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EFFECTS OF PROXIMAL STABILITY TRAINING ON SPORT PERFORMANCE AND PROXIMAL STABILITY MEASURES

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ABSTRACT OF DISSERTATION

Thomas Gerard Palmer

The Graduate School

University of Kentucky

2012

EFFECTS OF PROXIMAL STABILITY TRAINING ON SPORT PERFORMANCE AND PROXIMAL STABILITY MEASURES

ABSTRACT OF DISSERTATION

A dissertation submitted in partial fulfillment of the
Requirements for the degree of Doctor of Philosophy
in the College of Health Sciences
at the University of Kentucky

By
Thomas Gerard Palmer

Lexington, Kentucky

Co-Directors: Dr. Carl G. Mattacola, Professor of Athletic Training and

Dr. Dana Howell, Professor of Occupational Therapy

Lexington, Kentucky

2012

ABSTRACT OF DISSERTATION

EFFECTS OF PROXIMAL STABILITY TRAINING ON SPORT PERFORMANCE AND PROXIMAL STABILITY MEASURES

Proximal stability, or the ability to stabilize and actively control the spine, pelvis and trunk, has been reported to influence sport performance. Traditional training practices for the proximal segments have had little success improving sport performance. The purpose of this dissertation was to investigate the effects a sport specific proximal stability training program can have on throwing velocity and measures of muscular endurance and power which target the proximal segments of the pelvis, spine and trunk.

A stratified randomized clinical trial was implemented with a pre- to post-intervention design. Forty-six healthy, Division III collegiate female softball (n=17) and male baseball (n=29) players were randomly assigned to one of two training groups for 7 weeks; a traditional endurance training group (ET) (n=21) or a power stability training group (PS) (n=25). The primary outcome measures were the change in peak throwing velocity/Kg of body weight in mph. Mean throwing velocity, power outputs from a one-repetition maximum chop test and lift test (watts/Kg body weight), and muscular endurance plank tests. Student's independent t-tests were used to compare differences between change scores of all dependent variables. Peak throwing velocity change scores were significantly faster (ET= .21 ±.55 mph, PS= 3.4 ±1.1 mph, $p < .001$) in the PS at post-intervention when compared to the ET group. Change scores were significantly greater in the PS group for mean throwing velocity, (ET= 1.1 ±1.6 mph vs. PS= 3.7 ±1.8 mph, $p < .001$), chop (watts), (ET= 20 ±78 watts vs. PS= 105 ±68 watts, $p < .001$), and lift, (ET= 49 ±62 watts vs. PS= 114 ±73 watts, $p = .003$). There were no change score differences for the side and prone plank endurance measures in seconds ($p \geq .60$). The PS group increased primary outcome measures over the ET program, indicating a more sport specific training regimen targeting the proximal segments is beneficial to both the power measures and throwing performance.

KEYWORDS: Spinal Stability; Core Stability, Exercise Training, Performance Assessment

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DISSERTATION

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Chapter 1: Introduction

Proximal stability, or the ability to stabilize and actively control the lumbar spine, pelvis and trunk, has the potential to influence sport performance. Muscles at the spine, pelvis, and trunk work synergistically to provide varying increments of stability and mobility to facilitate sport tasks. Stability has been defined as a stiff or rigid body segment(s)[1,2] where as mobility is the act of performing dynamic or multi-planar movements.[2-4] In anticipation of movement the body's neurological feed forward mechanism activates the muscles which stabilize the inter-vertebral segments of the lumbar spine.[5-7] Regardless of the task, the rigid lumbar column provides a base of support for the muscles of the pelvis and trunk to generate, absorb, and transfer forces throughout the kinetic chain.[8-10] In sport, proximal stability enables ground reaction forces to be converted into high velocity movements at the extremities, such as seen with throwing or kicking.[4,9,11,12] Therefore, proximal stability has become a center piece for many training and assessment practices used to influence sport performance.[13-16]

Proximal stability has been hypothesized to be specific to the stability and mobility requirements of a given task. The muscle activation patterns at the pelvis, spine and trunk are dependent on the specific stability and mobility demands of a given sport task and require various degrees of muscular endurance, strength and/or power.[9,16-18] This specificity phenomenon referred to as the stability and mobility continuum, is characterized by the specific muscle activation patterns that occur for stability versus mobility tasks.[9] The assumption is that one end of the continuum represents stability or static tasks which have unified on-set, off-set and peak muscle contractions, while the opposite end of the continuum represents dynamic multi-planar movements which have sequential and individual on-set, off-set and peak muscle contractions at the proximal segments.[9,16,18] McGill et al[9] has demonstrated the activation sequence of the proximal musculature varies depending on specific tasks. Coactivation of the muscles about proximal segments provide incremental degrees of muscle stiffness specific to the stability or mobility requirements of a task. More muscle stiffness is established for stability tasks while mobility tasks have less muscle stiffness. Task intensity has also been reported to influence the muscle activation patterns.[9,10,16,19] Low intensity tasks, such as maintaining an up-right posture or an isometric plank position, have been reported to target the transverse abdominis, multifidus, and internal oblique muscles which exclusively stabilize the lumbar spine.[20-25] High intensity tasks have been proposed to target the larger, strength and power generating muscle groups of the trunk and pelvis.[9,16,26] Contrasting movement patterns like throwing a baseball require muscular strength, power and mobility, while a static plank entails muscular endurance, isometric co-contractions and stability at the proximal segments. [9,16] Therefore, it has been proposed that muscular endurance, strength and power are dependent on the amount of mobility desired and the intensity requirements specific to a given task.[9,16,18]

Recent literature suggests proximal stability training and assessment practices for sport should target the specific contributions of muscular endurance,[27] strength, [11,16] and power [9,15,16,28,29] used to establish the stability and mobility schemes specific to the sport in question.[9,18,30] In other words, sport tasks that require multi-planar high intensity and/or linear low intensity positions at the proximal segments should be trained and assessed with stimuli that mimic these movements. It has been proposed that proximal stability training interventions will positively influence force distribution to and from the extremities thus improving sport performance.[13-16] Several authors have reported improvements in proximal stability[31-39] and sport performance measures[36,40-42] following proximal stability training.[33-35,37,38,43] However, to date proximal stability interventions have not been evaluated in a comprehensive manner. For example the traditional training and assessment protocols have focused on isometric muscular endurance movements and not movements which account for muscular endurance, strength and power characteristic specific to sport.[9,44] The limitation with this approach is isometric tasks are often not specific to a sport and are rarely replicated in sport-related activities. Therefore, it has been difficult to fully surmise the current literature and interpret the true effectiveness of proximal stability interventions on sport performance. To better understand the impact proximal stability has on sport performance training and assessment practices, sport specific characteristics related to stability and mobility schemes at the proximal segments should be considered.[18,45]

There are three types of proximal stability intervention studies present in the current literature which include 1) isolated measures of proximal stability (Table 1.1), 2) isolated measures of sport performance (Table 1.2), and/or 3) measures of both proximal stability and sport performance (Table 1.3). It is commonly hypothesized that isolated training of the pelvis, spine and/or trunk may transfer into improvements in sport related performance. Improvements in muscular strength, endurance and EMG activation relative to the pelvis, spine and trunk are well documented following training interventions.[10,19,31,32,46] However, these claims are often supported by studies that neglect to use techniques which account for improvements to the muscular endurance, strength, and power characteristics specific to the proximal stabilizers and the sport.[10,31,32]

In many studies proximal stability is not specifically measured.[40-42,47,48] Authors have failed to provide data to support the concept that improvements in sport are related to proximal stability improvements. Myer et al reported significant improvements in pelvic stability following a perturbation training program specific to the hip and trunk. The authors concluded that the stability changes would transfer into improved performance for sport, but provided no sport performance measures.[31] In addition, proximal stability training has been reported to improve sport performance measures without adequate documentation of a proximal stability assessment. [40-42,47,48] Saeterbakken et al reported a 4.9% increase in throwing velocity following a 6 week unstable limb-suspended sling training program.[40] Seiler et al used a similar intervention and reported significant improvements in golf club velocity among junior golfers,[42] while Sato et al reported improvements in a 5000 m run following an unstable Swiss ball strength training program in middle aged recreational runners.[41] However, one limitation with these studies is the authors did not account for improvements in proximal stability. It is difficult to determine the effectiveness of the training interventions without quantifying improvements at the pelvis, spine, and/or trunk simultaneously with sport performance. The absence of pre to post proximal stability measure(s) makes it difficult to determine if the performance improvements are truly from enhanced proximal stability. There is a need for measuring both proximal stability and sport performance following a training intervention.

Studies which have collectively measured both proximal stability and sport performance have contradictory outcomes due to limitations in the training protocols and/or the assessment techniques used to measure proximal stability and sport performance. To date, Pedersen et al (2011)[36] is the only author to report significant improvements in both proximal stability as measured by isometric hip-abduction test ($p < .01$) and ball velocity for a soccer kick ($p = .04$) following an limb suspension intervention.[36] The authors reported a 33 – 50% improvement in isometric hip-abduction strength and a 3.3 km/hr improvement (93.7±6.8 to 97±5.1 km/hr) in kicking velocity following an intervention. However, the isometric hip-abduction assessment test used to assess proximal stability has not been validated in the literature and the authors did not provide any reliability or validity data regarding the technique.[36] Further, the multifaceted nature and limited research on limb suspended sling and balance-resistance training used in this study make it difficult to determine if this protocol truly targeted just the proximal segments.

Studies which report significant improvements in proximal stability measure(s) often report no effect for sport performance following an intervention.[33,37,43] Several authors have reported significant improvements in isometric endurance tests ($p < .05$), but not for explosive field tests or sport performance in swimming, running, throwing, and rowing.[33,35,37,38,43] The lack of improvement in performance is likely due to limitations in the training and assessment methods and/or specificity training adaptations that occur for with the assessment tests.[49-54]

Many of the proximal stability training interventions presented in the literature exclusively target linear and isometric muscular endurance tasks, not strength and power movements. There is limited support for the idea that endurance training methods are appropriate for sports that use predominately muscular strength and power movements.[38,52] Isometric endurance training may be warranted regardless of the sport due to its role in providing stability at the spine in anticipation of movement.[7,10,55-57] Strength and power movements have been hypothesized as being generated and transferred via the pelvis and trunk.[9,53] The literature supports this claim as muscular endurance training of the proximal stabilizers has been reported to improved muscular endurance and not explosive muscular power.[32,44,52,53,58] Muscular strength and power training for the lower extremity have been reported to influence performance on sport skills and field tests, such as vertical jump.[17,49,59] Therefore, it seems reasonable to consider both muscular endurance and muscular power movements would be more effective to improve sport performance measures than incorporating exercises that target only the endurance capacity of the muscle. There is a lack of evidence regarding the effect a combination of muscular endurance, strength and power training specific to sport may have on proximal stability and sport performance. The use of training stimuli specific to the endurance, strength, and power demands of sport maybe more appropriate in promoting improvements in proximal stability. Sports which require more power movements, such as softball, would require more strength and power training rather than endurance training when compared to events, such as, distance running.

One challenge with determining the effect of proximal stability training on performance is that many of the static endurance exercises used to train proximal stability and sport performance are very similar to the proximal stability endurance assessment techniques.[33,35-38] It seems practical that the endurance based interventions predominately reported in the literature have a specificity training effect exclusive to isometric endurance tests and not to field tests that are more explosive in nature. The literature supports the use of linear isometric endurance planks for assessing static muscular endurance of the proximal stabilizers; however these measures seem inappropriate for assessing explosive dynamic multi-planar tasks associated with sport.[44] To date, isometric measures have not correlated well with power and agility movements of sport, with correlations ranging from r= 0.3 – to r=0.6.[52,53] Despite the lack of scientific evidence researchers continue to predominately utilize static techniques to investigate improvements in explosive sport performance.[44,52,60]

There is a lack of proximal stability assessment techniques which provide reliable and valid data for power outputs.[17,43,49] However in a recent publication, Shinkle et al (2012) reported moderate correlations (r= .40 to .60) between an explosive medicine ball toss and explosive field tests such as a 1-repetition maximum squat and 40 yard dash.[30] The authors concluded ballistic training and assessment techniques, such as a ball toss, may be more appropriate in stressing proximal stability for movement patterns similar to those in power sports. The chop and lift 1-RM power tests have been recently identified as reliable measures of muscular power that challenge the proximal segments similar to sport.[18,61] Using the chop and lift tests in tandem with the traditional isometric muscular endurance planks may provide clinicians with a more comprehensive measure of proximal stability. The combined measures will allow clinicians to assess the endurance and power characteristic of the proximal stabilizers which are specific to the stability and mobility demands of a particular sport.[18,62]

Statement of the Problem and Purpose

It is unknown if proximal stability training can simultaneously improve measures in both sport performance and proximal stability.[9,18] To date no study has objectively quantified improvements in proximal stability and sport performance specifically focusing the intervention on muscular endurance versus strength and power. Therefore, the purpose of this dissertation was twofold: 1) to determine if a comprehensive proximal stability intervention using endurance, strength and power movements could improve throwing velocity among Division III softball and baseball players when compared to traditional endurance training, and 2) to examine the effects between the different training techniques on proximal stability as measured by the dynamic chop and lift 1-RM power protocol and static isometric endurance planks in a prone and side position.

Experimental Aims and Hypotheses

Specific Aim 1: To determine if a 7 week comprehensive proximal stability training intervention can improve throwing ball velocity and proximal stability measures among Division III softball and baseball players when compared to a traditional muscular endurance training protocol.

Hypothesis 1a: There will be a significant improvement in throwing velocity when the PS group is compared to the ET group.

Hypothesis 1b: There will be a significant improvement in the chop and lift 1-RM power measures when the PS group is compared to the ET group. There will not be an improvement in the prone and side endurance planks in the PS group when compared to the ET group at post-intervention.

Hypothesis 1c: There will be a significant improvement in endurance measures of proximal stability and not in throwing velocity or the chop and lift 1-RM power output tests at post-intervention in the ET group.

Specific Aim 2: To determine if there is a relationship between sport performance measures of throwing velocity and proximal stability measures of endurance planks and the chop and lift 1-RM power output tests among an athletic population.

Hypothesis 2a: There will be a weak correlation ($r < .3$) with isometric endurance proximal stability measures and ball velocity.

Hypothesis 2b: There will be strong statistically significant correlation ($r > .7$) between the 1-RM power chop test and lift test and ball velocity.[45,63]

Clinical Implications

To date there is little to no clinical evidence which supports the hypothesis that proximal stability training can positively influence sport performance. Improvements in sport performance and proximal stability measures following an intervention validate the use of proximal stability training for sport. The sport specific nature of explosive proximal stability assessments and training techniques are likely more appropriate for power sport movements, such as throwing velocity. The findings from this study support further investigation into the specificity of training and assessment practices for sport and proximal stability.

Operational Definitions

Human Kinetic Chain or the anatomical “linkage-system” of the body’s trunk, arms, and legs work in succession to absorb and transmit forces along the adjacent linked segments[64,65] to perform fundamental acts of daily living and sport.[4]

Proximal Stability is the ability within the kinetic chain to stabilize and actively control the lumbar spine, pelvis and trunk. Muscles at the spine, pelvis, and trunk work synergistically to provide proximal stability. Regardless of the task, muscles of the lumbar spine create a stable lumbar column to provide a base of support for the pelvis and trunk musculature to generate, absorb, and transfer forces.

Dynamic Stabilization is the synergistic effort and interdependency of the proximal segments to perform single and multi-planer activities of daily living or sport which require muscular power, strength and/or endurance.

