CLINICAL COMMENTARY

# THE CHOP AND LIFT RECONSIDERED: INTEGRATING NEUROMUSCULAR PRINCIPLES INTO ORTHOPEDIC AND SPORTS REHABILITATION.

**Michael L Voight, PT, DHSc, OCS, SCS, ATC, CSCS**[a]
**Barbara J Hoogenboom, PT, EdD, SCS, ATC**[b]
**Gray Cook, MSPT, OCS, CSCS**[c]

## ABSTRACT

The upper extremity bilateral PNF patterns, better known as the "chop and lift" are well known to physical therapists. These patterns which utilize spiral and diagonal motions of the upper extremity can be used for both assessment and treatment of sports and orthopedic injuries. Half kneeling and tall kneeling postures fall between low-level postures such as rolling and 4-point, and high-level postures of standing and walking. Half kneeling and tall kneeling can be considered transitional postures. When the chop and lift patterns are used in conjunction with the half and tall kneeling developmental postures, the techniques are an excellent assessment of core stability/instability. Combinations of the upper extremity patterns and the developmental postures can be powerful corrective training techniques. The combined experience of the three authors is used to describe techniques for equipment setup, testing, assessment, and treatment of athletic imbalances. These techniques require and promote instantaneous local muscular activity as developmental postures and balance reactions are incorporated. The therapeutic use of both PNF and developmental patterns has been a hallmark of rehabilitation of patients with neurologic dysfunction, but can be equally and effectively applied in the sports and orthopedic rehabilitation setting.

***Key Words:*** PNF, chop and lift patterns, reflex stabilization

**CORRESPONDENCE:**
Michael L Voight
Professor- Belmont University
School of Physical Therapy
1900 Belmont Blvd
Nashville, TN 37215
Email: voightm@mail.belmont.edu

[a] Belmont University School of Physical Therapy Nashville, TN

[b] Grand Valley State University School of Physical Therapy, Grand Rapids, MI

[c] Averett University Danville, VA

## INTRODUCTION

In orthopedic rehabilitation and conditioning, discovering a totally "new" exercise, testing method, or performance enhancement technique is rare. Although many skilled clinicians frequently create alternate versions of traditional exercises, a totally unique exercise or theory of exercise is uncommon. What often serves the professional involved in rehabilitation of patients and clients is a "new twist" on an older exercise or exercise concept. The bilateral upper extremity proprioceptive neuromuscular facilitation (PNF) patterns known as the chop and lift have a long history in rehabilitation, with roots in rehabilitation of clients with neuromuscular diagnoses. Equally time honored are the postures and patterns of growth and development such as kneeling and half kneeling.

The upper extremity chop and lift patterns are well known to most rehabilitation providers from the concepts and theory attributable to PNF. The original descriptors of these concepts were published by Margaret Knott and Dorothy Voss in 1956.[1] Despite early historical rehabilitation strategies that promoted "one motion, one joint, one muscle at a time," [1] the upper extremity chopping and lifting patterns arose from the upper extremity PNF diagonal patterns that are both spiral and diagonal in nature. The use of such spiral and diagonal patterns are observed to be much like normal human movements that are integrated and efficient without conscious attention to and awareness of the neurophysiologic input.

Unilateral PNF diagonal patterns have been used in sports physical therapy, athletic training, and orthopedic rehabilitation for many years with additions of manual resistance, weights, and elastic resistance in a variety of positions (supine, sitting, standing, etc.). The chop and lift patterns are applications of the upper extremity diagonals that involve the use of bilateral upper extremities. One upper extremity is performing the diagonal one pattern, while the other upper extremity is performing the diagonal two pattern, either both moving into flexion, "the lift" (figure 1A) or extension "the chop" (figure 1B) while using rotational (spiral) and diagonal/combination movements that cross the midline. The chop and lift patterns are combined movements of paired extremities which are asymmetrical.[1]

**Figures 1A and 1B.** *The traditional PNF lift pattern, 1A: Start position, 1B: Finish position.*

Interestingly, these same movements can be used to address impairments or movement asymmetries. Detecting a muscular imbalance requires a thorough musculoskeletal examination. Special tests such as the Thomas test or FABER test of the hip assist in identification of asymmetrical dysfunction. Knapik et al[2] noted that although weakness of a particular muscle group could be linked with injury, a significant number of injuries were noted in athletes with right-left strength or flexibility asymmetry. Use of a gross movement assessment may assist in identification of movement pattern imbalances and asymmetries. It is efficient and appropriate to look first at gross movement patterns for the presentation of limitation and asymmetry in order to utilize a consistent and reliable system to assist in the deductive problem solving process. If impairments are resolved but dysfunction remains, further clinical investigation is needed. Either additional impairments are present or the dysfunction needs to be addressed at a functional level where timing, muscular recruitment, and reflex stabilization can be addressed in order to retrain the pattern.

