precursors to higher function. Bilateral comparison is helpful when the clinician identifies qualitative differences between the right and left sides. These movements (like functional activities) can be compared quantitatively as well.

Finally, clinical measurements will be used to identify and quantify specific problems that are contributing to limitation of motion or limitation of control. Clinical measurements will first classify a patient through qualitative assessment. The parameters that define that classification must then be quantified to reveal impairment. These classifications are called hypermobility and hypomobility and help create guides for treatment that consider the functional status, anatomic structures, and the severity of symptoms. The clinician should not proceed into exercise prescription without proper identification of one of these general categories. The success or failure of a particular exercise treatment regimen probably depends more on this classification than on the choice of exercise technique or protocol.

Once the appropriate clinical classification is determined, specific quantitative measurements will define the level of involvement within the classification and set a baseline for exercise treatment. Periodic reassessment may identify a different major limiting factor or a weak link that may require reclassification, followed by specific measurement. The new problem or limitation would then be inserted as the purpose for a new exercise intervention. A simple diagram (Figure 19-1) will help the clinician separate the different levels of function so that intervention and purpose will always be at the appropriate level and assist in the clinical decision making related to exercise prescription.[51]

Posture

Posture is a word to help the clinician consider a more holistic approach to exercise prescription. The primary questions to ask for this principle appear in Table 19-4. Janda[52] stated an interesting point when discussing posture and the muscles responsible for its maintenance. Most discussions on posture and the musculature responsible for posture generally refer to erect standing. However, ". . . erect standing position is so well balanced that little or no activity is necessary to maintain it."[52] Therefore, "basic human posture should be derived from the principal movement pattern, namely gait. Since we stand on one leg for most of the time during walking, the stance on one leg should be considered to be the typical posture in man; the postural muscles are those which maintain this posture." Janda reported the ratio of single-leg to double-leg stance in gait to be 85% to 15%. "The muscles which maintain erect posture in standing on one leg are exactly those which show a striking tendency to get tight."[53] Infants and toddlers use tonic holding before normal motor development and maturation produce the ability to use cocontraction as a means of effective support. "Tonic holding is the ability of tonic postural muscles to maintain a contraction in their shortened range against gravitational or manual resistance."[54] An adult orthopedic patient may revert to some level of tonic holding after injury or in the presence of pain and altered proprioception. Likewise, adults who have habitual postures and limited activity may adopt tonic holding for some postures. Just as Janda uses single-leg stance to observe postural function with greater specificity than the more conventional double-leg erect standing, the developmental progression can offer greater understanding by examination of the precursors to single-leg stance.[55] As stated earlier, fundamental movements are basic representations of mobility, stability, and dynamic stability and include the transitional postures used in growth and development. From supine to standing, each progressive posture imposes greater demands on motor control and balance. Box 19-5 lists the most common postures used in corrective exercise.

Figure 19-1 Different levels of function

This approach will help the clinician consider how the mobility or stability problem that was isolated in the evaluation has been (temporarily) integrated by substitution and compensation by other body parts. The clinician must remember that motor learning is a survival mechanism. The principles that the clinician will use in rehabilitation to produce motor learning have already been activated by the functional response to the impairment. Necessity or affinity, repetition, and reinforcement have been used to avoid pain or produce alternative movements since onset of the symptoms. Therefore, a new motor program has been activated

Box 19-5 Most Common Postures Used in Corrective Exercise

Supine and prone	Kneeling and half kneeling
Prone on elbows	Symmetric and asymmetric stance
Quadruped	Single-leg stance
Sitting and unstable sitting	

to manage the impairment and produce some level of function that is usually viewed as dysfunction. It should be considered a natural and appropriate response of the body reacting to limitation or symptoms. The body will sacrifice quality of movement to maintain a degree of quantity of movement. Taking this into consideration, 2 distinct needs are presented.

Posture for Protection and Inhibition The clinician must restrict or inhibit the inappropriate motor program. In the case of a control or stability problem, the patient must have some form of support, protection, or facilitation. Otherwise, the inappropriate program will take over in an attempt to protect and respond to the postural demand. Although most adult patients function at the necessary skill level, on evaluation, many qualitative problems are noted. Inappropriate joint loading and locking, poor tonic responses, or even tonic holding can be observed with simple activities. Some joint movements are used excessively, whereas others are unconsciously avoided. Many primary stability problems exist when underlying secondary mobility problems are present. Moreover, in some patients, the mobility problem precedes the stability problem. This is a common explanation for microtraumatic and overuse injuries. It is also why bilateral comparison and assessment of proximal and distal structures are mandatory in the evaluative process. With a mobility problem, a joint is not used appropriately because of weakness or restriction. The primary mobility problem may be the result of compromised stability elsewhere. Motor programs have been created to allow a patient to push on despite the mobility or stability problem. The problems can be managed by mechanical consideration of the mobility and stability status of the patient in the fundamental postures.

For primary stability problems, mechanical support or other assistance must be provided. This can be done simply by partial or complete reduction of stress, which may include non–weight bearing or partial weight bearing of the spine and extremities or temporary bracing. If the stability problem is only in a particular range of movement, that movement must be managed. If an underlying mobility problem is present, it must be managed and temporarily taken out of the initial exercise movement. The alteration in posture can effectively limit complete or partial motion with little need for active control by the patient. The patient must be trained to deal with the stability problem independently of the mobility problem or be at a great mechanical advantage to avoid compensation. The secondary mobility problem, once managed, should be reintroduced in a nonstressful manner so that the previous compensatory pattern is not activated.