Spinal, Core, or Lumbar Stability is the act of establishing inter-vertebral stiffness by co-contraction of the deep uni-segmental muscles which exclusively support the lumbar spine. [3,66]

Trunk Stability, also referred to as active trunk control, is the act of controlling trunk position over a stable lumbar spine and pelvis.[51,67]

Pelvic Stability is defined as the ability to actively control the pelvic position necessary for the distribution of forces to and from the ground, spine, extremities and body.[68-70]

Stability Mobility Continuum represents the different muscle activation patterns at the proximal segments which are specific to the stability and mobility demands of a particular movement or task.[9] One end of the continuum represents static tasks which have unified on-set, off-set and peak muscle contractions, while the opposite end represents dynamic multi-planar movements which have more individualized on-set, off-set and peak muscle contractions at the proximal segments.[9,16,18]

Proximal Instability refers to the loss of muscular stiffness, weakness and/or ligamentous laxity between adjacent vertebra which translates into excess mobility or instability at a specific structure or joint.[57,71-73]

Muscular Compensation refers to altered muscle activation and stability strategies at the pelvis, spine, and trunk that may lead to decrements in spinal stability, muscular imbalance, and altered stabilization.[57,71,74,75]

Assumptions

It will be assumed that:

1. Self-reported activity levels reflected the current fitness capacity of each subject to the best of their ability.

2. Subjects honored the study process and provided maximal effort for testing and training sessions throughout the study.

3. Subjects in both groups maintained their current level of physical activity during the length of the study.

4. There was no cross contamination between the intervention, “active” control, and true control groups as the team’s strength coach monitored training outside of the intervention training sessions.

5. The 7 week training intervention would provide enough volume and intensity to result in a significant training effect.

Delimitation

1. Subjects were male and females recruited from the same cohort ages of 18 - 23.

2. Subjects were free of orthopedic injuries for the past 6 months.

3. Testing and training sessions were performed by the same certified athletic trainer and strength and conditioning coach with 19 years of experience.

Chapter 1: Tables

Table 1.1: Proximal stability training intervention studies measuring proximal stability performance

Study, Author, Year	Population	Treat Group N	Control Group N	Drop out N	Intervention	Dependent Measures		Results	Comments/Limitations
						Sport Performance	Proximal Stability		
Durall et al (2009)[32]	D-III college female gymnasts, non-athlete female controls	15	15	0	10wks, 20 sessions of endurance training,10 repetitions with 6s holds	None	Hold times Biering-Sorenson, trunk flexion and side planks	Training group improved 47s for the side, 34s for extension and 80s for the trunk flexion ($p < .05$)	No familiarization, possible learning effect, second testing likely a better baseline measure, training was identical to assessments
Myer et al (2008)[31]	Female high school volleyball players	14	7	0	10 wks, 20 sessions of plyometric/ perturbation training	None	Isokinetic hip Abduction, knee extension	Treatment group increased isokinetic peak torque in hip Abduction 15% and 17.1% in dominant and non-dominant leg. No change in knee flexion	Author concluded hip abduction strength were due to gains in proximal stability but did not measure proximal stability
Moffroid et al (1993)[34]	College physical therapy female students	13	12	3	Home program, isometric back extensions, 2x wk for 6 wks	None	Hold times Beiring-Sorenson at 0, 3, 6 wks	17% and 22% increase endurance time for intervention @ 3 and 6 wks ($p < .05$)	Subjects were stratified into high- or low activity, random allocation. No familiarization prior to testing possible learning effect
Stevens et al (2007)[10]	Healthy male/female college students	15	15	0	2x/wk/3 month spinal stabilization prevention program	None	Pre-post-EMG activation on static bridges, kneeling	Higher EMG activation of internal oblique Local to global muscle activation was significantly higher ($p<.01$)	Indicated isometric endurance tasks target the spinal stabilizers v. the global muscles trunk and pelvis. No familiarization, possible learning effect

Table 1.2: Proximal stability training intervention studies measuring sport performance

Study, Author, Year	Population	Treatment Group N	Control Group N	Drop out N	Intervention	Dependent Measures		Results	Comments/Limitations
						Sport Performance	Proximal Stability		
Saeterbakken et al (2011)[40]	High school female handball players	14	10	0	6 wk\12 session, sling, balance training	Throwing velocity	None	Significant increase in throwing velocity (4.9%; p = 0.01)	Difficult to determine if the gains are exclusively from the proximal stabilizers. No proximal stability measure. No familiarization
Sato et al (2009)[41]	Male/female adult, recreation completive runners	12	8	8	4x/wk, 6 wks, Russian twists, planks, Swiss ball	5000 m run, ground reaction forces (GRF)	None	No significant improvement GRF, lower leg stability or run	Subjects were level I or II on Sahrmann test indicating weak prior to training. No practice with Sahrmann test, no post-Sahrmann
Butcher et al (2007)[47]	Male/Female high school contact and non-contact athletes	Groups: trunk (TS=14),leg (LS=13),trunk\leg (TL= 14)	14	1	9 wk low load, low intensity isometric training	Take-off velocity of vertical jump	None	TS, TL improved at 3 wks and not wk 9. (p<.05) LS improved vs all at wk 9 only (p< .05)	Improvements at wk 3 likely due to neurological adaptation. Did thorough familiarization
Thompson et al (2007)[48]	Armature Senior Golf, mean age 70	11	7	0	8 wk total body endurance exercises	Improved Fitness (ROM, Strength)	None	Significant Improvements in club head speed (p< .05)	Activity level not reported, training not isolate to proximal stability. Practice was given but no formal familiarization
Seiler et al (2006)[42]	Junior golf mean age 15	10	10	0	9 wk/18 sessions, sling/ balance training	Golf club speed	None	Club speed increased 1.2% control, 3.7% in training (p<.01)	No description training or activity level of groups. No familiarization. Multiple exercises not necessary targeting proximal stability

Table 1.3: Proximal stability training interventions studies measuring proximal stability and sport performance.

Study, Author, Year	Population	Treatment Group N	Control Group N	Drop out N	Intervention	Dependent Variables		Results	Comments/Limitations
						Sport Performance	Proximal Stability		
Parkhouse et al (2011)[35]	Male/female college recreation athletes	6	6	0	6 wks, 12 endurance stable v. unstable sessions	Ball toss, 20 yard sprint, stork stand, Vertical jump	Leg lowering, isometric planks, isometric back extension	Improved endurance not power tests (p<.05). Post Hoc LSD: Dynamic group improved faster rate	Both training protocols were endurance stimuli. Groups not regular training; gains in neuromuscular adaptation or familiarization
Lust et al (2009)[33]	College baseball, 2 treatment groups, 1 control	Closed chain (8) Open-close-Core, (11)	15	6	6 wks, 18 endurance stable and unstable sessions	Throwing accuracy index	Extension, flexion, and side planks	Significant flexion improvement (p=.003), No change in throwing index	Intervention groups improved in scores, but not significant. Good program progression ideas. No familiarization
Pedersen et al (2006)[36]	Male competitive Soccer players (ages 19-29)	12	9	0	8 wk sling and balance exercise training	Soccer kick velocity, center of pressure velocity	Static pelvic stability hip abduction test	Gains in isometric strength, balance and non-approach kick velocity (p=.04).	Training enhanced neuromuscular control. Hip abduction test not previously reported as valid and reliable. No familiarization
Tse et al (2005)[38]	Male, college rowers	25	20	0	8 wk endurance training	Vertical/broad jump, shuttle, 2000m row	Side Planks, Medicine ball throw	Improve side planks (p=.05), not field tests	Endurance gains specific to training, 20% improvement common, No familiarization
Stanton et al (2004)[37]	Male, basketball/ football High school athletes	8	10	0	6 wks, 12 sessions, Swiss ball Strength; 2 x 8 repetitions	Running efficiency, VO2max	Prone plank on Swiss ball, Sahrmann pressure cuff test	Significant change proximal stability measures (p < .05), not in sport measures	Training was identical to proximal stability measures, Thorough familiarization
Scibek et al (1999) [43]	male/female, DI collegiate swimmers	18	15	2	6 wk, 12 sessions, Swiss ball training	100 yard Swim, vertical Jump, NueroCom	Front/back ball toss	Improved (p<.05) forward ball toss, NueroCom balance, No others	No periodization or familiarization. Training/testing not discussed. learning effect

Chapter 2: Literature Review

Introduction

The purpose of this literature review is to: 1) define proximal stability and its role regarding the body's kinetic chain, 2) discuss basic biomechanical concepts associated with proximal stability and sport performance, 3) provide a historical background of the literature regarding proximal stability, spinal stability and related deficits which affect performance, 4) discuss the current research regarding proximal stability training interventions and the effects on performance outcomes, and 5) discuss the implications for training proximal stability to improve sport performance in throwing velocity.

The Kinetic Chain

The human kinetic chain, or anatomical "linkage-system" of the body's trunk, arms, and legs, works in succession to absorb and transmit forces along the adjacent linked segments [64,65] to perform fundamental acts of daily living and sport.[4] At the center of all body movement, the goal of the kinetic chain is to promote efficient and successive force distribution from the proximal to more distal body segments.[4] Forces are commonly expressed over multiple planes and involve the constant interaction between several body segments during any given movement.[4,12,76] The proximal segments of the pelvis, spine, and trunk play a critical role in providing both stability and mobility for tasks of living. In sport, sequence and timing of proximal to distal segment interactions create both joint rotations and stiffness which result in high linear velocities at the more distal segment(s) and/or the extremities.[4] The inter-segmental dependent forces are transmitted between segments at precisely the time of optimal movement velocity and precision.[12,77] Controlling the angular motions and joint rotations between the adjacent segments contribute to the success or failure of the linear movements. [4,8,12] It has been reported that successful performance of dynamic tasks, such as throwing or kicking, are contingent upon motor control of the proximal muscles to activate prior to the distal segments. [8,12,15,77-79] The end result is commonly a ballistic high velocity movement of the hand or foot in an attempt to withstand a resistance or to propel an object with high directed force.[80]

The Theoretical Model of Spinal Stability

The spinal stabilizing system (SSS) described by Bergmark (1989) and Panjabi (1992) and earlier works have promoted the evolution of the proximal stabilization concept.[1,2,66,71,72] The location of the lumbar spine places it at the body's center of mass where forces are absorbed and transferred throughout the kinetic chain. Spinal integrity or stiffness must be established to provide a proximal support for the distal body segments.[4] Skeletally, the pelvis and trunk are inherently rigid supports while the lumbar spine is supple with five separate joined segments in the vertebrae.[66] The inter-vertebral segments of the spinal column receive forces from multi-directions which must be controlled or redirected in order for body movement and function to be maintained and perform work.[3,66]

The SSS has been described as having three structural subsystems*: passive, active, and neurological*.[3,66] The p*assive* structures are predominately the static or immovable bone and ligaments. The *active* structures consist of the deep and superficial muscles and tendons. The *neurological* or motor control system encompasses the functions of the central nervous system, primarily anticipated and unanticipated neurological feedback. Panjabi (1992) stressed the importance of the interdependent nature of these subsystems to attain spinal stability.[3] He stated that the subsystems must work synergistically to provide optimal and immediate proximal stiffness or a “base of support” at the lumbar spine, which in turn, allows the more distal segments of the pelvis and trunk to counter static and dynamic postural demands.[3,66]

As the spine encounters different postural demands, the inter-vertebral segments are stressed. The supporting *passive* ligaments/capsules maintain static alignment between the adjacent vertebrae and are often stretched to provide static blocks toward the end range of motion. In response, mechanoreceptors initiate afferent proprioceptive *neurological* signals to the central nervous system (CNS). Immediate efferent feedback in the form of *active* muscle stiffness and/or relaxation is initiated to support the impending load(s).[3,9,66,81] McGill et al[82,83] describes the symmetrical alignment of the spinal muscles as supporting guy wires. The local and global muscles are described to act on the proximal segments on three-dimensions to accomplish inter-vertebral, pelvic, and trunk control.[9,82,84] The amplitude and timing of the muscle co-contractions around the spine must work in concert to achieve inter-vertebral stability consistent with the direction and magnitude of the load.[9,16,55,84] It has been reported that inappropriate contraction sequences can cause excess mobility of a single segment resulting in compensatory loads to passive structures or other subsystems resulting in an instability. [57,73,82] Increases in instability accompanied with a perturbation or unexpected movement request puts the spinal stability system in jeopardy of failing.[11,51,85,86] An example of this was reported by Cholewicki et al (1992). Lumbar spine instability of the L-2 vertebra was observed in a weightlifter from a sagittal view using a video fluoroscope. The visual evidence of a spinal instability was accompanied by pain and a failure of the weight lifter to sustain the lift.[73]

The feed forward and feedback neural processes communicate with the active subsystem to anticipate, implement, and alter the warranted spinal stiffness needs.[3,66,72] The spinal muscles work synergistically to balance their individual contributions of stability.[3,66,72] Local muscles provide a rigid spine while the global muscles interact with the forces generated about the trunk and the more distal extremities.[3,66] It has been reported that the complexity of the neuromuscular system allows for immediate spinal stability prior to unexpected perturbations.[51,81] Cholewicki et al reported an increased reflex response of trunk muscle activation and lumbar spine stability prior to the implementation of a sudden trunk load.[5,7,81,87]

The multi-planar motion of the spinal column is guided by a “neutral zone”.[72] When operating optimally the coordinated efforts of the subsystems control spinal segment motion to insure the column stays within a safe range of motion that places negligible stress on the inter-vertebral disks and capsular ligaments. [72] It has been reported that disruption to a subsystem can create inter-vertebral laxity which translates into an increased neutral zone which may alter muscle stability schemes causing an unstable spine and potential weakness.[57,71-73] (Figure 2.1)

Spinal disruptions usually come in the form of pain, injury, degeneration, disease and/or inappropriate motor control patterns.[2,3,71] Originally proposed to occur when a vertebrae is beyond its end range of motion, recent literature has reported spinal degradation to occur at mid-range of the neutral zone and without vertebral displacement.

Commonly associated with low back pain, instability in this area(s) can impede the function of the spine and alter the effectiveness of force distribution at the spine. [3,57,72]

Muscular Supports for Spinal Stability

Naturally unstable, the spine depends greatly on the highly synchronized characteristics of the "local" and "global" musculature about the proximal segments.[1,3,66,82,88] Table 2.1 - 2.2 describe the local and global muscles and movement schemes for the lumbo-pelvic area. The transverse abdominus, multifidus, erector spinae, internal oblique, posterior fibers of internal oblique, the quadratus lumborum, diaphragm, and pelvic floor muscles have been classified as local muscles supporting the lumbar spine curvature and proximal cavity of the pelvis. These smaller and relatively single-jointed muscles provide inter-vertebral stability by means of their deep origin and insertional attachments.[2,65,66] The local muscles anticipate the loads at individual spinal segments and adjacent structures which provide localized mechanical stiffness to the spine.[7,66] The interaction of the local muscles provides a stable "column" responsible for maintaining the curvature and posture of the spine.[2,66,89]

The pelvic floor consists of a deep and superficial muscular layer known as the levator ani and the peroneal, respectively.[90] See Figure 2.2 for the pelvic floor anatomy. The levator ani consists of the caudal vertebral flexors and abductors: ischiococcygeus, ileococcygeus, and pubococcygeus. Collectively, this mass spans from the pubic pectinate line and the obturator internus to the coccyx. The peroneal layer consist of the puborectalis and the puboviceralis muscles which originate at the inferior pubic rami.[90] The puboviceralis muscle is made up of three parts: the pubococcygeus, puborectalis, and puboperineal, which support the deep visceral organs and sphincter function of the abdomen. [90]. It has been reported the pelvic floor muscles co-contract with the deep spinal stabilizers of the spine in anticipation of global muscle activation of the pelvis and trunk.[91-93]

The diaphragm, (Figure 2.3) is the roof of the spinal stability system which assists in maintaining intra-abdominal pressure and spinal stability through co-activation with the transverse abdominis. [94-96] In situations when respiration is under distress the stability provided by the diaphragm has been reported to be compromised.[96] The diaphragm and the pelvic floor muscles act jointly with the abdominal musculature and skeletal structures of the spine to provide proximal stability.[91-93,95,96] Solomonow (1998) suggests the layers of the thoracolumbar fascia and the adjacent appeneurosis of the latissimus dorsi assist to support of the spine and the abdominal musculature similar to a weight-lifting back-belt.[97] The shared attachments to the transverse abdominus allow the fascia to serve as a link between the upper and lower extremities while providing proprioceptive feedback for trunk positioning.[69,97] This assists the entire lumbo-pelvic area to withstand forces from the global muscles and intra-abdominal pressures.[66,98]