The chop and lift represent distinct spiral and diagonal movements that mimic functional patterns occurring in both sport and activities of daily living. These movements capitalize on the principles of proximal to distal and distal to proximal overflow (also known in the PNF literature as irradiation)[1]. According to Knott and Voss,[1] distal to proximal sequencing is essential to improvement of motor abilities. Reinforcement of the movements by addition of resistance may strengthen the response in a weaker portion of the pattern. Coordinated movements of multiple muscles acting in a kinetic sequence helps to provide sequential, fine-tuned muscular actions.

The chop and lift motions also are excellent at recruiting the musculature of the

core either for mobility or stability. When a destabilizing force acts on the trunk, a proper temporal and spatial recruitment of the core musculature is required to protect the spine.[3,4] Research has shown that when a limb is used to challenge the position of the body, a reactive force is produced within the body that is equal in magnitude but opposite in direction to the forces producing the destabilizing movement.[5-8] In other words, when the shoulder girdle and upper extremity moves in a diagonal chopping movement pattern, the destabilizing force acting on the center of mass is anterior causing the trunk to flex. The reactive stabilizing force (reactive strategy) is downward and backward to counteract the trunk movement. If these forces are equal or balanced, no net movement of the trunk occurs. In individuals without dysfunction, movement of the upper extremity is preceded by contraction of the erector spinae, multifidi, transversus abdominis, and both the internal and external oblique muscles. The early activation of these core muscles is not direction specific with regard to upper extremity movement.[7, 9] This muscle activation must be preprogrammed by the central nervous system because the muscles activation occurs in advance of the onset of activity of the muscles responsible for limb movement. Because proximal stability precedes distal mobility and postural adaptations are necessary for purposeful extremity movement, the use of these motions can be very effective in training the core. In individuals with dysfunction, the contraction of the core stabilizing muscles is delayed and, therefore, absent from the period preceding the onset of movement.