Manual articular and soft-tissue techniques, when appropriate, can be used for the primary mobility problem, followed by movement to integrate any improved range and benefit from more appropriate tone. If the limitation in mobility seems to be the result of weakness, one should make sure that the proximal structures have the requisite amount of stability before strengthening and then proceed with strengthening or endurance activities with a focus on recruitment, relaxation, timing, coordination, and reproducibility. Note that the word *resistance* was not used initially. Resistance is not synonymous with strengthening and is only 1 of many techniques used to improve functional movement in early movement reeducation. However, the later sections on position and pattern address resistance in greater detail. Posture should be used to mechanically block or restrict substitution of stronger segments and improve quality at the segment being exercised.

Posture for Recruitment and Facilitation The clinician must facilitate or stimulate the correct motor program, coordination, and sequence of movement. Although verbal and visual feedback is helpful through demonstration and cueing, kinesthetic feedback is paramount to motor learning.[56] Correct body position or posture will improve feedback. The posture and movement that occur early in the developmental sequence require a less complex motor task and activate a more basic motor program. This creates positive feedback and reinforcement and marks the point (posture) at which appropriate and inappropriate actions and reactions meet. From this point, the clinician can manipulate frequency, intensity, and duration, or advance to a more difficult posture in the appropriate sequence.

The clinician must also consider developmental biomechanics by dividing movement ability into 2 categories: internal forces and external forces. Internal forces include the center of gravity, base of support, and line of gravity. External forces include gravity, inertia of the body segment, and ground reaction forces. Accordingly, the clinician should evaluate the patient's abilities in the same manner by first observing management of the mass of the body over the particular base provided by the posture. The clinician then advances the patient toward more external stresses such as inertia, gravity, and ground reaction forces. This interaction requires various degrees of acceleration production, deceleration control, anticipatory weight shifting, and increased proprioception. Resistance and movement can stress static and dynamic postures, but the clinician should also understand that resistance and movement could be used to refine movement and stimulate appropriate reactions.[56] Postures must be chosen that reduce compensation and allow the patient to exercise below the level at which the impairment hinders movement or control. This is easily accomplished by creating "self-limited" exercises.[3] Such exercises require passive or active "locking" by limiting movement of the area that the patient will most likely use to substitute or "cheat" with during exercise.

Figure 19-2 Supine bridging movement

To review, posture identifies the fundamental movements used in growth and development. These movements serve as steps toward the acquisition of skill and are also helpful in the presence of skill when quality is questionable. Figures 19-2 through 19-5 illustrate a few examples of these types of movements.

By following this natural sequence of movement, the clinician can observe the point at which a mobility or stability problem will first limit the quality of a whole movement pattern. The specific posture of the body is as important as the movement that is introduced onto that posture. Clinicians may already know the movement pattern that they want to train, but they also need to consider the posture of the body as the fundamental neuromuscular platform when making a corrective exercise choice. The posture is the soil and the movement is the seed. A chop pattern with the arms can be performed while supine, seated, half kneeling, tall kneeling, and standing. Each posture will require different levels of stability and motor control.

When stability and motor control are the primary problems, a posture must be selected to start the corrective exercise process. A patient with a mild knee sprain or even a total knee replacement may demonstrate segmental rolling to one side, but "logroll" to the other simply to avoid using a flexion-adduction–medial rotation movement pattern with the involved lower extremity. The clinician has now identified where success and failure meet in the developmental sequence. The knee problem creates a dynamic stability problem in the developmental sequence long before partial or full weight bearing is an issue. Consequently, it must be addressed at that level. The patient is provided with an example of how limited knee mobility can greatly affect movement patterns (such as rolling) that seem to require little of the knee. However, by restoring the bilateral segmental rolling function, measurable

Figure 19-3 Rolling to prone

Figure 19-4 Prone on elbows with reaching

qualitative and quantitative improvements in many gait problems can be achieved. With use of postural progression, the earliest level of functional limitation can easily be identified and incorporated into the exercise program. Limitations can also be placed on the posture and movement (the self-limited concept) to control postural compensation and focus. If rolling from prone to supine does not present a problem, a more complex posture can be assumed. The obvious next choice would be to move to quadruped. From the all-fours position, alternate arms and legs can be lifted to an extended and flexed position. They can also be tucked into a flexed and extended position by bringing the alternate knee to the alternate elbow. This causes a significant motor control load by moving from 4 points of stability to 2. The load becomes even greater as movement of the extremities causes weight shifting, which must be managed continuously. If the movements are not compromised, the next progressive posture would be half kneeling with a narrow base. If this narrow-base half-kneeling posture demonstrates asymmetry and dysfunction, this is the posture for which the corrective exercise will be developed. Slightly widening the base improves control, and as control is developed, the base can be narrowed to challenge motor control.

Clinical Pearl

The clinician must define postural levels of success and failure to identify the postural level at which therapeutic exercise intervention should start. Otherwise, the clinician could potentially prescribe exercise at a postural level at which the patient makes significant amounts of inappropriate compensation and substitution during exercise.

Figure 19-5 Half-kneeling position

Position

The word *position* describes not only the location of the anatomic structure (eg, joint, muscle group, or ligament) at which impairment has been identified but also the location (with respect to movement and load) at which the greatest and least limitations occur. The limitations can be either reduced strength and control or restricted movement. The primary questions to ask for this principle appear in Table 19-4. Orthopedic manual assessment of joints and muscles in various functional positions demonstrates the influence of the impairment and symptoms throughout the range of movement. The clinician will identify various deficits. Each will be qualified or quantified through assessment and objective testing, and then addressed through the appropriate dosage and positioning for exercise.