The global muscles, which include a portion of the internal oblique, external oblique, latissimus dorsi, gluteus maximus, iliopsoas, and the rectus abdominus, are the larger superficial muscles spanning over several body segments of the pelvis and trunk.[2,3,66] They are responsible for creating, transferring and reducing loads between the thoracic cage and the pelvis.[1,66] The global muscles provide mobility and stability about the proximal segments depending on the given task.[9] Mobility can occur at high forces while stability tends to be incrementally based on intensity of the activity.[2]

The muscular complex of the hip has been suggested by some as a primary component of the proximal spinal stabilizers,[99,100] while others have described the hip involvement as a support structure of the kinetic chain.[16,44,101,102] The close proximity of the hip complex is ideal for force production relative to the pelvis, but not for implementing inter-segmental support to the spinal vertebrae or related structures.[8,9,60,72,77,103] Naito et al (2010) and McGill et al (2009) reported variations in peak EMG muscle activation between the deep transverse abdominis muscle and the distal biceps femoris and gluteus muscles of the hip. The authors concluded the activation patterns demonstrated an interaction between the proximal and distal segments necessary for the distribution of ground reaction forces. While the local muscles stabilize the spine, the forces from the hip assist to overcome rotational inertias about the ground, lower extremity, trunk and throughout the kinetic chain.[9,77] Therefore, the primary role of the hip has been referred to as a generator and mediator of forces transmitted from the ground rather than a stabilizer of the lumbar spine or core.[16,77,101]

Counter-rotation between the trunk and pelvis which normally occurs in acts of walking or throwing, contribute to the body’s ability to perform diagonal movements necessary for daily acts of living and sport.[65] Expressed as the “serape effect”,[104] it has been hypothesized that the contra-lateral pelvis/hip and trunk work in tandem to absorb and distribute loads to and from the extremities through a stable spine.[65,105] The term is coined from the way a Mexican serape or poncho aligns from contra-lateral upper to lower extremity. The contra-lateral connection incorporates activation of the rhomboids, serratus anterior, external obliques and internal obliques muscles.[104] These muscles are commonly active in over-head athletics, the inclusion of diagonal movements, and act as a direct link between the local and global muscles of the lumbo-pelvic area.[8,104,106]

Distinct Roles of the Local and Global Muscles

Several authors have reported that there are distinct responsibilities for the local and global muscles which contribute to proximal stability.[44] Kiefer (1997) used two spinal geometric muscle models to evaluate the distinct stabilizing mechanisms of the local and global activation patterns. Asymmetrical co-contractions of the global muscles were noted while co-contractions of the multifidus muscle was symmetrical during a variety of trunk and arm positions.[23] Others have reported the symmetrical action of the multifidus, transverse abdominis, and quadratus lumborum provide stability similar to guy wires of a bridge. It is commonly thought that the local and global muscles work collectively, but have distinctive roles in providing proximal stabilization. EMG analysis supports the exclusive roles of the global muscles and intra-abdominal pressure to provide stability and mobility predicated upon the intensity and type of task being performed.[9,16,107,108] Hodges et al and others have described the different functional responsibilities of the local and global muscles.[5,109,110] For example, the transverse abdominus and the multifidus muscles have been reported to be active prior to rapid arm movement and prior to the more global muscles of the trunk, i.e. external oblique.[5] The multifidus also acts concurrently with the erector spinae to assist in providing an outlet for force distribution from the deep and proximal muscles to the superficial global muscles.[109] Regardless of arm direction or intensity of movement the deep spinal stabilizing muscles appear to be primarily responsible for providing a stiff lumbar spinal segment.[5] This natural progression of co-contraction provides inter-vertebral stabilization enabling the global muscles position and orient the spine and adjacent segments.[5,22] The data from these studies highlights the anticipatory nature of the proximal stabilizers and offers important insight regarding motor control strategies and training implications.

The extremities rely on the dynamic and static stabilizing capabilities of the proximal kinetic chain to support distal function. Activation of the deep spinal stabilizer muscles has not demonstrated adaptability to task, but has consistently been reported to maintain a predominant role of inter-segmental stability in anticipation of movement.[6,24,108,111,112] The distinct relationship between the local and global muscles provides a nice blueprint for training and assessment practices. It appears that healthy individuals would need to maintain adequate function of this relationship in order to perform movement tasks efficiently. Thus, monitoring functional performance of the local and global muscles is likely a critical piece for training and assessment practices.

Structural Stability and Instability of the Spine

The term stability refers to a mechanical state of equilibrium about a structure.[66,113] The ability to maintain an equilibrium in a position or motion is critical to maintaining the integrity the original state.[113,114] Reported to be relatively weak, the spinal column relies on neuromuscular and ligament properties to maintain adequate degrees of stiffness in response to the loads applied.[113,115] It has been proposed that low levels (5-10%) of maximal voluntary isometric muscular contractions are adequate at providing lumbar stiffness regardless of the task intensity. [98] It has been hypothesized that stability of the spine is directly dependent on the neurological capabilities to control the mass and elastic properties of the proximal segments themselves.[66,82,84] As such, much of the spinal stability is provided by the muscular supports.[87]

Spine Instability

Instability can be defined as a loss of ligamentous stiffness or associated muscle weakness which creates a disequilibrium between spinal segments which can influence performance outcomes.[113] Pope and Panjabi (1985) presented a clinical definition of spinal stability which was characterized by the degree of stiffness provided by the ligaments and muscles about the spine. [84,113] A stable equilibrium is defined as the ability to maintain structural and functional integrity. An unstable equilibrium is an altered state in which the spinal anatomy structure and function cannot provide adequate support for the distal segments. This is important as a disruption to the stabilizing capabilities of the passive structures will directly impact that of the neuromuscular properties of the muscles ability to function properly.[57] Spinal instability commonly progresses from temporary dysfunction to unstable episodes which result in injury or loads that create change to the support structures, such as degenerative articulating facets and laxity in ligament supports.[74,116] Repeated episodes of structural compromise usually result in pain and further damage to support structures. The compromised joint function and stability result in more dysfunction and eventually an unstable vertebral-segment(s) and an inability to effectively transfer forces to and from the proximal to distal segments.[71,74,117,118] Overall, instability can lead to muscle weakness, disuse and poor performance.

A clinical instability of the spine or any anatomical structure may assist in identifying potential contributors to poor performance rooted at the proximal segments. Pain and impaired function of daily activities or sport are often the primary indicators instability exists. However, it has been hypothesized that pain or altered function due to a spine pathology, such as a limb or the inability to bear weight due to a disc lesion at L4-

L5, are preceded by undetectable morphological change(s) to the neuromuscular system.[57] These changes may go unrecognized and perpetuate long before any signs and symptoms of pain and dysfunction are noted. Hides et al attributed statistically significant muscle size asymmetries (p< .05) of 8 % in the multifidus for asymptomatic patients with a history of low back pain. The authors surmised these asymmetries contributed to a potential cyclical insufficiency at the spine. [56] In an attempt to maintain stability the neuromuscular system will adapt and create alternate muscle activation patterns.[3,57] The alternate strategies often compromise impaired joint capsule and ligamentous inter-vertebral mechanoreceptors which result in performance degradation.[57,119] As demands on the spine continue there is excessive stress on the vertebral bodies and supporting capsular ligaments, muscles, and adjacent structures. Joint impairments occur in the form of capsular laxity, irregular disc degeneration, osteophytes, muscle tightness, and hypotrophy or hypertrophy.[3,57,71,75] These physical changes will alter joint function and evoke additional change to the motor control processes of the spine which can alter both simple and complex motor function.[57] Richardson and others have reported delays in muscle activation for the transverse abdominis and multifidus muscles prior to the global muscles to compromise inter-vertebral stability.[73,120,121] However, such changes may contribute to performance deficits but not be detected initially through evaluation.[117,118] The visco-elastic qualities of the passive spinal restrains, such as discs and inter-vertebral capsules are thought to offer restraint in the absence of muscle stiffness.[113] In addition, the larger strength and power muscles of the pelvis and trunk have been hypothesized to compensate for the lack of endurance and stabilizing properties at the spine.[2,57,122,123] Over time the primary stabilizers of the spine become weak and lose the ability to provide a stable proximal column. The cycle of joint impairment and poor muscular support lead to localized dysfunctions between vertebra.[57] Such instability is likely to occur in three dimensions, resulting in impaired structure and function both proximal and distal to the pelvis and trunk.[75] As spinal stability is a center piece of function one cannot fully assume a person without symptoms of pain or weakness does not have compensatory biomechanics which may result in performance deficits.[2,117] Therefore, it may be important to implement training strategies that target spinal stabilization regardless of a person's functional capabilities.

Biomechanical Considerations for Proximal Stability and Force Distribution

The proximal segments of the pelvis, spine and trunk are responsible for distributing and initiating torque necessary to support the movement of the distal segments. For example, when throwing a baseball the adjacent proximal segments become the primary base of supports upon which the arm and legs can move.[4] As ground reaction forces are transmitted from the lower extremity to the pelvis the proximal musculature is responsible for positioning the pelvis, spine and trunk to support high velocity movements of the extremities.[9,11,12] Individual vertebrae of the lumbar, thoracic and cervical spine work in tandem to manage the tri-axial mobility of the trunk needed for throwing.[124] As forces are anticipated and received at the lumbar segments the deep inter-segmental transverse abdominis, multifidus, posterior internal oblique fibers and others are designed to provide ultimate stiffness of the adjacent proximal segments.[9,16,87] Collectively these segments distribute forces distally to adjacent structures about the pelvis, spine, trunk and extremities. [4,12,81] The large and rigid nature of the lumbar vertebrae provide adequate trunk flexion and extension, while trunk rotation is predominately provided by the thoracic and cervical segments.[124] Inter-segmental muscles work successively to resist shear and compressive forces in an attempt to conserve and transfer energy from one segment to the next.[4,12,77,78,124] The propagation of force is transmitted as muscle torques decelerate at the distal end of the joint axis of rotation for each joined segment. The distal ends of the proximal segment(s) become "fixed points" on which the proceeding distal segment(s) can receive and transfer gained momentum.[4,124] This conservation of momentum between adjacent segments will influence the total summation of momentum and the angular velocity at the distal segments.[78] The momentum of a given body segment is the product of the inertia multiplied by the angular velocity at that segment. Thus, the influences on proximal to distal force distribution depends greatly on the mass, distribution of the mass, length, and shape of the inter-dependent segments.

Properties Governing Rotational Inertia about the Kinetic Chain

Rotational inertia or resistance to change in body position during rotational motions will influence the ability to produce angular acceleration at the joint segments. Newton's law of acceleration states angular acceleration is directly proportionate to the torque generated at the joint segments, but inverse to the joints rotational inertia.[4,124] The torque necessary to create motion about a joint will be directly influenced by the shape of a body segment, the length, mass and the distribution of that mass. The perpendicular distance from the axis of rotation to the point of contact at the distal extremity or projectile is known as the radius of rotation. The greater the radius of rotation and the greater mass the more torque required to promote movement about a given segment.[12,77,78,124] If the mass is distributed further from the axis of rotation greater amounts of force will be needed to overcome the objects inertia. The distance from the proximal axis of rotation to the segment's concentration of mass is referred to as the radius of gyration. Increases in the radius of gyration are far more influential as rotational inertia is directly proportionate to the *square* of the radius of gyration.[4,124] Mass distributions close to the axis of rotation result in less rotational inertia and promote higher levels of angular acceleration potential at that segment.[124]

In the human body joined segments typically have greater amounts of mass distributed closer to the proximal joint segment. This anatomical arrangement of proximally distributed body mass decreases the body's radius of gyration, reducing inertia and promoting proximal to distal force production, absorption, and transportation. In the acts of throwing or kicking, rotational inertia is greater at the proximal segments when compared to the distal segments as a result of the differences in mass and radius of gyration. The large proximal segments of the pelvis and trunk require higher torque production while the smaller and lighter segments of the extremities do not.[8,77,124] The decreased mass, radius of rotation, and radius of gyration among the shoulder girdle and arm segments promote higher velocities at the distal segments. [12,124] Rotational inertia between the joined segments decrease as forces are distributed further from the proximal/original axis of rotation.[103,124] The combination of proximal to distal movement patterns, deceleration moments from the large proximal segments, and changes in segment mass allows the joint moment forces to be conserved and magnified at the smaller distal segments.[4,8,12] For example, during the cocking phase of throwing, medial rotation of the hip causes the trunk to pivot transversely and flex forward as the throwing arm is projected behind the trunk at 90 degrees of abduction and external rotation. Further forward flexion of the pelvis and trunk accentuates this position and stretches the anterior structures of the trunk and shoulder girdle into a terminal cocking phase. The erector spinae, transverse abdominis, multifidus, anterior fibers of the internal oblique, and the pelvic floor become primary contributors in stabilizing the lumbar spine into a stiff segment. The stiff proximal segment of the spine on the pelvis transmits forces that control trunk position. Collectively the body's proximal segments establish a large base of support for the smaller distal extremities. The forces from the proximal segments and the trunk's continued flexion/rotation moments create high angular velocities.[12,125] As the proximal segments decelerate, forces at the distal segments increase and greater angular velocity is achieved.[12] The stretch-shortening reflex assists in forward arm accelerations.[8,12,77,126] It is not uncommon for angular velocities of 600 degrees/second at the trunk to be transferred into 1100 – 1300 degrees/second at the upper torso and 6000 – 8000 degrees/second at the arm.[12,80,124,126,127] Ideally, the end result is a high linear velocity displacement of the hand at the time of ball release or at the foot at ball strike.[12,103,128]

Placing a weighted object or projectile at the distal extremity, such as a ball, bat or a racquet can alter the radius of gyration and the mass at the distal segment, requiring more torque to produce the same amount of angular acceleration at the distal extremity. Increased length by an object at the distal extremity will likely increase the radius of rotation. However, if the object is held closer to its concentrated weighted of the segment the radius of gyration will be diminished, reducing the rotational inertia which makes the projectile or object more manageable.[124] As such, the practice of “choking-up” on a bat or racquet handle to attain more control is common among novice or muscularly weak player(s).

The rotational inertia can also be influenced by the type of movement pattern being performed and the objective used for a particular pattern. Push-like and throw-like patterns are two distinct patterns commonly used to generate high linear velocities and/or to direct the accuracy of a projectile.[12,103,124,128] Push-like patterns, such as flexion/extension, abduction/adduction and protraction/retraction are referred to as lever-type motions and are most commonly used to achieve accurate placement of a projectile. For example, in setting a volleyball or throwing a dart the long bones of the arm(s) become levers which rotate perpendicular to the joint’s axis of rotation on a single plane. Throw-like patterns, such as throwing and kicking are categorized as wheel-axle motions. When throwing a baseball the humerus becomes the supporting axis on a horizontal plan for the forearm and hand to rotate as a wheel. Both lever and wheel-axle systems have rotational functions and are often used interchangeably in sport and daily acts of living to maximize control of the angular velocity at a distal segment. The ability for the wheel-axle system to shorten or lengthen the radius of rotation by flexing or extending the proximal joined segments allows for modifications in the forces distributed to the distal segments.[4,124,128] Lever motions have a large radius of rotation which result in a greater radius of gyration; resulting in an increased rotational inertia. The smaller radius of rotation in the wheel-axle system creates a lower radius of gyration, less rotational inertia and can produce a greater amount of linear velocity when compared to lever motions.[4,124] Faster forehand linear velocities have been reported in tennis players that are able to use the upper limb segments incorporating a wheel-axle motion rather than as a stiff lever segment.[103] Due to the lack of skill and precision of skill a novice performing the same forehand is likely to use a stiff lever movement. The necessity of emphasizing one movement pattern over another will depend on the objective of the task at hand; such that a 25 foot golf chip over a bunker versus a 2 foot flat putt requires more wheel-axle motion, rather than push-like motion, to get closer to the hole.