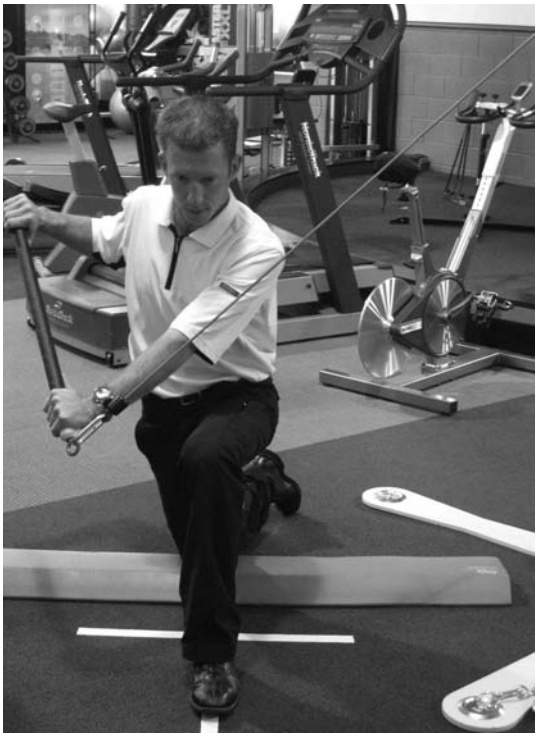

**Figure 2.** *The chop pattern performed in half kneeling with tubing resistance and stick.*

The "new twist" in this article, is the use of tall kneeling and half kneeling postures during the chop and lift patterns to add another dimension to functional assessment and training. The tall and half kneeling postures are developmental steps on the ladder of function. These two lower body postures are familiar to rehabilitation providers who practice neuro-developmental strategies during treatment of patients whose central nervous system function is compromised. Earliest or lowest developmental postures include bridging, quadruped, planking, and rolling. The highest level developmental posture is standing ("floor based" upright postures) or other functional postures which offer challenges to multiple systems (neuromuscular, proprioceptive/coordination, vestibular, etc.) with little external input. The authors of this article prefer the term "transitional postures" to describe the two kneeling postures. These transitional postures will be emphasized due to their ability to stress or recruit the smaller stabilizing muscles of the core.[10] The standing posture offers a wide, adaptable base of support that utilizes all portions of the lower extremity kinetic chain. In contrast, tall- and half-kneeling offer narrowed bases of support, rendering distal portions of the kinetic chain unable to assist in corrective movements. When these narrowed bases are combined with the chop and lift patterns, problems that appear minimal with a wider base are magnified. Wider than necessary bases of support are often used to compensate for poor stability, and subsequently reduce efficiency, compromise fluid movement transitions, and diminish the appropriate weight shifting during activities. Tall kneeling creates challenge to balance reactions in anterior and posterior directions. Half

**Figure 3.** *The chop pattern performed in tall kneeling with tubing resistance and stick.*

kneeling creates challenge to balance reactions laterally. Transitional postures can also aid the orthopedic rehabilitation specialist who is retraining movement patterns*(Figure 2,3)*.

For athletes, the legs often are the driving force behind complex, multi-segmental kinetic chain movements, such as the swing of a bat or the act of throwing a ball. Patients and clients place themselves in potentially injurious conditions if they use only their global muscles to stabilize the trunk during functional activities.[11] The small, local stabilizers of the core cannot possibly be stronger than the large, global muscles; therefore, the goal of training is not to isolate and selectively condition groups of stabilizers with conventional concentric exercises, but rather to work on reflex stabilization. Reactive neuromuscular training attempts to bridge the gap from traditional isolation strength training and quick reflexive muscle activation.[12] Many treatment philosophies use the concept of reflex stabilization or training of a motor program for effective stabilization of the core.[13-15] The global and local muscles must be programmed to react quickly in order to provide normal, effective reflex stabilization.[15] Frequently the muscles of the core do not receive adequate training, and the legs are used to compensate for the weakness of the torso. By using the kneeling postures during assessment, inappropriate compensatory strategies are temporarily removed from the activity in order to examine right-left asymmetry with respect to chop and lift patterns.

**Figure 4.** *End position of the lift pattern performed with cable column.*

Asymmetry of chop and lift performance may implicate deficits within the underlying reflex stabilization mechanism. Likewise, if the legs are removed from the task, upper extremity or core dysfunction and asymmetries will be magnified. If the movement imbalance happens to be within the legs, the imbalance will be obvious when the legs are added back into the movement. By using spiral and diagonal movements that challenge the core through upper extremity movement, proximal stability is emphasized with the distal mobility training. As such, proximal to distal overflow and distal to proximal overflow principles inherent to the practice of PNF are utilized in simple testing and training techniques.[1]

The techniques described in this clinical commentary do not "excuse" the therapist from treatment for basic mobility issues prior to training for stability. Since the half and tall kneeling chop and lift corrective strategies are classified as stabilization activities, it is important to manage soft tissue and articular mobility issues that would compromise the posture or movement pattern. If stabilization exercise is performed in the presence of limited mobility, the level of mobility will be reinforced. Proper positioning of the half and tall kneeling require a tall neutral spine and near 0º of hip extension (not hyperextension). The chop and lift patterns require mobility of thoracic extension and rotation, as well as scapulothoracic and glenohumeral articulations.

## SPECIFIC EQUIPMENT

A high-low pulley system or cable machine is the most user friendly piece of equipment with which to perform the chop and lift exercises. On a high-low cable machine, a cable from a low pulley can be pulled up or a cable from a high pulley can be pulled down. A large amount of weight is not needed because a long lever arm exists and many body parts contribute to the movement *(Figure 4)*.

An elastic tubing system can also be used to create the resistance necessary for training using the chop and lift pattern. With a conventional pulley system, the weight does not change throughout the movement, whereas elastic tension builds as elongation occurs. In addition, elastic resistance does not develop inertia. Thus, quicker and brisker movements can be used without inertia or jerking that would be noted on in a pulley system. An appropriate handle attachment is important, preferably a rigid stick with a secured eyelet in one end *(Figures 5,6)*.