Purpose is the obvious reason for exercise intervention, whereas posture describes the orientation of the body in space. Position refers to the specific mobilizing or stabilizing segment. Attention should be paid to positions of body segments not directly involved in the posture or movement pattern. For the "single-leg bridge" (Figure 19-6), the hip is moving toward extension. If ROM were broken down into thirds, this exercise would involve only the extension third of movement. The flexion third and middle third of movement are not needed because no impairment was identified in those respective ranges. Not only was the hip in extension, but the knee was also in flexion. This is important because the hamstring muscle will try to assist hip extension in the end range of movement when gluteal strength is not optimal. However, the hamstrings cannot assist hip extension to any significant degree because of "active insufficiency." Likewise, the lumbar extensors cannot assist the extension pattern because of the passive stretch placed on them via maximal passive hip flexion. Hip extension proprioception is now void of any inappropriate patterning or compensation from the hamstrings or spinal erectors through the positional use of active and passive insufficiency.[57]

Figure 19-6 Single-leg bridge

Qualitative measures will provide specific information about exercise start and finish position, movement speed and direction, open- and closed-chain considerations, and the need for cueing and feedback. Close observation of the osteokinematic and arthrokinematic relationships for movement and bilateral comparison is the obvious starting point. Specific identification of the structure and position represents mobility observed by selective tension (active, passive, and resisted movements), and the end feel of the joint structures would provide specific information about the mechanical nature of the limitations and symptoms.[58] Assessment of positional static and dynamic control will reveal limitations in stability and provide a more specific starting point for exercise.

Quantitative measures will reveal a degree of deficit, which can be recorded in the form of a percentage through bilateral comparison and compared with normative data when possible. ROM, strength, endurance, and recovery time should be considered, along with many other (quantitative) clinical parameters, to describe isolated or positional function. This will provide clear communication and specific documentation for goals, as well as be a tracking device for the effectiveness of treatment, information that will help define the baseline for initial exercise considerations. As stated earlier, any limitation in mobility or stability requires bilateral comparison, in addition to clearing of the joints above and below. The proximal and distal structures must also be compared with their contralateral counterparts. This central point of physical examination is often overlooked. Cyriax[58] noted, "Positive signs must always be balanced by corroborative negative signs. If a lesion appears to lie at or near one joint, this region must be examined for signs identifying its site. It is equally essential for the adjacent joints and the structures around them to be examined so that, by contrast, their normality can be established. These negative findings then reinforce the positive findings emanating elsewhere; then only can the diagnosis be regarded and established."

After position and movement options are established, a trial exercise session should be used to observe and quantify performance before prescription of exercise. Variables, including intensity and duration, can be used to establish strength or endurance baselines. Bilateral comparison should be used to document a deficit in performance, which is also recorded as a percentage. A maximum repetition test (with or without resistance) to fatigue, onset of symptoms, or loss of exercise quality is a common example. This will allow close tracking of home exercise compliance and help to establish a rate of improvement. If all other factors are addressed, the rate of improvement should be quite large. This is the benefit of correct dosage in prescription of exercise position and appropriate workload. Most of the significant improvement is not a result of training volume, tissue metabolism, or muscle hypertrophy, but of the efficient adaptive response of neural factors.[59] These factors can include motor recruitment efficiency, improved timing, increased proprioceptive awareness, improved agonist/antagonist coordination, appropriate phasic/tonic response to activity, task familiarity, and motor learning, as well as psychological factors. Usually, greater deficits are associated with more drastic improvement. Treatments should be geared to stimulate these changes whenever possible.

Pattern

The primary questions to ask for the pattern principle appear in Table 19-4. The word *pattern* serves as a cue to the clinician to continually consider the functional movements of the human body occurring in unified patterns that occupy 3-dimensional space and cross 3 planes (frontal, sagittal, and transverse).[3] Sometimes this is not easily ascertained by observing the design and use of fixed-axis exercise equipment and the movement patterns suggested in some rehabilitation protocols. The basic patterns of proprioceptive neuromuscular facilitation (PNF), for both the extremities and the spine, are excellent examples of how the brain groups movement. Muscles of the trunk and extremities are recruited in the most advantageous sequence (proprioception) to create movement (mobility) or control (stability) movement. Not only does this provide efficient and economical function, but it also effectively protects the respective joints and muscles from undue stress and strain. Voss et al[60] clearly and eloquently stated, "The mass movement patterns of facilitation are spiral and diagonal in character and closely resemble the movements used in sports and work activities. The spiral and diagonal character is in keeping with the spiral rotatory characteristics of the skeletal system of bones and joints and the ligamentous structures. This type of motion is also in harmony with the topographical alignment of the muscles from origin to insertion and with the structural characteristics of the individual muscles." When a structure within the sequence is limited by impairment, the entire pattern is limited in some way. The clinician should document the limited pattern, as well as the isolated segment causing the pattern to be limited. The isolated segment is usually identified in the evaluation process and outlined in the "position" considerations. The resultant effect on one or more movement patterns must also be investigated. A review of the basic PNF patterns can be beneficial to the rehabilitation specialist. Once a structure is evaluated, one should look at the basic PNF patterns involving that structure. Multiple patterns can be limited in some way, but usually one pattern in particular will demonstrate significantly reduced function. Obviously, poor function in a muscle group or joint can limit the strength, endurance, and ROM of an entire PNF pattern to some degree. However, the clinician must not simply view reduced function of a PNF pattern as an output problem. It should be equally viewed as an input problem. When muscle and joint functions are not optimal, mechanoreceptor and muscle spindle functions are not optimal. This can create an input or proprioceptive problem and greatly distort joint position and muscle tension information, which distorts the initial information (before movement is initiated), as well as feedback (once movement is in progress). Therefore, the clinician cannot consider only functional output. Altered proprioception, if not properly identified and outlined, can unintentionally become part of the recommended exercises and therefore be reinforced. The clinician must focus on synergistic and integrated function at all levels of rehabilitation. An orthopedic outpatient cannot afford to have a problem simply isolated 3 times a week for 30 minutes only to reintegrate the same problem at a subconscious level during necessary daily activities throughout the remaining week. PNF-style movement pattern exercise can often be taught as easily as an isolated movement and will produce a significantly greater benefit. Therapeutic exercise is no longer limited by sets as repetitions of the same activity. Successive intervals of increasing difficulty (although not physically stressful) that build on the accomplishment of an earlier task will reinforce one level of function and continually be a challenge for the next. A simple movement set focused on isolation of a problem can quickly be followed by a pattern that will improve integration. The integration can be followed by a familiar fundamental movement or functional activity that may reduce the amount of conscious and deliberate movement and give the clinician a chance to observe subcortical control of mobility and stability, as well as appropriate use of phasic and tonic responses.