Degrees of Freedom and Motion

The body's mass about the upper and lower extremity remain constant throughout a movement sequence, however the rotational inertia changes as the segments move relative to the proximal axis of rotation. Alteration to a given movement pattern can change the joint axis and segment position. The degrees of freedom or the minimally allowable planar motion at each joint will dictate which movement sequences are efficient and attainable for a given task.[4,12,77,78,124] Velocities attained at the hand during an overhead throw or striking motion generally consist of joint rotations attained from the six adjacent segments of the pelvis, thorax, shoulder girdle, humerus, forearm, wrist and hand. Approximately, 12 degrees of freedom are used to throw an object: three at the trunk, three at the shoulder, one at the elbow, one at the forearm, two at the wrist, and two at the metacarpophalangeal finger and thumb joints. [4] Similarly, kicking a soccer ball consists of eight segments: the trunk, pelvis, right and left thigh, lower leg, and foot. The seven joints which connect these segments provide approximately 18 degree of freedom: four at the trunk and pelvis, seven at the right leg and seven at the left leg.[77]

Total force production for a given motion is contingent upon the summation principle or the collective contribution of forces generated by each segment during the movement sequence. [4,12,103] The more joint segments included within a movement pattern the greater potential for force manipulation about the degrees of freedom. While this adds complexity to skill acquisition it offers precision and adaptation potential to performance.[4,12] Added degrees of freedom can be helpful in the body's ability to adapt to potential constraints, such as opposing forces from a competitor or a change in joint position to manipulate a pitch or ball position upon the contact of a volleyball during a spike.[4,8,76,77,124] Likewise, degrees of freedom offer the body multiple movement patterns or compensatory functions when adjacent joints are compromised with fatigue, injury or weakness.[4,116,129] As such, even common movement sequences, such as an over head throw, can have variable degrees of diversity in motion and effectiveness in speed and accuracy when compared between different performers.[106,126,130,131] The biomechanical constructs that govern movement properties at the proximal segments and sport performance have been reported throughout the scientific literature and continue to evolve.

Historical Background

The early works pertaining to posture assessment,[132,133] low back pathologies,[71,134,135] and functional motor control[65] serve as foundations of the proximal stability concept. Evidence of mechanical instability at the spine was introduced by Knutssen (1944).[71] Radiographic films were used to show spinal segment displacements associated with degenerative lumbar disc and spinal pathology. [71] It was not until some forty years later that Cholewicki et al (1992) observed a spinal segment shift of the L-2 vertebra from a sagittal view using a video fluoroscope in a weightlifter performing a maximal lift. This instability of the vertebrae was associated with pain and failure to sustain the lift.[73] Kabat et al[136] and others[137] proposed imbalanced and insufficient muscle co-contractions to be a primary reason for the movements necessary for daily tasks of living, such as walking.[136-138] It was hypothesized that the synergistic agonist-antagonist muscle relationships of the head, neck, trunk and pelvis were critical to the function at the extremities.[136-138]

The role of the proximal segments and how they relate to function was further explored within the development of proprioceptive neuromuscular facilitation (PNF) exercises. In an extensive documentary, Voss (1967) [17] used several case reports to outline the fundamental concepts of PNF exercises. Many of the theoretical concepts presented mimic what is commonly referred to today as the kinetic chain model, which include segmental interdependence and spinal stability (p862).[65] The primary focus of PNF techniques has been documented to use distal segment mobility to promote proximal muscular strength and endurance. These exercises generally progress from uni-planar or “primitive” linear movements to that of more advanced multi-planar diagonal movements. Advanced exercises are often aimed at improving contra-lateral function between the trunk and the pelvis; otherwise known as the serape effect. Some of the exercises presented by Voss are similar to the techniques used today which promote spinal stabilization: total body rolls, quadruped postures, static isometric bridges, and manually resisted diagonal trunk flexion/extension patterns.[65]

Kendall (1968) and Janda (1968) presented a theoretical model which emphasized muscle coordination between the anterior and posterior or agonist-antagonist muscles of the lumbo-pelvic area.[133,139] It was hypothesized that muscles which develop strength from training are often subject to becoming shortened and have lower excitatory thresholds.[139,140] Shortened muscles often cause agonistic responses which results in further shortening or disuse and weakness.[133,139,140] Over time, shortened muscles become over worked, fatigued, tight and atrophied. Lengthened muscles get overloaded or over stretched and lose strength. [133,139,140] This concept reinforced the need to accurately identify muscle weaknesses throughout the kinetic chain. Weak lumbo-pelvic and trunk muscles were proposed to be a primary cause of performance deficits resulting in low back pain and related pathologies.[3,71,116,133]

The evolution of isometric endurance testing and training paralleled the conceptual development of the spinal stability system. The works by Voss (1967), Steindler (1977), Pope (1985), Bergmark (1989), and Panjabi (1992) promoted the theory that local and global muscles work synergistically to stabilize the proximal segments which allows for distal mobility and energy transfer throughout the kinetic chain.[3,4,66,113]

Over time "stabilization" exercises have been implemented into clinical practice in order to target the local and global stabilizing schemes. [46,141] Hides et al (2008) and others have reported deep muscle co-contraction and isometric endurance training could reverse the inhibition of spinal stabilizers, such as the multifidus and transverse abdominis muscles in acute low back pain patients following an intervention of training.[7,22,56,121,142,143] In addition, healthy subjects were also reported to have a significant increase in EMG activation of the internal oblique muscle ($p < .001$) among healthy subjects following a low-load isometric intervention with bridges.[10]

A variety of isometric muscular endurance techniques remain among the most prominent assessment and training methods used for the proximal stabilizers.[134,144]

Isometric muscular endurance tests are reliable and valid techniques used to assess or train proximal stability.[144] Pederson et al (1972) investigated the correlation of four different strength tests used to target the isometric and lifting potential of the trunk muscles. It was concluded that the standing isometric extension test was the best predictor of maximal lift potentials ($r = .72$, $p < .05$). Similarly, Biering-Sorenson (1984) was among the first authors to report significant differences in prone isometric back endurance hold times between male workers at risk for a first time episode of low back pain and those without ($p = .03$). It was reported that individuals scoring below 54 seconds were 2 times more likely to have a back pain episode.[27] Schellenberg et al (2007)[145] used a simplified self-supported plank test technique to compare performance times between office workers with and without low back pain. Subjects without back pain recorded average hold times of 72.5 ± 32.6s in prone and 170.4 ± 42.5s in supine. Average plank times for subjects with back pain were significantly lower when compared to controls ($p = .05$). Back pain subjects recorded 28.3 ± 26.8s in prone and 76.7±48.9s in supine. See Tables 2.3 and 2.4 for isometric endurance planks and the Biering-Sorenson test performance hold-times (seconds).

Training Implications for Sport Performance

Training the proximal stabilizers has become a primary focus for nearly all sport enhancement training programs. While several training methods for the proximal stabilizers have been reported to enhance sport related performance, only a few have empirical evidence.[47,60] A majority of the evidence reporting significant performance improvements following isolated training of the proximal stabilizers has been for patients with low back pathology undergoing rehabilitation and not sport.[44,60] Those studies that have evaluated sport performance outcomes have been difficult to interpret due to inconsistencies defining proximal stability. The biomechanical contributions of the proximal stabilizers, as previously stated, clearly have potential to influence performance of the distal segments/extremities during dynamic tasks.[4,12,103,124,128] Therefore, it seems reasonable to isolate the proximal stabilizers when training for sport. The following section will provide a review of the scientific literature which supports proximal stability intervention techniques and implications for enhancing sport performance outcomes, such as throwing or kicking a ball.

Spinal Stability and Isometric Endurance

It has been reported that lumbar spine stability is provided by very low levels of anticipatory muscle activation of the deep inter-vertebral muscles prior to movement.[7,87,108,146] As low as 5-30% of EMG maximal voluntary isometric contractions are necessary to sustain inter-vertebral stability of the lumbar spine.[87] [55] These levels of lumbar stiffness can withstand large moments during lifting and dynamic movements.[147] The feed-forward mechanism of the spinal stabilizers establishes a proximal base of support for the distal segments.[6,7,22,120] The transverse abdominis, multifidi, and erector spinae are among the primary muscles that have been reported to stabilize the spine prior to limb movements in healthy subjects but are delayed in patients with low back pain.[6,7,22,120] Thus, it has been hypothesized that poor isometric muscular endurance of the proximal stabilizers may result in injury or poor performance.[27]

Low intensity isometric endurance techniques have been reported to isolate the deep inter-vertebral muscles of the lumbar spine rather than the global muscles of the trunk and pelvis.[5,9,16,148,149] Abdominal hollowing or a “drawing in” of the abdomen has been reported to enhance the muscle activation of the spinal stabilizers, such as the transverse abdominis.[6,121]. Thus, rehabilitation and/or training techniques used to target the deep spinal stabilizers have incorporated both isometric endurance tasks with abdominal hollowing.[10] However, controversy exists as to whether abdominal muscles can truly be isolated and if the hollowing or related techniques are appropriate for providing stability at the spine during tasks that are dynamic and require multiple planes of motion.[11,84,150-152]

Combined with low intensity isometric endurance exercises, abdominal hollowing has been reported to improve symptoms related to back pain.[121,141] O’Sullivan et al (1997) and Richardson and Jull (1995, 2002) reported significant reduction of low back pain and improved disability scores following similar low intensity interventions ($p< .05$).[46,68,121] Richardson et al (2002) reported abdominal hollowing in healthy subjects resulted in significant increases in sacroiliac joint stability when compared to abdominal bracing ($p\leq 0.026$).[68] Stevens et al (2007) was the first author to report a significant increase in EMG activation patterns of the internal oblique muscle ($p < .001$) among healthy subjects following an intervention of hollowing and low-load isometric bridges.[10] The improvements in healthy and pathological populations offers evidence that isometric endurance exercises and abdominal hollowing may be effective as a training or preventative technique.[10]

Conversely, Grenier et al[153] reported a statistically significant difference in stability between abdominal hollowing and abdominal “bearing-down” or bracing (p= 0.001) with abdominal bracing as a more effective technique in providing proximal stability.[11,86] The transverse abdominis contribution to stability was minimal. The action of abdominal hollowing was reported to reduce the moment arm of the rectus abdominis by 5 cm which resulted in less stability about the pelvis and trunk.[153] Other authors have suggested that despite the very low levels of muscle activation, the transverse abdominis cannot be isolated due to its tandem action with the internal oblique muscles.[44,154] Additional findings by Cholewicki et al (1996, 2002) and McGill et al (2009) indicate no single muscle activation is more important than any other in providing proximal stability, especially when considering dynamic tasks.[9,55,87]

Junker et al (1998), and Kacvic et al (2004) reported EMG activation of individual muscles of the pelvis, spine and trunk to become more synchronized as loads or intensity increase.[9,115,154] McGill et al (2009) used EMG activation of the trunk muscles to report different activation patterns for activities requiring mobility versus those requiring stability. Mobility activities, such as throwing, had significantly higher levels of peak muscle activation and a selective recruitment order compared to trunk stiffening tasks (p< .05). Rapid trunk isometric stiffening or abdominal bracing used in a quick punch revealed no significant differences between muscle onset or peak activation (p< .05). [9] The alterations in force and timing constraints of the muscle activation patterns were task selective or sport specific regarding the intensity and varied stability-mobility requirements. Such differences indicate that stability schemes at the proximal segments may require different training and assessment protocols to account for dynamic versus static tasks.[9] Intensity and desired movement pattern appear to direct whether a stability or mobility scheme is needed for a specific skill.[19,154]

Stabilization schemes at the proximal segments appear to be dependent on the specific mobility and intensity characteristics necessary for the completion of a given task.[9,18] The intensity, stability, and mobility demands of a task seem to determine the degree of muscular endurance, strength and/or power that is necessary to complete a task. These findings suggest a training specificity model may be appropriate when assessing or training the proximal segments.[18,45,68,McGill, 2009 #117,121] Therefore, it is reasonable to consider that abdominal hollowing is likely more appropriate for training at lower levels of activity, perhaps in the earlier phase of rehabilitation. Abdominal bracing is likely more appropriate for higher intensity activities typically seen in advanced or sport skills. To date there are limited assessments and training techniques which account for task specificity of the proximal stabilizers. Future research is needed to explore sport specificity stability schemes which account for establishing proximal stability to ensure distal mobility.

The importance of maintaining a stable proximal base has been reported to be critical when performing total body movements. In such a case the spinal stabilizers as well as the global muscles of the pelvis and trunk provide both static and dynamic stability incrementally.[148,155,156] Santana et al and McGill et al used EMG to measure trunk muscle activity while performing unique strength and power exercises commonly used in sport and competition. Santana et al reported significant increases in trunk muscular activation while performing a 1-repetition maximal effort on a unilateral standing cable press when compared to a traditional bench press ($p < .01$). Bench press

EMG readings were greater in the anterior deltoid and pectoralis major while the standing press had the highest EMG activity in the latissimus dorsi. Overall, the standing press decreased peak output values by 50 kg.[11] In a similar fashion, McGill et al reported the quadratus lumborum musculature to have an increased activation level during maximal effort total body carrying tasks.[16] It has been suggested that the increased activation at the proximal segments are necessary compensatory moments directed at improving potential force and mobility to the distal trunk, pelvic, and extremities.[16,148] Willardson et al[155] and others[64,69,148,157] suggest total body movements may be essential when training the proximal segments as they appear to provide essential support in the utilization of ground reaction forces or performance at the extremities. Activities or sports that encounter heavy or reactive forces between the upper and lower extremity should implement total body movements that mimic these force(s).[9,156,158] Olympic lifts or multi-planar resistance training, such as a chop or lift with the upper extremity while in a straddled stance, may promote proximal stabilization similar to sport.[159-161]

Others have proposed the use of unstable surfaces, such as unilateral stance, wobble boards or Swiss ball to increase muscle activation about the proximal segments.[162,163] There is an increased frequency of motor recruitment as a result of trying to maintain body position and equilibrium while balancing external loads. [143,149] Such movements are thought to promote to increased excitability of antagonistic muscles which promotes greater co-contractions and synergistic spinal stabilization.[72,101,162] However, unstable surfaces reduce the ground reaction forces which compromise one’s ability to apply external loads comparable to that of a stable surface. Limits in external load elicit less muscle activation and less overload effect necessary for strength gains.[155,163] The more unstable the surface the greater reduction in potential external loads.[164,165] It has been hypothesized that the reduction in load potential accompanied with increased muscle activation may be beneficial in rehabilitation settings where external loads are not warranted due to injury.[163] Being able to increase resistance on stable surfaces appears to be more effective in promoting muscle activation at the proximal segments when compared to lighter loads on unstable surfaces. Kohler et al (2010) reported increases in EMG activation of the rectus abdominis, external oblique, deltoid and triceps during a stable verse unstable bench press and shoulder press lift.[164] Willardson et al (2009) reported resistances of 75% of a 1 RM to be more effective in activating both proximal and extremity segment musculature when compared to 50% of a 1RM on wobble discs.[165] Ground based or training on stable surfaces for total body Olympic style lifts have been reported to incorporate greater proximal muscular activation and inter-segmental coordination similar to tasks related to daily acts of living and sport.[163] Thus, unstable and stable surfaces both appear to be effective in stimulating muscle activation at the proximal segments. Unstable surfaces which necessitate a reduction in external loads and promote more proximal muscular co-activation may be more appropriate for training spinal stability or used in low intensity settings. While Olympic and total body lifts of higher intensities may maximize overload progressions which promote dynamic stabilization, similar to dynamic tasks or sport.[9,156,166,167]

Sport Specific Training

Some authors have suggested diagonal and forceful movement patterns that simulate motions associated with sport to be more functionally appropriate in challenging the proximal stabilizers. [9,18,44,60,62,149,156] It has been hypothesized that the proximal stabilizers require muscular power, strength, and endurance to meet the demands of a given task.[9,16,148,156,158] Tasks that require more dynamic motion and involve higher intensities tend to create greater muscle torque activations.[9,87] Throwing an object requires a great deal of strength to overcome the inertia of the multi-planar positioning of the pelvis and trunk segments, while also relying heavily on the mobility and torque production of the adjacent segments from the ground to the extremities.[4,12] On the other hand, abdominal bracing or bearing-down may involve muscular power, strength and/or endurance capabilities to produce high degrees of muscular stiffness without establishing any degree of linear of planar motion.[9,16] Maintaining a balance between appropriate muscular stiffness and mobility seems to be imperative for being successful at a given skill.[9,127,168] Such a premise supports the basis behind the stability-mobility continuum. The theoretical basis indicates training and assessment practices for the proximal segments should target the specific muscular contributions of endurance, strength, and power as they relate to the stability and mobility demands specific to sport. Acknowledgment of the stability and mobility requirements of a sport skill will guide the development of strength and condition programs targeting proximal stability.