### Half-Kneeling Chop and Lift as Testing and Training Movements

Once a functional movement assessment/screen has been performed, take note as to whether a symmetrical (bilateral) or asymmetrical (unilateral) dysfunction is identified. Half kneeling chopping and lifting is usually performed when an asymmetrical problem is identified. Asymmetrical movements are movements where a left-right assessment reveals obvious functional differences either qualitatively or quantitatively. Chopping and lifting

**Figure 5A-5B.** *Half kneeling chop using tubing resistance and stick, A = start position, B = finish position.*

patterns are not used in the context of this commentary to enhance performance of the specific task of chop and lift. Rather, the patterns represent a unique way to standardize assessment of and magnify dysfunction in patients. A good rule to follow is to use the tall kneeling chop/lift posture when no stability asymmetry is present in the lower quarter but when upper quarter stability asymmetry is suspected. This position will provide the same base when testing chops and lifts to the left and right sides. When movement patterns show lower quarter stability asymmetries or a combination of lower and upper quarter stability asymmetries, use half kneeling posture for assessment and treatment. If the patient has an functional asymmetry in the lower quarter (Trendelenberg dysfunction in single limb stance, valgus collapse in stepping, inappropriate weight shifting in squatting) as compared to stability problem in the upper quarter (scapular instability, inappropriate tone of the upper trapezius muscle, inconsistencies of thoracic spine motion in standing which resolves in sitting) or they have a combination of symmetrical and asymmetrical dysfunction, focus on the asymmetry first. By first assessing and correcting the side to side asymmetry, the body is best prepared to then address symmetrical dysfunction. When a unilateral lower extremity test or screen shows a deficit, a half kneeling position on that side will demonstrate adaptations made by the core in order to compensate for the problems of static stability of lower body. The compensation may be identifiable when comparing the half kneeling position between sides. However, adding the chop or lift motion to the position will magnify the difference in mobility and stability, so the quality of the movement must be closely monitored. The use of a video camera may capture data that might not be apparent to the naked eye.

The half-kneeling chop and lift is an excellent starting point for movement imbalance training. In order to determine where to begin with training, an assessment of function in the chop and lift patterns must be undertaken. In order to assess function, find a weight that is comfortable for more than eight repetitions and then perform the chop and lift movement for as many repetitions as possible without compensation, loss of form, or excessive fatigue on one side. Take special note of left and right differences with both the chop and the lift. Repeat this on the other side. The left-right differences in those repetitions will indicate the extent of movement imbalance. Both the chop and lift will probably show left-right differences, but identify the movement that had the greatest discrepancy between left and right. Differences in the ability to perform repetitions of 10 to 15 percent as compared to the opposite side are acceptable and considered to be a

**Figure 6A-6B.** *Half kneeling lift using tubing resistance and stick, A = start position, B finish position.*

result of the fact that most people have a dominant upper extremity for functional tasks and activities of daily living. Anything in excess of a 10 to 15 percent right/left difference is considered an unnecessary movement imbalance and should be targeted for intervention.

When progressing from assessment to training using the chop and lift patterns, note that by improving one pattern, you will probably change the other, as they are related. Begin training by targeting the weakest link. Train only that one movement and then retest the right chop, left chop, right lift, and left lift. Note the differences. If improvement is noted but complete symmetry is not achieved, continue with the same program. If adequate improvement is not demonstrated after this exercise intervention, train both the chop and lift imbalances or modify other parameters of the exercise, or reconsider other impairments.

A tip for developing exercise proficiency in the weak pattern (weak quadrant) is to not prescribe a set of 6 or 12 but rather to require 6 to 12 "sets of one". By this, the authors mean separating each repetition into a separate motor performance event, with a small pause in between reps. This helps the therapist and the patient/client focus on precision and correct execution of the movement. Programming and setting up to perform an exercise accurately is more important than performing multiple reps. It should be noted that the body often will sacrifice quality of movement for quantity of repetitions. Precision is the key. Remember the intent is to train reflex stabilization, not attempt to "strengthen" the core stabilizers. Make sure the patient/client does not use momentum. Use proper breathing[14] and solid gripping to stimulate better natural stabilization.