Clinical Pearl

By continuously considering the pattern options, as well as pattern limitations, the clinician will be able to refine the exercise prescription and reduce unnecessary supplemental movements that could easily be incorporated into pattern-based exercise.

Direction, speed, and amount of resistance (or assistance) will be used to produce more refined patterns. Manual resistance, weighted cable or elastic resistance, weight-shifting activities, and even proprioceptive taping can improve recruitment and facilitate coordination. The clinician should refrain from initially discussing specific structural control such as "pelvic tilting" or "scapular retraction." Instead, the clinician should use posture and position to set the initial movement and design proprioceptive feedback to produce a more normal pattern whenever possible.

Reestablishing Proprioception and Neuromuscular Control

Although the concept and value of proprioceptive mechanoreceptors have been documented in the literature, treatment techniques focused on improving their function have not generally been incorporated into the overall rehabilitation program. The neurosensory function of the capsuloligamentous structures has taken a back seat to the mechanical structural role. This is mainly a result of lack of information about how mechanoreceptors contribute to the specific functional activities and how they can be specifically activated.[61,62]

Effects of Injury on the Proprioceptive System

After injury to the capsuloligamentous structures, it is thought that partial deafferentation of the joint occurs as the mechanoreceptors become disrupted. This partial deafferentation may be caused by either direct or indirect injury. Direct effects of trauma include disruption of the joint capsule or ligaments, whereas posttraumatic joint effusion or hemarthrosis[19] illustrate indirect effects.

Whether from a direct or indirect cause, the resultant partial deafferentation alters the afferent information received by the CNS and, therefore, the resulting reflex pathways to the dynamic stabilizing structures. These pathways are required by both the feed-forward and feedback motor control systems to dynamically stabilize the joint. A disruption in the proprioceptive pathway will result in an alteration in position and kinesthesia.[63,64] Barrett[65] showed that there is an increase in the threshold for detection of passive motion in a majority of patients with anterior cruciate ligament (ACL) rupture and functional instability. Corrigan et al,[66] who also found diminished proprioception after ACL rupture, confirmed this finding. Diminished proprioceptive sensitivity has likewise been shown to cause giving way or episodes of instability in the ACL-deficient knee.[67] Therefore, injury to the capsuloligamentous structures not only reduces the mechanical stability of the joint but also diminishes the capability of the dynamic neuromuscular restraint system. Consequently, any aberration in joint motion and position sense will affect both the feed-forward and feedback neuromuscular control systems. Without adequate anticipatory muscle activity, the static structures may be exposed to insult unless the reactive muscle activity can be initiated to contribute to dynamic restraint.

Restoration of Proprioception and Prevention of Reinjury

Although it has been demonstrated that a proprioceptive deficit occurs after knee injury, both kinesthetic awareness and reposition sense can be at least partially restored with surgery and rehabilitation. A number of studies examined proprioception after ACL reconstruction. Barrett[65] measured proprioception after autogenous graft repair and found that proprioception was better after repair than in an average patient with an ACL deficiency but still significantly worse than in a normal knee. He further noted that patients' satisfaction was more closely correlated with their proprioception than with their clinical score.[65] Harter et al[68] could not demonstrate a significant difference in the reproduction of passive positioning between the operative and nonoperative knee at an average of 3 years after ACL reconstruction. Kinesthesia has been reported to be restored after surgery, as detected by a threshold for detection of passive motion in the midrange of motion.[63] A longer threshold for detection of passive motion was observed in a knee with a reconstructed ACL than in the contralateral uninvolved knee when tested at the end ROM.[63] Lephart et al[69] found similar results in patients after arthroscopically assisted ACL reconstruction with a patellar-tendon autograft or allograft. The importance of incorporating a proprioceptive element in any comprehensive rehabilitation program is justified from the results of these studies.

Methods to enhance proprioception after injury or surgery could improve function and decrease the risk for reinjury. Ihara and Nakayama[70] demonstrated a reduction in neuromuscular lag time with dynamic joint control after a 3-week training period on an unstable board. Maintenance of equilibrium and an improvement in reaction to sudden perturbations on the unstable board improved neuromuscular coordination. This phenomenon was first reported by Freeman and Wyke, in 1967, when they stated that proprioceptive deficits could be reduced with training on an unstable surface.[51] They found that proprioceptive training through stabilometry, or training on an unstable surface, significantly reduced episodes of giving way after ankle sprains. Tropp et al[53] confirmed the work of Freeman and Wyke by demonstrating that the results of stabilometry could be improved with coordination training on an unstable board.