McGill et al (2009) evaluated three different sport related tasks: ballistic stiffening of the trunk, trunk stiffening with a punch, and throwing a baseball. The authors concluded diverse muscle stiffness requirements are necessary for tasks with different goals.[9,16,152] Ballistic stiffening of the lumbo-pelvic area had a unified and symmetrical muscle activation patterns while activities which required more mobility of the trunk and the arms had selectively different activation patterns. The rapid isometric stiffening with and without a quick punch revealed no significant differences between muscle onset or peak activation. [9] Throwing a baseball had significantly higher levels of peak muscle activation and selective on-off motor-recruitment sequences throughout the task ($p < .05$).[9] These findings suggest proximal stabilizers are selective when initiating or responding to forces and muscle activation patterns are therefore more variable. It would seem reasonable that training programs should be sport specific for the proximal segments in mimicking the movements similar to the sport.[9,17,49,148]

Keogh et al (2009) reported less skilled golfers had increased stiffness in the proximal musculature and less hip mobility while hitting with a driver. They concluded the increase in proximal stiffness decreased the speed and motion of the pelvis. Less rotational torque was attainable at the trunk and the extremities which resulted in a slower club speed and thus hindered ball distance.[4,9,127,168,169] These unwarranted increases in stability may also be present when rotational tasks resemble a push-like motion rather than a wheel-axel motion.[4,103,124,125] Elliott et al (1989) reported elite tennis players to have significantly higher average angular and linear velocities at the wrist and the distal end of the racquet during a forehand when the segments of the arm moved in a progressive sequence relative to each other, rather than as a joined unit ($p < .05$).[103] As the primary objective of these motions is to attain maximum linear velocities at the distal segments, trunk rotation is necessary to influence the angular accelerations that occur at each distal segment.[4,12,103,124,169] Cronin et al (2005) reported velocity of movement to be the most important variable in improving power outputs for sport.[45] Therefore, training protocols for throwing and kicking sports should consist of trunk rotational movements tailored toward specific performance outcomes mimicking velocity and type of movement. [9,17,49,52,169] Using sport specific training techniques which mimic the motion, timing, magnitude and speed of the proximal stabilizers may have more appropriate performance benefits.[9,16,156,158] However, there is limited evidence supporting claims that targeting the proximal stabilizers can improve sport performance.[44,60,152,156]

Training Implications with the Goal to Improve Throwing Velocity

There are several biomechanical factors involving the proximal segments which contribute to improvements in throwing velocity. Stodden et al (2001, 2005, 2006) used 3-D kinematics to measure trunk position during throwing activities. They reported that trunk position had a significant influence on ball velocity in pitchers ($p < .001$).[106,126,131] The primary performance variables noted to improve ball velocity were the anterior tilt of the pelvis at the precise time of ball release,[126,131] a pelvic to shoulder girdle rotation differential of 47 to 60 degrees during the terminal cocking phase of throwing[126] and increased velocity of the trunk during the acceleration phase of throwing.[126,131] The authors proposed training dynamic trunk control in motions similar to those measured in their study. They hypothesized that this training technique would likely improve pitching motion and performance.[106,126,131,170] In a more recent study, Stodden et al used 3-D video analysis to compare the angular velocity and trunk rotation of four proximal stability training exercises and throwing motion. Trunk rotation was reported to be greater on average to the athletes' dominant throwing side.[169] The maximum angular velocity of the pelvis and trunk during the exercises was only about 50% of that to the throwing motion. It was concluded that the increased inertia from the resistance of a medicine ball and elastic bands used during the exercises decreased the angular velocity of the proximal segments in order to compensate for the increased radius of gyration.[169] It was further hypothesized that the reduction in trunk speed produced during the exercise sessions would be less likely to promote performance gains.[19,169] Others have reported similar adaptations to trunk speed due to the change in size, mass, or length of a distal projectile.[103,125,127] The resistance applied during the exercises seemed appropriate and feasible for making strength gains, but is not the only factor related to a faster ball velocity. Lighter resistance would allow the proximal stabilizers to be trained at velocities similar to throwing. As the development of strength has a been reported to improve power movements combining strength exercises and speed specific training with movement patterns similar to overhead throwing may facilitate power development at the proximal segments that will influence throwing velocity. Moderate to heavy loads ranging from 30-90% of a 1 RM have been reported to facilitate the predominate recruitment and development of type II muscle fibers resulting in gains in muscular power.[171-175] Increases in trunk speed have been reported to amplify trunk muscle activation of the local and global muscles. [9,16,176] Training at fast velocities, such as 300 degrees/second have been shown to increase type II fiber morphology and improve power output capabilities of the muscle.[50,59] Resisted movements which mimic the high speed characteristics of throwing are more likely to promote improvements in linear velocity due to changed characteristics of the muscle.[12,19,77,78,103]. Elliott et al reported rotational velocities transmitted from the trunk to the shoulder girdle were the primary contributors for racket head speed at impact.[128] Thus, improvements in throwing velocity are likely to be influenced by exercises which target increased pelvic and trunk strength and control, rotational range of motion, rotational movements (weighted and un-weighted) in a standing position which mimic the stable base and foot position common to throwing and the speed of motion. An explosive weighted medicine ball throw using both arms to support the weight to the throwing side in a standing position, is a practical exercise to promote improvements in throwing velocity.

Neuromuscular control at the proximal segments in the sagittal and coronal planes has been theorized to impact performance.[14,15,67,70] Using sport specific exercises to maximize the plyometric abilities or the stretch-shortening cycle at the proximal segments may be a preferred method in promoting improvements in linear velocity of throwing or kicking skills.[64,104,105,177] As the muscles of the trunk and extremities are eccentrically stretched in the preparatory or cocking phase of a throw or kick, potential energy is gained among the segments. Immediate concentric mobility from the proximal to distal segments of the trunk and extremities assist in maximizing the arms forward velocity. The amortization phase or the exchange from the loading and stretch of the muscles in the cocking phase to the concentric contraction of the muscles has been reported to be critical in transferring potential to kinetic energy of the muscles.[19,159,178-180] Werner et al (2008)[181] and others[159,178-180,182,183] reported a short amortization phase and fast pelvic and trunk velocity is necessary to produce greater acceleration at the distal extremities resulting in increased ball velocity upon throwing. Therefore, it seems reasonable to combine plyometric or neuromuscular control training which can maximize the rotational differential between the shoulder girdle and the pelvis while also activating the stretch-shortening reflex. Medicine ball tosses which incorporate explosive side to side eccentric loads and ballistic concentric contractions will provide loads which promote a shorter amortization phase for rotational moments.

The theoretical and biomechanical constructs for proximal stability offer good support for clinical interventions to improve sport performance. Throwing or kicking movements require rotational motion and the velocities and range of motion that is recommended to improve performance should be task specific. Proximal stability exercises should include using progressions that incorporate endurance, strength, and power specific to the demands of the sport in question. Low-load isometric endurance and motor control training support targeting the proximal stabilizers, but lack evidence to enhance to support changes in performance. Abdominal hollowing may be useful in the earlier, low-intensity phases of training while abdominal bracing may be used for the higher levels of activity or sport specific intensities. Skills requiring mobility should be performed throughout a full range of motion in order to maximize torque production and the stretch-shortening cycle. Training at the appropriate speed and motion of a skill will assist in maximizing both rotational torques and corresponding linear velocity. Whole-body training techniques, such as standing cable press or Olympic style lifts maybe useful in challenging the proximal stabilizers similar to the multi-directional motions of sport.

Proximal Stability Performance Outcomes

Low-intensity isometric endurance assessment and training techniques are appropriate for evaluating proximal stability.[10,44,46] Unfortunately, many studies are rehabilitative in nature and may not be appropriate for dynamic, explosive multi-planar movements common to sport. It is well documented that training the pelvis, spine or trunk will result in isolated adaptations to the specific demands of the implemented program.[19] Myer et al reported significant improvements in pelvic stability as measured by hip abduction strength among young female volleyball players following a perturbation training program specific to the hip and trunk ($p < .05$).[31] Others have reported significant improvements in EMG muscle activation patterns, muscular endurance-strength measures following isolated training for the spine and trunk musculature, respectively.[10,25,32,120] Static isometric muscle endurance training, such as back extension or side planks, are among the most common techniques reported to improve endurance hold times in both general and athletic populations.[32,34] As a result several authors have claimed that these training methods may improve sport related performance. However, the findings from these studies were not evaluated or compared with measures of sport performance and did not provide a comprehensive measure for all the proximal segments.

Studies that have reported improved sport performance without assessing proximal stability make it difficult to determine the effectiveness of the training intervention.[31,40-42,47,48] Saeterbakken et al reported a 4.9% increase in throwing velocity ($p = .01$) following a 6 week unstable limb-suspended sling training program.[40] Seiler et al used a similar intervention and demonstrated significant improvements in golf club velocity among junior golfers ($p < .001$).[42] Sato et al reported improvements in a 5000 m run following an unstable Swiss ball strength training program in middle aged recreational runners ($p< .05$).[41] Each of these studies seems to offer support that proximal stability training improves sport performance. However, the absence of pre to post proximal stability measures makes it difficult to determine if the performance improvements are truly from enhanced proximal stability.

Studies which have collectively measured both proximal stability and sport performance have contradictory outcomes due to limitations in the training protocols or the assessment techniques used to measure proximal stability and sport performance. Pedersen et al[36] reported significant improvements in both a proximal stability measure (p< .01) and ball velocity for a soccer kick (p=.04) following an intervention.[36] The training and assessment techniques utilized to measure proximal stability in this study have not been fully validated in the literature. It is difficult to determine if the combination of sling and balance training techniques isolated the proximal segments and to what extent the separate training stimuli contributed to the reported improvements. Further, the isometric hip abduction test used to validate changes in the proximal stability has no reported psychometric properties, was performed without a familiarization period and appears to be limited in testing hip strength.

Studies which report significant improvements in proximal stability measure(s) often do not measure sport performance following a proximal stability intervention. Scibek et al,[43] Stanton et al[37] and Lust et al[33] all reported significant improvements in proximal stability as measured by static and dynamic flexion motions (p< .05) but not in sport performance. The authors concluded the interventions were effective in improving proximal stability, but did not translate into sport performance effects. Specifically, the training stimuli were not sport specific and only trained static stability movements. Similarly, Tse et al[38] and Parkhouse et al[35] reported significant improvements in isometric endurance tests (p < .05), but not in explosive field tests or rowing performance following proximal stability endurance training. The lack of improvement in sport performance and the explosive field tests is likely due to training specificity and limitations in the training and assessment methods utilized.[49-54]

The majority training interventions presented in the literature exclusively targeted isometric muscular endurance and spinal stability, and neglected to measure pelvic or trunk control. Gains in muscular endurance are not likely to influence performance for sport skills and field tests which require explosive strength or power.[52,53] Many of the static endurance exercises used to train sport performance and proximal stability are very similar to the proximal stability assessment techniques.[33,35-38] For example, Stanton et al,[37] measured isometric endurance of the proximal stabilizers with a static plank test for time on a Swiss ball following a Swiss ball training intervention where planks were routinely performed for time.[37] Parkhouse et al reported significant improvements in three “core” endurance measures (p<.05) following a six week intervention among two separate proximal stability training groups: static and dynamic. No improvements were reported for either group on explosive field tests.[35] This was not a surprise as the training interventions, although different (static vs. dynamic), were endurance based training protocols on subjects that had never participated in a proximal stability training program. However, high positive correlations (r=.92) were noted between the dynamic training group for the 20 m sprint and planks, while the static group had strong negative correlations (r-=-.81, r=-.82) with the 20 m spring and the plank/leg lowering, respectively. The high correlations between the stability measures and the explosive activities for the dynamic training group are likely due to similarities among the stabilizing schemes used for the specific tasks and the training effect post intervention. It seems reasonable that the endurance based interventions predominately reported in the literature have a specificity training effect exclusive to the isometric endurance proximal stability tests and may not be as applicable for improving explosive movements nor being measured via explosive field tests. Training on unstable surfaces seems to alter endurance based training which may influence dynamic or power performance. Proximal stability training which incorporates static and dynamic endurance, strength and power movements specific to the sport may be more appropriate for promoting improvements in proximal stability and sport performance.[9,18,156]

Nesser et al (2008, 2009) investigated the correlation between sport performance measures, such as a 20 and 40 yard sprint, vertical jump and traditional plank and trunk flexion/extension tests. Low to moderate correlations (r= .099 – r=.6) were reported between isometric endurance measures and power performance measures among football and female soccer players.[52,53] It was concluded trunk stability had very little to do with high intensity athletic performance measures. While this might be accurate it might also be plausible that the tests used were possibly not sensitive to trunk stability performance. The tests used in these studies were primarily static muscular endurance tests and not explosive anaerobic tasks commonly associated with sport performance.[52,53] The low correlation between the endurance testing of the proximal stabilizers and the ballistic activities may indicate the need for a more appropriate measure and/or training protocol. In a more recent study, Shinkle et al reported a moderate (r=.6, p= .01) correlation between a power test of proximal stability as measured by a medicine ball toss and explosive field tests.[30] While the ball toss tests tend to have inconsistently reported reliability, the relationships cited in this study with the power measures of sport and the proximal stability offer new insight for interpreting performance outcomes of power related to those of endurance.

Certain outcomes following a proximal stability intervention may be associated with a learning effect. Butcher et al investigated the effects of a 9 week low-load and low intensity proximal stability intervention on vertical jump take-off velocity in an athletic population. [47] Athletes were assigned to one of four different intervention groups: core stability training, leg training, combination training, or a control. The core stability group was the only group to record significant improvements in vertical jump velocity at week 3 when compared to controls ($p < .05$). The leg training group was the only group to record significant improvements at week 9 ($p < .05$).[47] The authors concluded core stability and leg training to be equally effective in improving vertical jump take-off velocity. However, the improvements in the core stability group were likely due to a learning effect or neurological adaptation.[54,184] Lust et al reported similar findings for the effectiveness of a 6 week intervention program to improve throwing accuracy. Subjects were randomly assigned to one of four training groups: open kinetic chain, close kinetic chain, isometric trunk endurance, or a control. While no significant differences were noted between all the experimental groups at 6 weeks, a significant learning effect was reported for the pre- to -post test throwing performance ($p = .001$). [33] Others have reported as much as a 20% increase in isometric performance from session one to session two.[27] While these studies offer good insight to the effectiveness of a trunk focused intervention, future studies need to account for potential learning effects by maximizing the familiarization period. Stevens et al reported functional measures of the proximal segments may require as much as 3 to 5 levels of testing to avoid a learning effect.[185] Caution is needed when interpreting results which do not account for a learning effect.

Summary on Performance Literature

The performance literature offers very little support for using low-intensity spinal stabilization schemes when assessment of dynamic activates or sport skills is the outcome of interest. However, the potential use of dynamic training or assessment techniques may offer future insight into the role proximal stability may have during different static or dynamic tasks. Dynamic training may be more appropriate for improving dynamic activities or sport. The relationship between training interventions and assessment techniques needs to be further examined. An investigation which simultaneously measures static and dynamic proximal stability and sport specific performance outcomes, following a proximal stability intervention will help to determine if there is a causal relationship between training and performance measures.