### Half-Kneeling Chop

With one knee down (0/90) and one knee up (90/90) kneel with the designated and reproducible orientation to the source of resistance. The base of support should be narrow with approximately six inches width between the knee of one leg and the heel of the other leg. Use a floor grid or strip of tape on the floor in order to standardize the position of the lower extremities during testing and training *(Figure 7)*.

**Figure 7.** *Half kneeling chop showing the use of floor tape for consistent alignment of the lower extremities during assessment.*

The hips should be directly under the body. The spine should be erect, the pelvis stabilized in neutral position, and the shoulders should be in line with the trunk. When viewing the patient from the side, the ear should be in line with the shoulder, the shoulder in line with the hip, and the hip in line with the knee upon which the patient is kneeling. The knee closest to the side of the resistance is up; the knee furthest away from the resistance is down in the hip extended position. The arms should be elongated with the palms in the down position.

The resistance or tubing should be pulled down and across the body into the open space created by the half-kneeling position, in a spiral and diagonal fashion. When using a stick or long rope, pull the stick or rope to the midpoint of the chest with the lower arm. The angle of pull should remain steady from start to finish. Hold the cable close to the body, forcing a bend in the elbows in the middle of the movement when the cable is closest to the body.

Make a conscious transition into a push with the upper arm downward, continuing the same angle of the initial pull. Keep the cable close to the body. The angle of the cable should not change during the descent, and its orientation in front of the body should stay the same.

Finish the movement by relaxing the lower hand and pushing through to extension with the upper arm. The shoulders should turn minimally or not at all. All of the motion should be in the arms. The trunk and hip are being used in an isometric or stabilizing mode. By pulling down and across the body with the arms, a torque is imposed both on the core and on the hip of the weight bearing knee. The ability to manage this imposed stress and not alter trunk and pelvis/hip posture demonstrates stability. This stability is the foundation of a strength and endurance program.

A common a mistake in the half-kneeling chop is flexion at the hip or in the trunk. Throughout the entire

movement, a gentle stretch should be felt over the front thigh in the muscles that flex the hip and extend the knee. If the trunk is weak, the muscles of the thigh are often activated as a compensatory strategy. The purpose of this exercise is to maintain a stable trunk while the hip provides a stable base. If the hip is moving, a stable base cannot be provided. If the trunk is moving, the exercises will not develop stability. A gentle stretch across the front thigh demonstrates that these muscles are not being contracted. The minute the stress disappears, the front thigh muscles are being incorporated instead of activating the core muscles. Maintain the front thigh stretch throughout the movement.

This exercise is valuable for making left-right comparisons. Ability to hold the position and the quality of movement are the first things to consider when comparing performance between sides. Only after ability to hold and quality of movement is demonstrated bilaterally should the focus be on how many quality repetitions can be completed. An athlete may be able to do the same number of repetitions on each side, but one side may demonstrate constant postural adjustments or display poor mechanics during the movement.

**Half-Kneeling Lift**

The half-kneeling lift is the reverse of the half-kneeling chop. Kneel with the designated and reproducible orientation to the source of resistance with the inside knee down, hip extended, and the outside knee up. This position puts the open space in the cable's path. Use a narrow base and an erect vertical spine. To achieve a more vertical line of pull, it may be necessary to elevate the down, weight bearing knee on a 4-8 inch step *(Figure 8)*.

This position will put the patient further away from the pulley and allow the patient to increase the vertical inclination of the cable. Taller people will need more of a vertical path in the chop and lift, and shorter people will need a less vertical path. Once the patient masters the arm movement, he/she will feel the natural spiral and diagonal nature of the pattern.