Relationship of Proprioception to Function

Barrett[65] demonstrated the relationship between proprioception and function. Their study suggested that limb function relied more on proprioceptive input than on strength during activity. Blackburn and Voight[33] also found high correlation between diminished kinesthesia and the single-leg hop test. The single-leg hop test was chosen for its integrative measure of neuromuscular control because a high degree of proprioceptive sensibility and functional ability is required to successfully propel the body forward and land safely on the limb. Giove et al[71] reported a higher success rate in returning athletes to competitive sports with adequate hamstring rehabilitation. Tibone et al[72] and Ihara and Nakayama[70] found that simple hamstring strengthening alone was not adequate; it was necessary to obtain voluntary or reflex-level control of knee instability for return to functional activities. Walla et al[73] found that 95% of patients were able to successfully avoid surgery after ACL injury when they could achieve "reflex-level" hamstring control. Ihara and Nakayama[70] found that the reflex arc between stressing the ACL and hamstring contraction could be shortened with training. With the use of unstable boards, the researchers were able to successfully decrease the reaction time. Because afferent input is altered after joint injury, proprioceptive sensitivity to retrain these altered afferent pathways is critical for shortening the time lag in muscular reaction to counteract the excessive strain on the passive structures and guard against injury.

Restoration of Efficient Motor Control

How do we modify afferent/efferent characteristics? The mechanoreceptors in and around the respective joints offer information about change in position, motion, and loading of the joint to the CNS, which, in turn, stimulates the muscles around the joint to function.[70] If a time lag exists in the neuromuscular reaction, injury may occur. The shorter the time lag, the less stress on the ligaments and other soft tissue structures around the joint. Therefore, the foundation of neuromuscular control is to facilitate the integration of peripheral sensations related to joint position and then process this information into an effective efferent motor response. The main objective of the rehabilitation program for neuromuscular control is to develop or reestablish the afferent and efferent characteristics around the joint that are essential for dynamic restraint.[21]

Several different afferent and efferent characteristics contribute to efficient regulation of motor control. As discussed earlier, these characteristics include the sensitivity of the mechanoreceptors and facilitation of the afferent neural pathways, enhancement of muscle stiffness, and production of reflex muscle activation. The specific rehabilitation techniques must also take into consideration the levels of CNS integration. For the rehabilitation program to be complete, each of the 3 levels must be addressed to produce dynamic stability. The plasticity of the neuromuscular system permits rapid adaptations during the rehabilitation program that enhance preparatory and reactive activity.[21,40,46,69,70,74]

Clinical Pearl

Specific rehabilitation techniques that produce adaptations to enhance the efficiency of neuromuscular techniques include balance training, biofeedback training, reflex facilitation through reactive training, and eccentric and high-repetition/low-load exercises.[21]

The 3-Phase Rehabilitation Model

The following is a 3-phase model designed to progressively retrain the neuromuscular system for complex functions of sports and ADL (Table 19-6). The model phases are successively more demanding and provide sequential training toward the objective of reestablishment of neuromuscular control. This 3-phase model has also been described as RNT. Ideally, the phases should be followed in order and should use the 4 rehabilitation considerations mentioned earlier (the 4 Ps) at each phase. Application of the 4 Ps at each phase is crucial to place successive demands on the athlete during rehabilitation. In addition, progression of exercise is guided by the 4 × 4 design. The 4 × 4 method of therapeutic exercise design refers to the 4 possible exercise positions combined with the 4 types of resistance used (Table 19-7).

The difficulty of any exercise can be increased by either changing the position (non-weight bearing being the easiest and standing being the toughest) or changing the resistance (unloaded with core activation being the easiest and loaded without core activation being the hardest). It is important to remember that exercises that present too much difficulty will force the patient to revert back to a compensation pattern. Therefore, the first set of exercises following a change in mobility will

Table 19-6 Three-Phase Rehabilitation Model

Phase	Description	Objective
1	Restore static stability through proprioception and kinesthesia	Restoration of proprioception
2	Restore dynamic stability	Encourage preparatory agonist-antagonist cocontraction
3	Restore reactive neuromuscular control	Initiate reflex muscular stabilization

Table 19-7 Four-by-Four Method for Design of Therapeutic Exercise

The 4 Positions	The 4 Types of Resistance
Non-weight bearing (supine or prone)	Unloaded with core activation
Quadruped	Unloaded without core activation
Kneeling (half kneeling or tall kneeling)	Loaded with core activation
Standing (lunge, split, squat, single leg)	Loaded without core activation

give all the information that one needs to know by producing 1 of 3 responses:

- **It is too easy.** The patient can perform the movement for more than 30 repetitions with good quality.
- **It is challenging, but possible.** The patient can perform the movement 8 to 15 times with good quality of movement and no signs of stress. Between 5 and 15 repetitions, however, there is a sharp decline in quality as demonstrated by a limited ability to maintain full ROM, balance, stabilization, and coordination, or the patient just becomes physically fatigued.
- **It is too difficult.** The patient has sloppy, stressful, poorly coordinated movement from the beginning, and it only gets worse.

Using this as a corrective exercise base, the clinician can observe the response and act accordingly. If the initial choice of exercise is too difficult, decrease the difficulty, observe the response to the next set, and repeat the process. If the initial exercise is too easy, increase the difficulty, observe the response to the next set, and repeat the process. Increasing difficulty rarely means increased resistance. A more advanced posture, a smaller base of support, or a more complex or involved movement pattern is usually indicated to increase the difficulty. A typical example is some form of activity with a rolling movement pattern moving to a quadruped exercise, then going to a half-kneeling activity, and finally progressing to movement with a single-leg stance.