Chapter 2: Tables

Table 2.1: Muscles of the Local and Global Movement Schemes for the Lumbo-pelvic Area.[2,66,186]

Local "Deep" Muscles	Global "Superficial" Muscles
Transversus abdominis	Rectus abdominis
Multifidi	Erector Spinae
Psoas major	Internal oblique (anterior fibers)
Quadratus lumborum	External oblique
Diaphragm	Iliocostalis (thoracic portion)
Internal oblique (posterior fibers)	Gluteus Complex
Iliocostalis, longissimus (lumbar portions)	

Table 2.2: Muscle Characteristics: Local and Global Movement Schemes.[101,186]

Local Musculature Schemes	Global Musculature Schemes
Uni/Inter-segmental, static stability of the spinal vertebrae	Multiple segments, dynamic, torque producing
Core or Spinal Stability	Trunk/Pelvis stability-mobility
Deep orientation	Superficial
Slow-twitch nature	Fast-twitch nature, fusiform
Anticipatory action, endurance emphasis	Active in power activities, compensate for weaknesses at spine
Selectively weaken	Preferential recruitment
Poor recruitment, may be inhibited	Shorten and tighten
Activated at low resistance levels	Activated at higher resistance levels

Table 2.3: Mean ± Standard Deviation for Isometric Endurance Hold-times in Seconds for Flexion, Extension, and Side Planks among Healthy Participants

Test	N	Men		Women	
		Mean	±SD	Mean	± SD
Extension	187	134	39	167	57
Flexion	92	119	59	154	78
Side Planks, right	66	87	27	86	37
Side Planks, left	58	88	30	86	34

Pooled results from McGill et al. 1999[187], Chen et al. 2003[188], Leetun et al. 2004[100], Nesser et al. 2008[52], Nesser et al. 2009[53]

Table 2.4: Mean ± Standard Deviation for Isometric Endurance Hold-times in Seconds for the Biering-Sorenson Test in Patients with and without Low Back Pain

Test	N	Men		Women	
		Mean	±SD	Mean	± SD
Back Pain					
Extension	163	94	85	89	76
Without Back Pain					
Extension	95	158	53	137	79

Pooled results from Biering-Sorenson et al. 1984[27], Schellenberg et al. 2007[145], Latiemer et al. 1999[189], Underman et al. 2003[190]

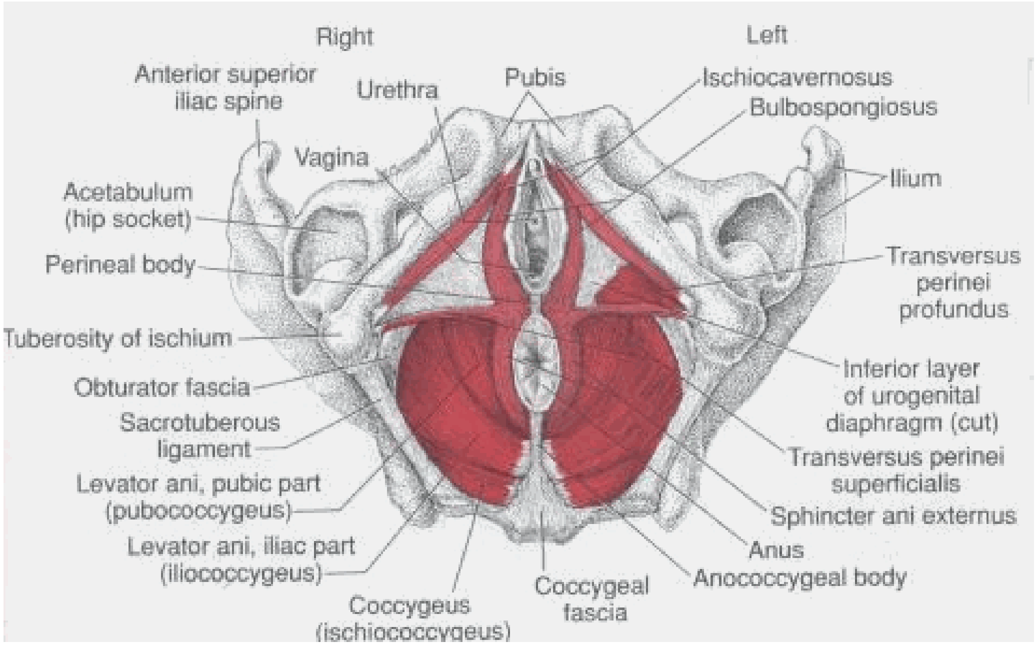
Chapter 2: Figures:

Figure 2.1: Neutral Spine Diagram

a. b.

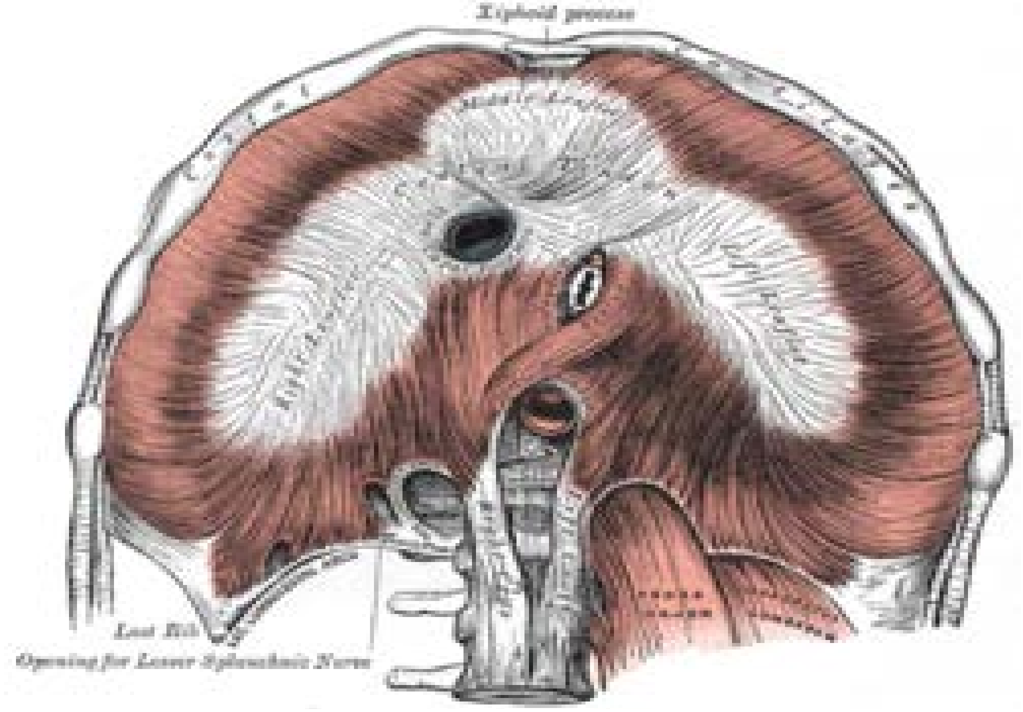
a. Spinal segments functioning within a neutral zone. b. Spinal segments function outside the neutral zone.

Figure 2.2: Pelvic Floor Anatomy



http://lucy.stanford.edu/levator.html

Figure 2.3: Diaphragm Anatomy



http://headbacktohealth.com/

Chapter 3: Methods

Subjects

Subject demographics are listed in Table 3.1. Forty-six healthy, Division II collegiate female softball (n=17) and male baseball (n=29) players with a mean age = 20 ± 1.3 years, height = 175.7 ± 8.7 cm, weight = 79 ± 13.9 Kg from the same university volunteered to participate in a training intervention study with pre- and post-intervention measures. Players were randomly assigned using a permuted stratified block of four to one of two training groups: a traditional endurance training group (ET) (n=21), or a power stability training group (PS) (n=25).[34] The twenty-one volunteers for the ET group were composed of 8 females and 13 males: 1 female and 4 male pitchers; 7 female and 9 male fielders with a mean age = 20.3 ± 1.3 years, height = 176.3 ± 8.6 cm, pre-intervention weight = 80.1 ± 13.8 Kg, and post-intervention weight = 80.5 ± 8.6 Kg. The twenty-five members of the PS training group were composed of 9 females and 16 males: 1 female and 4 male pitchers; 8 female and 12 male fielders with a mean age = 19.8 ± 1.2 years, height = 179.2 ± 9 cm, pre-intervention weight = 74.1 ± 12.3 Kg, and post-intervention weight = 74.5 ± 13.2 kg. Both groups consisted of returning players with the equal amount of average years of experience in their respective sports of 12 ± 3 years and a mean Tegner Activity score of 7.2 ± .15. Inclusion criteria consisted of collegiate, overhead throwing athletes participating in softball or baseball. Individuals reporting any major orthopedic injury within the past three months resulting in the inability to perform sport training activities were excluded from the data collection. Participants reported to an information meeting where they reviewed and signed an informed consent document. All 46 subjects participated in two familiarization periods, baseline data collection, a 7 week periodized training program and post-intervention data collection. There were no reported drop-outs and training session compliance was 92 ± 8 percent for the traditional training group and 91 ± 9 percent for the proximal stability training group. Testing and training occurred immediately following the Fall-season practice and game sessions. Study protocol and procedures were approved by a University Institutional Review Board.

Instrumentation and Data Capture

Informed Consent Process: An initial meeting was held to inform volunteers about the testing procedures, assure subject safety, to determine if volunteers met the inclusion criteria and to obtain informed written consent. A copy of the consent form was provided to each subject. Once consent was received each volunteer completed a Tegner Activity Scale. Volunteers were then randomly assigned to the traditional endurance training group or the proximal stability training by a blinded investigator and concealed from the person enrolling the subjects in the study. (Appendix A: Randomization Scheme)

Research Procedures

Testing procedures were performed on all participants by the same investigating team. Subjects participated in two familiarization sessions for each dependent measure, baseline testing, and post-intervention testing. Baseline and post–intervention testing occurred during off-season training one week prior to and one week following the intervention period. We assumed a 7 week intervention time period would be adequate to result in a significant training effect as was previously reported in the literature [32,34,35,47]

Both the ET and PS groups were trained by the same investigators for 30 minutes 2 times per/week for 7 weeks for a total of 14 sessions.[33] The ET group received linear isometric stabilization and endurance repetition training exercises while the PS group received a combination of linear isometric endurance/stabilization, strength, and power exercises with an emphasis on multi-planar rotational and sport specific movements for baseball. The traditional endurance training protocol is listed in Table 3.2 and the comprehensive power stability training protocol is listed in Table 3.3.

Familiarization Testing: Two familiarization periods were used to prevent a potential learning effect for the all dependent measures.[27,185] Multiple test attempts were performed for each dependent variable to ensure proper technique of the skills.[185] A video was shown to each participant followed by instructional corrections to ensure the appropriate technique for the chop and lift tests on two separate sessions approximately one week apart. Practice sessions for throwing velocity and plank tests were performed one week apart and one week prior to testing. The chop and lift 1-RM power protocol occurred in the laboratory setting while the isometric endurance planks and throwing velocities were assessed in a university gymnasium.

Testing: The chop and lift 1-RM power protocol testing was performed in the Musculoskeletal Laboratory at the University of Kentucky on the BTE Primus, (BTE Technologies, Hanover, MD). Throwing velocity assessments and isometric endurance planks in the prone and dominate side positions were performed in an open gym by two investigators blinded to the treatment group allocations. The order of power tests and isometric endurance planks (prone, side) were counterbalanced using a Latin-square design and tested by a team of investigators. All participants were instructed to produce a maximal effort for each test. Baseline and post-intervention assessments were taken one week prior and one week after the seven week intervention period.

Throwing Velocity Assessment: A calibrated hand-held Prospeed-Professional radar gun (Decatur Electronics, Phoenix AZ), was used to capture the peak throwing velocity in miles-per hour. Prior to testing, each athlete completed a 5 minute jog, general flexibility and progressive throwing warm-up. From a flat surface, participants performed 5 two step throws into a 4 foot square target from a 30 foot distance with maximal effort. Players were instructed to simulate throwing with maximum force while maintaining control of the ball. A minimum of 1 minute rest was allowed between throws. All attempts that hit the target were recorded. The highest recorded velocity was recorded.[178,191,192]

Chop and Lift Tests: Participants were allowed to practice while viewing a video demonstration of the chop and the lift movements. Corrective feedback was provided by the primary investigator to ensure proper technique. Participants were placed into a half-kneeling position and asked to maintain an erect trunk and hip position while performing the tests. Each participant was placed in a 90° hip flexion/knee flexion position with a 2 x 6 x 60-in (5.08 x 15.24 x 152.4-cm) wood plank placed between the knee and foot of the opposite legs. The knee and foot maintained flush in contact with the board to keep the base of support narrow which mandated an erect posture and static proximal stability. A standard 46 x 43 x 13-cm^3 block of medium-density foam pad (Airex AG, Sins, Switzerland) was used to support the weight-bearing knee for the comfort of the participants. The sport package for the PrimusRS is equipped with a 1.9-lb (0.86-kg), 36-in (91.44-cm) metal dowel rod that can be secured to a 9-ft (2.75-m), 3-dimensional cable motion system (Figure 3.1). While looking at a fixed point each participant performed approximately 5 to 10 practice repetitions with a sub-maximal weight. Initial testing resistance was standardized to 15% and 25% of the individual's body mass for the lift and chop tests, respectively.[18] The weight of the dowel rod (1.9 lb [0.86 kg]) was calculated as part of the test resistance provided by the PrimusRS system. Resistance was increased by 3 lb (1.35 kg) for the lift and 5 lb (2.25 kg) for the chop after a successful 1RM. Inability to produce an equal or greater peak power output value from the previous test trial resulted in a reduction in resistance by 1 lb (0.45 kg) for the lift and 3 lb (1.35 kg) for the chop. Further adjustments were made to the resistance in 1-lb (0.45-kg) increments (up or down) until the maximal peak muscular power was achieved. Participants performed a series of 1RM efforts for each test with a minimum rest period of 30 seconds between attempts. Peak muscular power (watts) and the number of repetitions (3 ± 1 repetitions) to achieve this level were recorded in each direction for both groups and both testing sessions.

Chop position: (Figure 3.2) In a unilateral tall kneeling stance a dowel rod was placed diagonally in the two o'clock position. The bottom hand grasped the dowel rod with the shoulder slightly flexed, horizontally adducted, and internally rotated and the elbow flexed to 60 - 80 degrees. The top hand grasped the dowel rod with the shoulder slightly flexed, internally rotated and abducted to approximately 145 – 160 degrees. The arms pull (bottom hand) and push (top hand) into a "chopping" diagonal pattern across the torso toward the opposite hip/kneeling limb. The end of the movement is marked by the top hand being in line with the opposite (kneeling) hip and the bottom hand extended behind that same hip.

Lift position: In a unilateral tall kneeling stance the dowel rod was placed diagonally in the four-thirty position. Participants used the top hand to support the rod across the chest with the shoulder abducted to approximately 130 degrees with the elbow in terminal flexion and the forearm pronated. The bottom hand/arm was abducted with slight forearm pronation. The dowel rod was lifted so the top hand becomes inverted with the shoulder adducted and the elbow flexed + 90 degrees. The bottom hand was moved into an overhead position with the shoulder internally rotated, horizontally adduction and flexed (Figure 3.3).

Endurance Planks: Participants were placed in the respective prone, supine, or lateral position. With the body maintaining an erect position participants were asked to support their body weight by means of their feet and elbows/forearms Participants were timed in seconds to see how long they were able to maintain the neutral position. The test was terminated if the neutral position was disrupted due to fatigue, pain, or fault in trunk position. Deviations in a position of 5 degrees prompted the examiner to ask the participant to return to a neutral position. If the participant was not able to comply, the test was terminated and time recorded.[145] Previous literature has reported a typical performance to range between approximately 90 to 240 seconds or more in healthy athletic populations.[187,193] Therefore, a maximal time of 4 minutes was allowed for the test and a test lasting 4 minutes was stopped and recorded. A 1:4 test to rest ratio was used.[189] Testing procedures were performed by the same examiners and the same protocol for all testing sessions. The examiners had an average of 10 years' experience as a certified strength and conditioning professional and were blinded to the participants' group allocation. The order of testing was counterbalanced using a Latin square design.

Participants were verbally coached and encouraged to maintain their static position throughout the testing protocol, but were not told the duration of their respective tests at any time during the study.

Prone Plank Position: Participants were placed in a prone position with the legs, torso, and body fully extended and suspended bilaterally by the elbows flexed at 90 degrees and ankle/foot neutral position(Figure 3.4).

Side Plank Position: With the legs and torso fully extended participants were asked to maintain a suspended side lying position supported by a flexed elbow and the lateral side of their feet. The supporting arm was abducted to approximately 80-85 degrees in a frontal plan with 90 degrees of elbow flexion. The non-support arm was placed across the chest with the hand on the opposite shoulder (Figure 3.5).