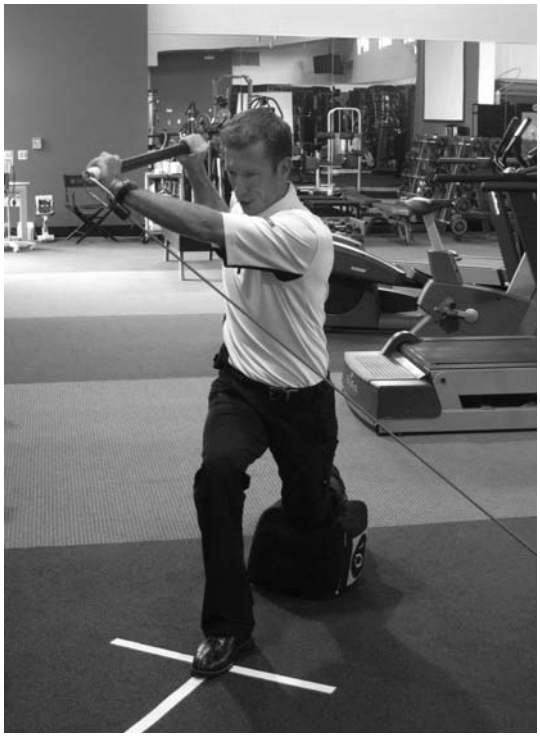

**Figure 8.** *Alteration of the half-kneeling lift posture, showing elevation of the down knee 4-8" to adjust line of pull of the upper extremities.*

If the patient is using a stick or long rope, pull it up to the center of the chest with the palms down, beginning with the outside arm and then finishing with a press of the inside arm. The shoulders should have minimal turn. The movement is a total-arm movement on a stabilized trunk, much like the chop pattern. Maintain the front thigh stretch throughout the entire exercise and compare the left and right side for both quality and repetitions as previously described.

**Tall Kneeling Chop and Lift**

After the half kneeling testing and training sequence has restored symmetry, the tall kneeling testing sequence commences. The tall kneeling chop and lift is the next step to identify an imbalance. If the patient had difficulty with the deep squat during screening, it would be wise to explore chop and lift movement patterns with respect to the tall kneeling. When squatting or forward bending patterns are identified as faulty, tall kneeling is used as a corrective exercise for trunk stability. The tall kneeling position holds both hips in a symmetrical stance and complements spinal stability strategies for squatting. Tall kneeling takes away all compensation occurring at the hip, knee, ankle, and foot. Excessive out-turning of the feet, caving in of the knees, rolling of the ankles, and loss of a stable foot position, compensate for a lack of range of motion or stability within the hips and core. The patient who is quad dominant and hip-flexor dominant is moved into a position where they are unable to use anything but appropriate core stability for performance of the chop and lift movements.

To assume the starting position, the patient kneels so he/she is sitting on their heels with the torso upright. Extend the knees so that an imaginary vertical line connects the ear, shoulder, hips and knees from a side view. Make sure that the hips are fully extended and the pelvis is in neutral alignment. Follow the same instructions for the performance of the half-kneeling chop and lift, but from the tall kneeling position. Maintain the correct position throughout the movement by not flexing the hips, losing pelvic neutral, or losing the tall spine position. If a symmetrical problem has been

identified, perform a chop to the right and to the left with the exact same amount of weight for each direction in a tall kneeling position. Then, perform a lift with the exact same amount of weight for each direction in a tall kneeling position both to the left and to the right. Perform the chop first and use approximately 2/3 greater weight than the lift (this is due to gravity and leverage). Choose a weight, or resistance, that the client can perform 6-12 repetitions and then look for discrepancies in quality and the ability to reach maximum repetitions. Use the description recording grid as described previously for subjective observations. Do not simply pick a weight and have the patient/client perform a set number of repetitions. Lifting the weight should be a mild struggle. This activity is a test for investigating posture, control, stability, strength, body awareness, symmetry, and mobility. The patient should max out on repetitions within 6 to 12 repetitions. Take the test to the point of fatigue, loss of appropriate posture, absence of smooth movement, or to the point where a struggle is demonstrated. Again, video analysis can assist the clinician to capture subtle postural or movement control losses. Follow the same format as the half kneeling chop and lift and remember to compare the right and left sides for both movements. Standardize cable column or tubing position for repeatability during testing. When the test is complete make an assessment of both quality and quantity in four quadrants – the right and left chop and the right and left lift in the tall kneeling position. Find the weakest quadrant and work there until symmetry is restored.