Phase I: Restore Static Stability Through Proprioception and Kinesthesia

Functional neuromuscular rehabilitation activities are designed to both restore functional stability about the joint and enhance motor control skills. The RNT program is centered on stimulation of both the peripheral and central reflex pathways to the skeletal muscles. The first objective that should be addressed in the RNT program is restoration of proprioception. Reliable kinesthetic and proprioceptive information provides the foundation on which dynamic stability and motor control is based. It has already been established that altered afferent information received by the CNS can alter the feed-forward and feedback motor control systems. Therefore, the first objective of the RNT program is to restore the neurosensory properties of the damaged structures while at the same time enhancing the sensitivity of the secondary peripheral afferents.[69]

To facilitate appropriate kinesthetic and proprioceptive input into the CNS, joint reposition exercises should be used to provide maximal stimulation of the peripheral mechanoreceptors. The use of closed-kinetic-chain activities creates axial loads that maximally stimulate the articular mechanoreceptors via the increase in compressive force.[10,55] The use of closed-chain exercises not only enhances joint congruency and neurosensory feedback but also minimizes shearing stress about the joint.[75] At the same time, the muscle receptors are facilitated by the change in both length and tension.[10,55] The objective is to induce unanticipated perturbations and thereby stimulate reflex stabilization. Persistent use of these pathways will decrease the response time when an unanticipated joint load occurs.[76] In addition to weightbearing exercises, active and passive joint-repositioning exercises can be used to enhance the conscious appreciation of proprioception. Rhythmic stabilization exercises can

Table 19-8 **Upper-Extremity Neuromuscular Exercises**

Phase I: Proprioception and Kinesthesia	Phase II: Dynamic Stabilization	Phase III: Reactive Neuromuscular Control
Goals		
Normalize motion	Enhance dynamic functional stability	Improve reactive neuromuscular abilities
Restore proprioception and kinesthesia	Reestablish neuromuscular control	Enhance dynamic stability
Establish muscular balance	Restore muscular balance	Improve power and endurance
Diminish pain and inflammation	Maintain normalized motion	Gradual return to activities/throwing
Stability Exercises		
Joint repositioning	PNF D_2 Flex/Ext	PNF D2 Flex/Ext
Movement awareness	Supine	RS with T-band
RS	Side-lying	Perturbation RS
RI	Seated	Perturbation RS—eyes closed
SRH	Standing	90 degree/90 degree
PNF D_2 Flex/Ext	PNF D_2 Flex/Ext at end range	ER at end-range RS
PNF D_2 Flex/Ext RS, SRH, RI	90 degrees/90 ER at end range	ER Conc/Ecc
Side-lying RS, SRH, RI	Scapular strengthening	ER Conc/Ecc RS
Weight bearing (axial compression)	Scapular PNF—RS, SRH	ER/IR Conc/Ecc
Weightbearing RS, RI	ER/IR at 90 degree abduction—eyes closed	ER/IR Conc/Ecc RS
Standing while leaning on hands		Eyes closed
Quadruped position	PNF D_2 Flex/Ext—eyes closed	Standing on one leg
Tripod position	Balance beam	Reactive plyoballs
Biped position	PNF D_2 Flex/Ext—balance beam	Pushups on unstable surface
Axial compression with ball on wall	Slide board—side to side	UE plyometrics
OTIS	Slide board pushups	Two-handed overhead throw
	Axial compression—side to side	Side-to-side overhead throw
	Axial compression—unstable surfaces	One-handed baseball throw
	Plyometrics—two handed (light and easy)	Endurance
		Wall dribble
	Two-handed chest throw	Wall baseball throw
	Two-handed underhand throw	Axial compression circles
		Axial compression—side/side
		Sports specific
		Underweighted throwing
		Overweighted throwing
		Oscillating devices
		Boing
		Body blade

Conc, concentric; Ecc, eccentric; ER, external rotation; Ext, extension; Flex, flexion; IR, internal rotation; OTIS, oscillating techniques for isometric stabilization; PNF, proprioceptive neuromuscular facilitation; RI, reciprocal isometrics; RS, rhythmic stabilization; SRH, slow-reversal-hold; UE, upper extremity.

be included early in the RNT program to enhance neuromuscular coordination in response to unexpected joint translation. The intensity of the exercises can be manipulated by increasing either the weight loaded across the joint or the size of the perturbation (Tables 19-8 and 19-9). The addition of a compressive sleeve, wrap, or taping about the joint can also provide additional proprioceptive information by stimulating the cutaneous mechanoreceptors.[21,65,77,78] Figures 19-7 through 19-10 provide examples of exercises that can be begun in this phase.

Table 19-9 **Lower-Extremity Neuromuscular Exercises**

Phase I: Proprioception and Kinesthesia	Phase II: Dynamic Stabilization	Phase III: Reactive Neuromuscular Control
Goals		
Normalize motion Restore proprioception and kinesthesia Establish muscular balance Diminish pain and inflammation Develop static control and posture	Enhance dynamic functional stability Reestablish neuromuscular control Restore muscular balance Maintain normalized motion	Improve reactive neuromuscular abilities Enhance dynamic stability Improve power and endurance Gradual return to activities, running, jumping, cutting
Stability Exercises		
Bilateral to unilateral Eyes open to eyes closed Stable to unstable surfaces Level surfaces Foam pad Controlled to uncontrolled PNF Rhythmic stabilization Rhythmic isometrics Slow reversal hold	OTIS AWS PWS MWS LWS Chops/lifts ITIS PACE PNF Rhythmic stabilization Rhythmic isometrics Slow-reversal-hold Stable to unstable surface Rocker board Wobble board BAPS Balance beam Foam rollers DynaDisc	Squats Assisted AWS PWS MWS LWS Chops/lifts Lunges (front and lateral) AWS PWS MWS LWS Stationary walking with unidirectional WS Stationary running PWS MWS LWS AWS Mountain climber CKC side to side Fitter Slide board Plyometrics Jumps in place Standing jumps Bounding Multiple hops and bounds Hops with rotation Bounds with rotation Resisted lateral bounds Box jumps Depth jumps Multidirectional training Lunges Rock wall Clock drill Step-tos Four-square Agility training