Training Intervention Programs

The training interventions were periodized in a linear design for the ET training group and undulating design for the PS group. Both programs were designed to target the proximal segments. The ET group was designed to mimic the traditional linear and isometric endurance programs currently cited in the literature to improve spinal stabilization and purported to improve sport performance.[32-35,38,43] The PS group used an undulating model as it has been reported as the preferred design for gains in muscular strength.[174,194,195] The power stability training program was a comprehensive and novel training approach as it incorporated spinal stabilization, but emphasized multi-planar, rotational strength, and power resistance techniques which targeted the proximal segments and were sport specific to throwing. Volume and intensity for each training session was controlled in an attempt to have similar time and repetitions for each group.

Workload was calculated by multiplying the number exercises, sets, repetitions and resistance recorded for each group and each training session throughout the intervention. Estimated workloads are listed in Table 3.4 and Table 3.5 for the traditional and proximal stability groups, respectively. Program compliance was monitored with attendance sheets.

Traditional Endurance Training Program

The ET group received isometric muscular endurance and repetition exercises for spinal stability exercises.[38,52,53] Each program consisted of warm-up [19] exercises, such as form run, tuck jumps, horizontal long jumps, and general flexibility (Figure 3.6).[19,179]Muscular endurance training exercises consisted of primarily static planks (prone, supine, side), torso extension, flexion, dead bug, bird dog and lateral muscular endurance movements, (Figure 3.7).[34,39,83,87,145,196] Exercise sessions were approximately 30 minutes, 2 times per week over 7 weeks for 14 total sessions. The program incorporated approximately 12 exercises per session.[179] All training sessions consisted of a 5 minute low intensity steady state jog followed by general static flexibility program for the legs, arms, and trunk muscles. The initial training phase lasted five sessions and focused on developing appropriate technique in establishing abdominal hollowing and linear static postures for long durations which has been commonly reported to improve spinal stabilization.[95,111] Exercises were performed at a high volume static holds of 30 seconds to a few minutes per exercise bout or set. The second training phase consisted of training static postures with both linear and multi-planar limb movements for four sessions.[10,197] The third training phase consisted of three training sessions of static postures and linear repetitive movements.[10,197] The final training phase lasted two sessions and incorporated static postures with limb movement advancing to different seated and plank postures (Figure 3.8).

Power Stability Training Program

The PS training progression followed a undulating blocked periodized model consisting of exercises for muscular endurance, perturbation and unstable surfaces (Bosu and Swiss ball), resistance and plyometric exercises using medicine balls, free weights, and body weight for endurance, strength and power training of the pelvis, spine and trunk.[19] Exercises progressed from floor work, to tall kneeling exercise to standing and functional movements which were sport specific to throwing. The program consisted of approximately 10-15 exercises per session. The exercise sessions were approximately 30-45 minutes, 2 times per week over 7 weeks for a total of 14 sessions.[178,191] (Table 3.3).

Phase one of the PS program consisted of three training sessions which emphasized 80% low intensity muscular endurance and spinal stability training limited to body weight resistance. The remaining 20% of this microcycle emphasized strength and power movements in all cardinal planes.[155] The second phase consisted of three weeks or five sessions with a decrease in exercise bout volume (3-4sets with 3-8 repetitions, 10-45 seconds) and increased intensity with resistance 20 – 50% of body weight or 10-30% of 1 RM bench press and plyometric progressive resistance reported to improve strength, power and throwing velocity.[149,198] At this stage, 90% of the program consisted of basic undulating sessions between strength and power exercises. The remaining 5-10% of the program consisted of muscular endurance exercises. The third training phase incorporated two sessions which acted as a short duration non-traditional transition preparatory period which emphasized high intensity strength, high load, low volume, and slow movements.[19,199] The final phase consisted of four high intensity low volume sessions emphasizing rapid sport specific movements with resistance < 20% of body weight or 10-30% of 1 RM bench press, such as medicine ball throw and catch. [19,179,194,199,200]

Table 3.1: Subject Demographics (mean ± standard deviation)

Group	N	Gender F/M	Age	Height, cm*	Weight, Kg Pre-*	Weight, Kg Post-*	Handed Left/Right	Pitchers, F/M	Non-Pitchers F/M
ET	21	8/13	20.3 ±1.3	176.3 ±8.6	80.1 ±15.1	80.5±15.7	2/19	1F/4M	7 F/9 M
PS	25	9/16	19.8 ±1.2	175.2 ±9	74.1 ±12.6	74.5 ±13.2	2/23	1F/4M	8 F/12 M
Total	46	17/29	20 ±1.3	175.7 ±8.7	77.2 ±13.9	78 ± 14.7	4/42	2F/8M	15 F/21M

ET= Traditional training intervention group.
PS= Power stability intervention group.
Pre- = Subject weight in Kg at pre-intervention data collection.
Post- = Subject weight in Kg at post-intervention data collection.
Handed= Indicates number of left and right handed throwing athletes.
M/F= F=female/softball players. M=male/baseball players.
Pitcher= Subjects reported primary position as a pitcher.
Non-Pitcher= Subjects reported primary position other than pitching.
*= Indicates no statistical difference for height and weight between the groups at .05 level of significance.

Table 3.2: Traditional Endurance Training Protocol
The following are examples of exercises performed for the endurance training group. Both static hold and repetition exercises were used in variation per each training session.

Training mode:	Phase Emphasis and Prescribed Muscular Endurance Training
Warm-up	Form run, general flexibility same for all training sessions
Phase I	Muscular endurance without limb movement (body weight)
Sessions 1-5	Static Hold Exercises: Progress from 3 sets of 30-60 second holds to 5 sets of 60 second holds. Pelvic Tilts and Holds* Prone/supine planks* Inch-worm walks* Superman extension to trunk Flexion Supine plank hip heist – double leg to single leg* Repetition Endurance Exercises: 3 sets of 25 repetitions Curl ups -shoulder to elbow up,*breath/brace* Dead bugs –no arm movement, progress from short to large* Short Birddog four point NO reach – lift hands, feet each limb* *exercises with abdominal hollowing
Phase II	Muscular endurance with limb movements (body weight)
Sessions 6-9	Static Hold Exercises: 4-5 sets of 60-90 second holds. Prone/Supine/Side planks with abdominal hollowing* Superman extension to trunk flexion Prone plank walks* Repetition Endurance Exercises: 3-5 sets of 25 repetitions Curl ups -shoulder to elbow up,*breath/brace* Dead bugs -progress from rapid short to rapid large* Birddog short to tall with reach of hands, feet* Tall Birddog four point LONG reaches bilateral/unilateral Prone plank unilateral reach backs –Legs only Supine plank hip heist – double to single leg *exercises with abdominal hollowing
Phase III	Muscular endurance with limb movements (body weight)
Sessions 10-14	Static Hold Exercises: 4-5 sets of 75-90 second holds. Prone/Supine/Side planks with abdominal hollowing* Superman extension to trunk flexion* Repetition Endurance Exercises: 4-5 sets of 25-50 repetitions Curl ups - Curl ups -legs open-toe touch Dead bugs -progress from rapid short to rapid large* Birddog short to tall with reach of hands, feet* Tall Birddog four point LONG reaches bilateral/unilateral Prone plank unilateral reach backs –Arms and Legs Supine plank hip heist – double to single leg *exercises with abdominal hollowing

Table 3.3: Power Stability Training Protocol
A combinations and variations of the following exercises were used for the training sessions.

Training Mode:	Phase Emphasis and Prescribed Exercises
Warm-up	Form running, Dynamic flexibility (Same for all training sessions/phases)
Phase I Sessions 1-3	Emphasis on Muscular Endurance: Body weight as the primary resistance
Endurance Exercises	<u>Static Hold Exercises</u>: Progress from 3 sets of 30-60 second hold-times Prone/Supine planks* Superman extension to trunk Flexion Supine plank hip heist – double leg to single leg* <u>Repetition Endurance Exercises</u>: 3 sets of 25 repetitions Curl ups -shoulder to elbow up Dead bugs –short/large range* Birddog four point reaches bilateral/unilateral* *exercises with abdominal hollowing
Perturbation Exercises	Airex- Russian Twist: 3 sets of 25repetitions Swiss Ball Flexion: 3 sets of 25 repetitions
Weight Resistance Exercises	Top Shelf: (20-50% Body weight): 3 sets of 8 repetitions Back Extensions (20-50% Body weight): 3 sets of 8 repetitions
Resistance/ Plyometric Exercises	Medicine ball: 3 sets of 25 repetitions Seated overhead throw Tall kneeling throw downs Overhead double arm forward throws
Phase II Sessions 4-8	Basic Strength/Power: Moderate to heavy resistance (20-50% body weight or 10-30% of 1 RM Bench Press)
Endurance Exercises	<u>Static Hold Exercises</u>: Progress from 3 sets 60 second hold-times Prone/Supine planks* Superman extension to trunk Flexion <u>Short</u> Birddog four point reaches bilateral/unilateral* *exercises with abdominal hollowing
Perturbation Exercises	Airex- Russian Twist BOSU Ball Flexion BOSU Ball Back Extensions Supine Swiss ball shoulder- rotations straight arm with resistance
Weight Resistance Exercises	Lunge with dumbbell\plate transverse and lateral trunk rotation, flexion Top Shelf Back Extensions, Lateral V-ups, Russian Twist
Resistance/ Plyometric Exercises	Medicine ball: Tall kneeling/seated/standing forward ball toss and throw down Back toss to wall – overhead Crow hop front ball toss/throw down

Table 3.3: Power Stability Training Protocol, Continued

Phase III Sessions 9, 10	Strength/Power heavy resistance (30-50% body wt.)
Endurance Exercises	Prone/side plank rotation reach opposite arm/leg *exercises explosive fast movement
Perturbation Exercises	Lunge with PNF Pattern, lateral bends, rotation Swiss ball/BOSU Flexion, Extension, Lateral V-ups
Weight Resistance Exercises	Top Shelf, lateral V-ups, back extensions, Russian twist
Resistance/ Plyometric Exercises	Medicine ball - Standing and tall kneeling face to face push press partner exchange -Throw downs –opposition -Standing and tall kneeling Transverse underhand throw -Crow hop overhead two arm throw-
Phase IV sessions 11-14	Power (5-20% body wt.) (Final week taper)
Endurance Exercises	Static Hold Exercises: Prone/Supine planks Superman extension to trunk Flexion Repetition Endurance Exercises: 3 sets of 25 repetitions Curl ups -shoulder to elbow up Dead bugs –short/large range
Perturbation Exercises	Lunge with PNF Pattern, lateral bends, rotation BOSU -Seated Russian twists* Swiss ball – curl-ups, extensions -Supine Plank shoulder rotation with resistance -lateral V-ups –resistance *explosive fast movement
Weight Resistance Exercises	Lunge lateral bend\transverse rotation Top Shelf Supine plank with hip heist – double to single leg
Resistance/ Plyometric Exercises	Med-ball - Standing and tall kneeling face to face push press partner exchange -Crow hop overhead two arm throw -Wall toss– overhead, transverse, oblique -Standing trunk twist throw downs -Straddle partner exchange- front receive transverse underhand toss

Table 3.4: Estimated Training Work Load for the Traditional Endurance Training Group.

Training Session	Type of Exercise	Number of Sets	Hold-time/ Repetitions Per Exercise	Number of Exercises	Resistance	Session Sub-totals	Session Totals	Total Work Load
1,2	Static Repetition	5 3	30 seconds 25 repetitions	5 6	Body Weight	750 450	1200	2400
3,4	Static Repetition	5 3	45 seconds 25 repetitions	5 6	Body Weight	1125 450	1575	3150
5	Static Repetition	5 3	60 seconds 25 repetitions	5 6	Body Weight	1500 450	1950	1950
6	Static Repetition	5 4	60 seconds 25 repetitions	5 7	Body Weight	1200 700	1900	1900
7, 8	Static Repetition	4 5	75 seconds 25 repetitions	5 7	Body Weight	1500 875	2375	4750
9	Static Repetition	5 5	90 seconds 25 repetitions	5 7	Body Weight	2250 875	3100	3100
10	Static Repetition	5 5	70 seconds 50 repetitions	5 6	Body Weight	1750 1500	3250	3000
11, 12	Static Repetition	5 5	80 seconds 35 repetitions	5 6	Body Weight	1875 1050	2925	5850
13	Static Repetition	5 5	80 seconds 35 repetitions	5 6	Body Weight	2000 1050	3050	3050
14	Static Repetition	4 4	90 seconds 25 repetitions	5 6	Body Weight	1800 600	2400	2400
							Total Estimated Work =	29795

The estimated total work load was determined by multiplying the number of exercises by the number of sets and the number of repetitions prescribed to be performed. Session sub-totals were the total per the type of exercise for that particular training session. Session total is the total of the exercise workload for the entire training session. All exercise were performed with no external resistance.[19]

Table 3.5: Estimated Training Work Load for the Power Stability Training Group

Training Session	Type of Exercise	Number Sets	Hold-time/ Repetitions Per Exercise	Number of Exercises	Resistance	Session Sub-totals	Session Totals	Total Work Load
1,2	Static	4	30 seconds	5	Body wt.	600	1219	2436
	Repetition	3	25 repetitions	3	Body wt.	225		
	Resistance	3	8 repetitions	2	3% (2 Kg)	96		
	Perturbation	3	25 repetitions	2	Body wt.	150		
	Plyometric	3	25 repetitions	2	8% (6 Kg)	150		
3	Static	3	60 seconds	3	Body wt.	540	1560	1560
	Repetition	3	50 repetitions	2	Body wt.	300		
	Resistance	2	8 repetitions	2	10% (10Kg)	320		
	Perturbation	2	25 repetitions	2	Body wt.	100		
	Plyometric	2	25 repetitions	1	8% (6 Kg)	300		
4, 5	Static	3	60 seconds	3	Body wt.	540	1890	3780
	Resistance	5	5 repetitions	3	20% (15Kg)	225		
	Perturbation	3	8 repetitions	2	20% (15Kg)	720		
	Perturbation	3	50 repetitions	1	Body wt.	150		
	Plyometric	4	5 repetitions	2	5% (4Kg)	160		
6	Static	3	60 seconds	2	Body wt.	240	2435	2435
	Repetition	2	25 repetitions	1	Body wt.	50		
	Resistance	5	3 repetitions	3	50% (37Kg)	1665		
	Perturbation	2	8 repetitions	2	20% (15Kg)	480		
7,8	Repetition	2	25 repetitions	2	Body wt.	50	3335	6670
	Resistance	5	3 repetitions	3	50% (37Kg)	1665		
	Perturbation	5	3 repetitions	3	40% (30Kg)	1350		
	Plyometric	3	3 repetitions	2	20% (15Kg)	270		
9	Resistance	4	3 repetitions	2	50% (37Kg)	888	2688	2688
	Perturbation	4	3 repetitions	2	50% (37Kg)	888		
	Plyometric	4	3 repetitions	2	30% (22Kg)	528		
	Plyometric	4	8 repetitions	2	8% (6 Kg)	384		

Table 3.5: Estimated Training Work Load for the Power Stability Training Group, Continued

10	Static	2	75 seconds	2	Body wt.	300	2886	3086
	Resistance	2	5 repetitions	3	50% (37Kg)	1110		
	Perturbation	2	3 repetitions	2	50% (37Kg)	444		
	Plyometric	4	3 repetitions	2	50% (37Kg)	888		
	Plyometric	4	3 repetitions	2	8% (6 Kg)	144		
11	Repetition	2	50 repetitions	2	Body wt.	200	1672	1672
	Resistance	4	8 repetitions	2	5% (4Kg)	256		
	Perturbation	4	8 repetitions	2	20% (15Kg)	960		
	Plyometric	4	8 repetitions	4	3%(2Kg)	256		
12	Repetition	2	50 repetitions	2	Body wt.	200	1726	1726
	Resistance	4	4 repetitions	4	5% (4Kg)	256		
	Perturbation	4	4 repetitions	4	5% (4Kg)	256		
	Plyometric	4	4 repetitions	4	20%(15Kg)	960		
	Plyometric	3	3 repetitions	3	3%(2Kg)	54		
13	Repetition	2	50 repetitions	2	Body wt.	200	2012	2012
	Resistance	2	6 repetitions	3	40% (30 Kg)	1080		
	Perturbation	2	6 repetitions	2	10% (8 Kg)	192		
	Plyometric	5	6 repetitions	2	10%(8 Kg)	480		
	Plyometric	5	3 repetitions	2	3% (2 Kg)	60		
14	Static	2	75 seconds	2	Body wt.	300	1398	1398
	Perturbation	3	3 repetitions	3	20% (30 Kg)	810		
	Plyometric	3	3 repetitions	4	3% (8 Kg)	288		
							Total Estimated Work=	29463

The estimated total work load was determined by multiplying the number of exercise by the number of sets, external resistance and the number of repetitions prescribed to be performed. % Resistance represents the estimated resistance for a participant using the % of the average body weight of 74 Kg reported for the proximal stability training group.[19] Session sub-totals were the total per the type of exercise for that particular training session. Session total is the total of the exercise workload for the entire training session.