## CONCLUSION

Finding the weakest link chop and lift quadrants is a completely different way to look at core issues in patients. Do not think of the chop and lift patterns as simple, bilateral, asymmetrical, upper extremity exercise. These patterns do not have to look like a functional activity or sport movement in order to be valuable. The movements are primitive patterns that expose the core to three dimensional stresses, incorporating both lower-body weight shifting and upper-body movement. The patterns also work at a slow enough speed to provide feedback about the way a movement is achieved and allow the patient to make corrections. These movement patterns are excellent methods to teach core stability, by laying the foundation for other strength training. The patterns are also simple, reproducible tests of left-right movement pattern balance. Choose half kneeling for asymmetrical problems (half kneeling, lunging, and single leg stance) problems involving one hip to a greater extent than the other and choose tall kneeling for symmetrical problems (squatting, dead-lifting, and simple forward bending) and problems involving the back and hips equally.

Combining the PNF chop and lift patterns with the half kneeling and tall kneeling postures will help the clinician bridge the gap between low level patterns and postures (rolling, crawling, creeping) and high level, functional patterns and postures (squatting, lunging, stepping, pushing, pulling). To this end, the intermediate postures can also be referred to as "transitional patterns and postures." The patterns require and promote instantaneous local muscular activity as they tap into early developmental reflex movement and balance reactions. The therapeutic use of both PNF and developmental patterns has been a hallmark of rehabilitation of patients with neurologic dysfunction, but can be equally and effectively applied in the sports and orthopedic rehabilitation setting. Use of the patterns and postures described in this commentary illustrate the principle of mass movement, described as "characteristic of normal motor activity…that the brain knows nothing of individual muscle action, but knows only of movement."[1] After use of these techniques, the end result is that the patient or client's neuromuscular system becomes integrated and highly organized for action, without awareness of individual muscle action, conscious programming, and other neurophysiologic compensations.[1]

## REFERENCES


1. Voss DE, Ionta MK, Myers BJ. *Proprioceptive Neuromuscular Facilitation. Patterns and Techniques.* Philadelphia, Harper & Row Publishers, 1985.
2. Knapik JJ, Bauman CL, Jones BH, et al: Preseason strength and flexibility imbalances associated with athletic injuries in female collegiate athletes. *Am J Sports Med.* 1992;19:76-81.
3. Panjabi MM. The stabilizing system of the spine. Part I: Function, dysfunction, adaptation, and enhancement. *J Spinal Disorders.* 1992;5:383-389.
4. Panjabi MM. The stabilizing system of the spine. Part II: Neutral zone and stability hypothesis. *J Spinal Disorders.* 1992;5:390-397.
5. Bouisset S, Zattara M. A sequence of postural adjustments precedes voluntary movement. *Neurosci Letters.* 1981;22:263-270.

6. Bouisset S, Zattara M. Biomechanical study of the programming of anticipatory postural adjustments associated with voluntary movement. *J Biomech.* 1987; 20:735-742.

7. Hodges PW, Richardson CA. Relationship between limb movement speed and associated contractions of the trunk muscles. *Ergonomics.* 1997;40:1220-1230.

8. Hodges PW, Cresswell AG, Thorstensson A. Preparatory trunk motion precedes upper limb movement. *Exp Brain Res*. 1999;124:69-79.

9. Hodges PW, Richardson CA. Feedforward contraction of transverses abdominus is not influenced by the direction of arm movement. *Exp Brain Res.* 1997;114:362-370.

10. Tarnanen SP, Ylinen JJ, Siekkinen KM. Effect of isometric upper extremity exercises on the activation of core stabilizing muscles. *Arch Phys Med.* 2008;89:513-521.

11. Cholewicki J, McGill SM. Mechanical stability of the in vivo lumbar spine: Implications for injury and chronic low back pain. *Clin Biomech.* 1996;11:1-15.

12. Voight ML, Hoogenboom BJ, Prentice W. *Musculoskeletal Interventions: Techniques for Therapeutic Exercise.* New York, McGraw-Hill Medical, 2007.

13. Sahrmann SA. *Diagnosis and Treatment of Movement Impairment Syndromes.* St. Louis, Mosby, 2002.

14. Richardson C, Hodges PW, Hides J. *Therapeutic Exercise for Lumbopelvic Stabilization: A Motor Control Approach for the Treatment and Prevention of Low Back Pain,* 2nd edition. London, Elsevier, 2004.

15. Cholewicki J, Panjabi MM. Stabilizing function of the trunk flexor-extensor muscles around a neutral spine. *Spine.* 1997;22:2207-2212.