AWS, anterior weight shift; BAPS, biomechanical ankle platform system; CKC, closed-chain kinetic; ITIS, impulse techniques for isometric stabilization; LWS, lateral weight shift; MWS, medial weight shift; OTIS, oscillating techniques for isometric stabilization; PACE, partial-arc controlled exercise; PNF, proprioceptive neuromuscular facilitation; PWS, posterior weight shift; WS, weight shift.

Figure 19-7 Rhythmic stabilization

Figure 19-8 Quadruped position with manual perturbations

Figure 19-9 Single-limb balance on an unstable (foam) base

Figure 19-10 Single-limb balance with oscillating techniques for isometric stabilization

Box 19-6 Balance Variables That Can Be Manipulated in the Dynamic Stability Phase to Produce a Sensory Response

Bilateral to unilateral stance	Stable to unstable surfaces
Eyes open to eyes closed	

Phase II: Restore Dynamic Stability

The second objective of the RNT program is to encourage preparatory agonist-antagonist cocontraction. Efficient coactivation of the musculature restores the normal force couples that are necessary to balance joint forces, increase joint congruency, and thereby reduce the loads imparted onto the static structures.[21] The cornerstone of rehabilitation during this phase is postural stability training. Environmental conditions are manipulated to produce a sensory response (Box 19-6). The use of unstable surfaces allows the clinician to use positions of compromise to produce maximal afferent input into the spinal cord and thus produce a reflex response. Dynamic coactivation of the muscles about the joint to produce a stabilizing force requires both the feed-forward and feedback motor control systems. To facilitate these pathways, the joint must be placed in positions of compromise for the patient to develop reactive stabilizing strategies. Although it was once believed that the speed of the stretch reflexes could not be directly enhanced, efforts to do so have been successful in human and animal studies. This has significant implications for reestablishing the reactive capability of the dynamic restraint system. Reducing electromechanical delay between joint loading and protective muscle activation can increase dynamic stability. In the controlled clinical environment, positions of vulnerability can be used safely (see Tables 19-8 and 19-9). Figures 19-11 and 19-12 provide examples of exercises that can be implemented in this phase.

Figure 19-11 Plyoback, two-handed upper-extremity chest pass

Figure 19-12 Lunging movement, forward with sport cord resistance

Proprioceptive training for functionally unstable joints after injury has been documented in the literature.[38,53,70,79] Tropp et al[53] and Wester et al[80] reported that ankle disk training significantly reduced the incidence of ankle sprains. Concerning the mechanism of the effects, Tropp et al[53] suggested that unstable surface training reduced the proprioceptive deficit. Sheth et al[79] demonstrated changes in healthy adults in patterns of contraction of the inversion and eversion musculature before and after training on an unstable surface. They concluded that the changes would be supported by the concept of reciprocal Ia inhibition via the mechanoreceptors in the muscles. Konradsen and Ravin[81] also suggested from their work that afferent input from the calf musculature was responsible for dynamic protection against sudden ankle inversion stress. Pinstaar et al[82] reported that postural sway was restored after 8 weeks of ankle disk training when performed 3 to 5 times a week. Tropp and Odenrick also showed that postural control improved after 6 weeks of training when performed 15 minutes per day.[39] Bernier and Perrin,[54] whose program consisted of balance exercises progressing from simple to complex sessions (3 times a week for 10 minutes each time), also found that postural sway was improved after 6 weeks of training. Although each of these training programs do have some differences, postural control improved after 6 to 8 weeks of proprioceptive training in subjects with functional instability of the ankle.

Phase III: Restore Reactive Neuromuscular Control

Dynamic reactive neuromuscular control activities should be initiated into the overall rehabilitation program after adequate healing and dynamic stability have been achieved. The key objective is to initiate reflex muscular stabilization.

Progression of these activities is predicated on the athlete satisfactorily completing the activities that are considered prerequisites for the activity being considered. With this in mind, progression of activities must be goal oriented and specific to the tasks that will be expected of the athlete.

The general progression of activities to develop dynamic reactive neuromuscular control is from slow-speed to fast-speed activities, from low-force to high-force activities, and from controlled to uncontrolled activities. Initially, these exercises should evoke a balance reaction or weight shift in the lower extremities and ultimately progress to a movement pattern. A sudden alteration in joint position induced by either the clinician or the athlete may decrease the response time and serve to develop reactive strategies to unexpected events. These reactions can be as simple as static control with little or no visible movement or as complex as a dynamic plyometric response requiring explosive acceleration, deceleration, or change in direction. The exercises will allow the clinician to challenge the patient by using visual or proprioceptive input, or both, via tubing (oscillating techniques for isometric stabilization) and other devices (eg, medicine balls, foam rolls, or visual obstacles). Although these exercises will improve physiologic parameters, they are specifically designed to facilitate neuromuscular reactions. Therefore, the clinician must be concerned with the kinesthetic input and quality of the movement patterns rather than the particular number of sets and repetitions. When fatigue occurs, motor control becomes poor and all training effects are lost. Therefore, during the exercise progression, all aspects of normal function should be observed, including isometric, concentric, and eccentric muscle control; articular loading and unloading; balance control during weight shifting and changes in direction; controlled acceleration and deceleration; and demonstration of both conscious and unconscious control (see Tables 19-7 and 19-8). Figures 19-13 through 19-15 are examples of exercises that can be implemented in this phase.

When dynamic stability and reflex stabilization have been achieved, the focus of the neuromuscular rehabilitation program is to restore ADL and sport-specific skills. It is

Figure 19-13 Dynamic training; Body Blade, low position

Figure 19-14 Dynamic training; Body Blade, elevated position

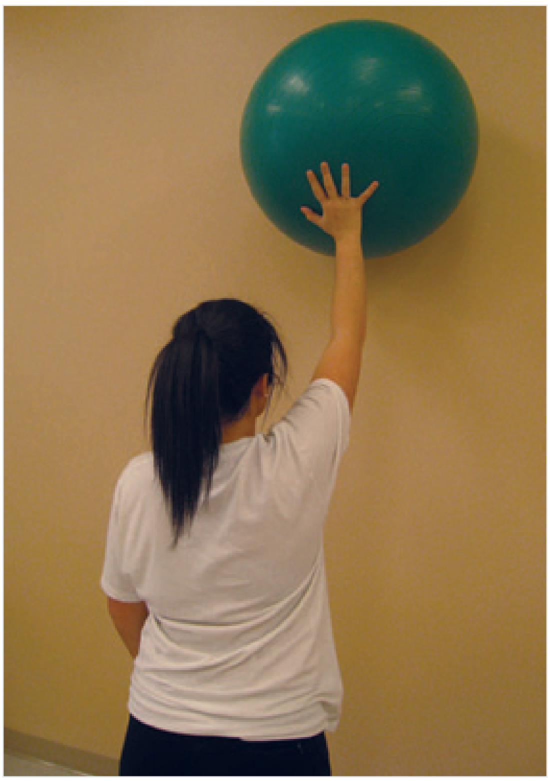

Figure 19-15 Elevated wall dribble

essential that the exercise program be specific to the patient's needs. The most important factor to consider during rehabilitation of patients is that they should be performing functional activities that simulate their ADL requirements. This rule applies not only to the specific joints involved but also to the speed and amplitude of movement required in ADL. Exercise and training drills that will refine the physiologic parameters required for return to preinjury levels of function should be incorporated into the program. The progression should be from straight plane to multiplane movement patterns. ADL movement does not occur along a single joint or plane of movement. Therefore, exercise for the kinetic chain must involve all 3 planes simultaneously. Emphasis in the RNT program must be placed on progression from simple to complex neuromotor patterns that are specific to the demands placed on the patient during function. The function progression breaks an activity down into its component parts so that they can be performed in a sequence that allows acquisition or reacquisition of the activity. Basic conditioning and skill acquisition must be achieved before advanced conditioning and skill acquisition. The training program should begin with simple activities, such as walking/running, and then progress to highly complex motor skills requiring refined neuromuscular mechanisms, including proprioceptive and kinesthetic awareness, which provides reflex joint stabilization. A significant amount of "controlled chaos" should be included in the program. Unexpected activities during ADL are by nature unstable. The more patients rehearse in this type of environment, the better they will react under unrehearsed conditions. The clinician needs to learn how to categorize, prioritize, and plan effectively because corrective exercises will evolve and equipment will change. The clinician's professional skill must be based in a systematic approach. Just being great at a technique is not good enough. Technical aspects of exercise will change. The clinician should not worry. This system is not based on exercise. It is based on human movement, not equipment, techniques, or trends. The final and most important consideration of this phase is to make the rehabilitation program fun. The first 3 letters of functional are FUN. If the program is not fun, compliance will suffer and so will the results.

SUMMARY

1. Increased attention has been devoted to the development of balance, proprioception, and neuromuscular control in the rehabilitation and reconditioning of athletes after injury.
2. It is believed that injury results in altered somatosensory input, which influences neuromuscular control.
3. If static and dynamic balance and neuromuscular control are not reestablished after injury, the patient will be susceptible to recurrent injury and performance may decline.
4. The 3-phase model for RNT may be an excellent method to assist athletes in regaining optimal neuromuscular performance and high-level function after injury or surgery.
5. The 3-phase model consists of restoring static stability through proprioception and kinesthesia, dynamic stability, and reactive neuromuscular control.
6. Current information has been synthesized to produce a new perspective for therapeutic exercise decisions. This new perspective was specifically designed to improve treatment efficiency and effectiveness and have a focus on function.
7. The 4 principles of purpose, posture, position, and pattern assist problem solving by providing a framework that categorizes clinical information in a hierarchy.
8. The 4 principles serve as quick reminders of the hierarchy, interaction, and application for each therapeutic exercise prescription principle. The questions of *what*, *when*, *where*, and *how* for functional movement assessment and exercise prescription are answered in the appropriate order.
   a. Functional evaluation and assessment = purpose.
   b. Identification of motor control = posture.
   c. Identification of osteokinematic and arthrokinematic limitations = position.
   d. Integration of synergistic movement patterns = pattern.
9. The clinician should always ask whether the program makes sense. If it does not make sense, it is probably not functional and therefore not optimally effective.
10. Clinical wisdom is the result of experience and applied knowledge. Intense familiarity and practical observation improve application. To be of benefit, the knowledge available must be organized and tempered by an objective and inclusive framework. It is hoped that this framework will provide a starting point to better organize and apply each clinician's knowledge and experience of functional exercise prescription.

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