Chapter 3: Figures

Figure 3.1**:** PrimusRS 3-dimensional cable motion system

Figure 3.2: 1 RM Power Chop Test and Lift Test

a. Chop Start Position b. Chop Finish Position

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Figure 3.3: 1 RM Power Lift Test

a. Lift Start Position

b. Lift Finish Position

Figure 3.4: Prone Endurance Plank

Figure 3.5: Side Endurance Plank

See Appendix C for a photo representation of the following training exercises:

Figure 3.6: Warm up drills: high knees, strides, leg swings, bounds, squat/lunge
Figure 3.7: Endurance Training
    Supine/Prone abdominal hollowing
    Birddog –four-point reaches ipsilateral/unilateral
    Curl ups
    Superman flexion to extension
    Dead Bugs
    Plank Series:
    Plank Variations
    Supine Plank- Heel Touches
    Supine Plank Hip Heist –double to single leg
    Side Plank with Hip Heist
    Heals to the Heavens

Figure 3.8: Perturbation/Heavy Resistance Exercises
    BOSU –Back Extension
    BOSU V-ups
    Swiss Ball Weighted Back Extensions
    Swiss Ball Weighted Flexion
    Swiss ball T-Spine Rotations (High)
    Swiss ball T-Spine Rotations (Low)

Figure 3.9: Resistance/Plyometric Training
    Weighted Medicine Exercise Balls
    Seated Overhead Ball Toss
    Tall Kneeling Over Head Throw Downs
    Standing Over Head Throw Downs
    Standing Overhead Forward Toss
    Standing Over back Ball Toss
    Various Partner Exchange Ball Toss
    Russian Twist for Speed and Power
    Standing Ball Twists
    Medicine Ball: Side Underhand Toss (Receive and Toss)
    Medicine Ball: Over Shoulder Front Throw (Side View)

Figure 3.10: Resistance Training
    Standing Rotation/Lunge Rotation -Fast and Slow
    Lunge with Torso Lateral Bend/rotation
    Top Shelf, Russian Twist for Strength (Heavy Resistance)

Chapter 4: Data Reduction

Statistical Analysis

A randomized controlled trial was implemented with a stratified permuted block and a pre- to post-intervention design. Sex and player position were stratified with blocks of size 4 (Appendix B: Randomization Schedule). The independent variables were the traditional training group (ET) and the proximal stability training group (PS). The primary dependent variable of interest was the change in peak throwing velocity/kg of body weight in mph when compared between pre- and post-intervention time points. Additional dependent variables were mean throwing velocity/Kg body weight (mph), one-repetition maximum for a chop test/Kg body weight and lift test/Kg body weight (watts), and static hold-times for the prone and side isometric muscular endurance plank tests (seconds).[184]

Group differences and change scores for each dependent variable were assessed with a two-tailed independent sample T-test and a Mann-Whitney U test. Percent change from pre- to post-intervention for all dependent variables was calculated by dividing pre-intervention values into the change scores for the corresponding dependent variable. The treatment effect between the groups was further analyzed by calculating effect sizes (ES) with corresponding 95% confidence intervals (CI) for each dependent variable normalized by body weight.[201] ES was based on a Cohn's *d* calculation and was calculated as the mean of the traditional group minus the mean of the proximal stability group divided by a pooled standard deviation. ES were interpreted as small (0 – 0.39), medium (0.40 – 0.69) or large (≥ 0.70).[201]

Secondary analysis was performed using a Pearson Product Moment correlation to assess the relationships between throwing velocity, chop and lift power outputs and the prone and side plank hold-times. A Fisher's *Z* transformation was used to determine if the correlation between peak throwing velocity and the proximal stability measures of power and endurance were significantly different from one another with 95% confidence (p=.05). The lowest correlation for the power measure was compared to the highest endurance measure. Statistical comparisons between these correlations, are possible because the sampling distribution of the transformed *Z* score move toward a normal distribution for comparison more rapidly than that of a bivariate distribution *r.* A correlation-coefficient dependent T-test with the alpha level set at $P <$ .05 was used to determine if differences did exist between the correlations.

Training compliance and the maximum test number of repetitions required to reach the1-RM power outputs were analyzed via descriptive methods. All statistical analysis was performed using SPSS/PAW v19.0 (SPSS, IMB Inc., Chicago, IL.) with an a priori significance level of $p \leq .05$.

Results

The results are listed individually by research hypothesis and the corresponding statistical analyses. Each section concludes with a brief explanation of the results as related to the statistical outcomes and the projected hypothesis. Further discussion is contained in Chapter 5: Discussion.

Hypothesis 1a (Primary): A two-tailed independent sample Students T-test was used to test the hypothesis that change scores for peak throwing velocity would be significantly faster in the PS group when compared to the ET group. The significant change between groups translates into a 6% (mph) difference in the PS group when compared to the ET group, (ET= .21 ±.55 mph, PS= 3.4 ±1.1 mph, *p*< .001) which may prove to positively influence a throwing athletes' performance.

Hypothesis 1b (Secondary): It was hypothesized that change scores for mean throwing velocity (mph), the chop test (watts) and the lift test (watts) would be significantly higher in the PS group when compared to the ET group while the prone and side plank hold-times (seconds) would not be different between groups. A two-tailed independent sample Students T-test confirmed that the change scores for mean throwing velocity (mph), (ET= 1.1 ±1.6 mph, PS= 3.7 ±1.8 mph, *p*< .001), the chop test (ET= 20 ±78watts, PS= 105 ±68 watts, *p*< .001), and lift test (ET= 49 ±62 watts, PS= 114 ±73 watts, *p*= .003), were significantly higher in the PS group, when compared to the ET group. A two-tailed independent sample Mann-Whitney T-test and a independent sample Students T-test indicated no change score difference between groups for prone plank hold-times (seconds), (ET= 26 ±33sec, PS= 26 ±39sec, *p*= .98) and side plank hold-times (seconds), (ET= 19 ±18 sec, PS= 22 ±23 sec, *p*= .60). Specificity adaptations occurred as the power based intervention targeting the proximal segments (PS) produced change scores in power measures of mean throwing velocity, 1RM chop, and 1RM lift tests, but not in endurance hold-times for the prone and side planks when compared to an endurance training intervention (ET). The simultaneous change in proximal stability measures and sport support the use for sport specific training stimulus that mimics the stability and mobility demands of the proximal segment to be specific to sport.

Hypothesis 1c: It was hypothesized that a significant improvement in endurance measures of proximal stability and not in throwing velocity or the chop and lift 1-RM power output tests would be observed at post-intervention in the ET group. A paired T-test was used to support that a change within each group occurred over time. Displayed in Table 4.1, the PS group had statistically significant differences for peak (p< .001) and mean (p < .001) throwing velocity/Kg of body weight, chop (p< .001) and lift (p< .01) power outputs/Kg of body weight, prone (p=.001) plank hold-times and the side (p= .01) plank hold-times. The ET group had statistically significant differences pre- to post-intervention for mean throwing velocity/Kg of body weight (p= .01), lift power outputs/Kg of Body weight (p= .02), prone plank hold-times (p< .001) and side plank hold-times (p=.001). Additional secondary analysis of between group differences for each dependent variable was performed using a two-tailed independent sample Students T-test to determine if group differences did exist at post-intervention. Displayed in Table 4.2, significant differences were observed between the groups for peak (ET= .83 ±.1, PS= .94 ±.09, *p*< .001) and mean, (ET= .83 ±.1, PS= .93 ±.09, *p*< .001) throwing velocity/Kg of body weight (mph), chop (ET= 6.7 ±1.9, PS= 8.1 ±2.3, *p*= .003), and lift (ET= 3.6 ±1.0, PS= 4.6 ±1.6, *p*= .004) power outputs/Kg of body weight (watts). There were no statistical differences for prone (ET= 154 ±54, PS= 151±42, *p*= .9) and side plank hold-times (seconds), (ET= 90 ±.27, PS= 98 ±24, *p*= .6). The PS and ET groups demonstrated specificity adaptations consistent with the training stimuli and revealed that endurance stability training is limited in producing sport specific outcomes for over head throwing.

<u>Hypothesis 1 Post Hoc Analysis</u>: A treatment effect and percent change in performance compared between the groups was performed to examine the treatment effect for each dependent variable at post-intervention and is displayed in Table 4.3, and Figure 4.4. The treatment effect was large for peak (ES=1.0, CI= .97-1.03) and mean

(ES= 1.1, CI= .08-1.04) throwing velocity/Kg of body weight and the lift power outputs/Kg of body weight (ES=.85, CI= .47-1.23). There were medium effects for the chop power outputs/Kg of body weight (ES=.67, CI= .06-1.28). Small effects were observed for both the prone plank (ES=.09, CI= -8.5-10.2) and the side plank (ES=.25, CI= -9.05- 9.55). The percent change in performance for each dependent variable from pre- to post-intervention was larger in the PS group for peak and mean throwing velocity, the chop test, and the lift test when compared to the ET group. There were similar percent changes in the prone and side plank hold-times for both groups.

A independent sample Students T-test revealed that there were no between group differences at baseline for subject height, weight, years of playing experience and performance dependent measures as reported in Table 4.5, ($p > .05$). The change in all dependent variables from pre- to post-intervention is presented in Table 4.4.

Hypothesis 2: It was hypothesized that strong ($r > .7$) correlations would exist between throwing velocity and the power measures of proximal stability; the chop test and the lift test. A Pearson Product Moment Correlation revealed significant moderate to strong relationships between peak and mean throwing velocity/Kg of body weight with the chop ($r= .69$, $r= .64$, $p = .001$) and lift ($r= .73$, $r= .58$, $p = .001$) power outputs/Kg of body weight. The variance explained by the power measures throwing velocity reveal they are likely using similar mechanics for much of the movements.

Hypothesis 2a: In contrast it was hypothesized that there would be weak ($r < .03$) correlations between peak throwing velocity and the endurance plank measures. There were statistically significant weak and moderate correlations between peak and mean throwing velocity/kg of body weight with the prone ($r= .31$, $p=.007$, $r=.50$, $p=.001$) and side (r= 39, p= .006, r= .47, p= .016) plank hold-times. While these movements seem to share some similarities related to the muscles being used to perform the tasks, the differences in movement intensity and duration appear to limit the relationship between these skills.

Hypothesis 2b: It was hypothesized that there would be a weak (r < .03) correlation between the power chop test and lift test and endurance plank measures of proximal stability. However, the chop test had weak and moderate significant correlations with the side (r= .29, p=.04) and prone (r= .45, p=.002) endurance measures, respectively. There was a weak, non-significant correlation between the lift test outputs and the endurance prone (r= .22, p= .15) and side (r= .23, p= .13) plank measures of proximal stability. The similarities in muscle action for the chop and prone plank versus those of the lift and side plank seem to account for the tangential relationships the different power movements have with that of the endurance planks.

Hypothesis 2 Post Hoc Analysis: A direct comparison of a Fisher's Z transformation using a t-test with 95% confidence demonstrated that peak throwing velocity had a statistically significant stronger relationship with the power chop test (r= .69, t= 2.02, p < .05) and lift test (r= .73, t=2.39, p < .05). No significant differences were found for peak throwing velocity correlations between the endurance prone (r= .31, t= -.37, p >.05) and side (r= .39, t= -.42, p > .05) planks. The statistically significant correlations regarding throwing velocity and power verse endurance measures of proximal stability support the use of power oriented assessments for power oriented skills. Correlations for the dependent variables are displayed in Table 4.6.

Additional Post Hoc Analysis: Subject training compliance exceeded 90 percent for both intervention groups as reported in Table 4.7. The number of average repetitions recorded for the 1-RM power outputs was 3 ± 1 repetitions for both groups and both testing sessions are reported in Table 4.8.

Table 4.1: Means, Standard Deviations, With-in Group Differences and Level of Significance for Differences in the Dependent Variables at Post-Intervention

Dependent Variables/ Kg Body Weight	Group	N	Pre-intervention Mean ± sd	Post-intervention Mean ± sd	p-value (p ≤ .05)
Peak Throwing Velocity, mph	ET	21	.85 ± .1	.85 ± .1	.60*
	PS	25	.90 ± .09	.95 ± .09	.001*
Mean Throwing Velocity, mph	ET	21	.82 ± .1	.83 ± .1	.02*
	PS	25	.88 ± .09	.93 ± .09	.001*
Chop Output, watts	ET	21	6.5 ± 2.0	6.6 ± 2.0	.38*
	PS	25	6.6 ± 2.1	8.0 ± 2.2	.01*
Lift Output, watts	ET	21	3.0 ±1.2	3.6 ± 1.0	.001#
	PS	25	3.1± 1.3	4.7 ± 1.6	.01#
Prone Plank Hold-times, seconds	ET	21	128 ± 41	154 ± 54	.001#
	PS	25	126 ± 32	151 ± 42	.003*
Side Plank Hold-times, seconds	ET	21	75 ± 14	90 ± 27	.03#
	PS	25	72 ± 32	98 ± 24	.01#

ET= Traditional Training Intervention Group.

PS= Power Stability Intervention Group.

*= Dependent Paired Sample T-Test.

#= Wilcoxon Paired Sample T-Test.

Table 4.2: Means, Standard Deviations, Between Group Differences and Level of Significance for Dependent Variables at Post-Intervention

Dependent Variables	Group	N	Mean	Standard Deviation	p-value ($p \leq .05$)
Peak Throwing Velocity/Kg Bwt., mph	ET	21	.83	.10	.001*
	PS	25	.94	.09	
Mean Throwing Velocity/Kg Bwt., mph	ET	21	.83	.11	.001*
	PS	25	.93	.09	
Chop Output/Kg Bwt., watts	ET	21	6.7	1.9	.003*
	PS	25	8.1	2.3	
Lift Output/Kg Bwt., watts	ET	21	3.6	1.0	.004#
	PS	25	4.6	1.6	
Prone Plank Hold-times, seconds	ET	21	154	54	.9#
	PS	25	151	42	
Side Plank Hold-times, seconds	ET	21	90	27	.6*
	PS	25	98	24	

PS= Power Stability Intervention Group.
ET= Traditional Training Intervention Group.
*= Independent Student T-Test.
#= Independent Sample Mann-Whitney U test.

Table 4.3: Cohn's *d* Treatment Effect Size, Confidence Intervals and Percent Change from Pre- to Post-Intervention Between Groups for Dependent Variables

Dependent Variable	Effect Size	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	% Change Pre- to Post-Intervention
Peak Throwing Velocity/Kg Bwt.	1.00*†	0.97	1.03	ET= 0% PS= 6%
Mean Throwing Velocity/Kg Bwt.	1.11*†	1.08	1.14	ET= 2% PS= 6%
Chop Power Output/Kg Bwt.	0.67#†	0.06	1.28	ET= 5% PS= 27%
Lift Power Output/Kg Bwt.	0.85*	0.47	1.23	ET= 29% PS= 51%
Prone Plank Hold-times, seconds	0.09	-8.5	10.2	ET= 24% PS= 23%
Side Plank Hold-times, seconds	0.25	-9.0	9.5	ET= 31% PS= 25%

*= Indicates large Effect.

#= Indicates Moderate Effect.

†= Indicates significant difference (p≤ .5) between traditional training and proximal stability training groups for dependent variable.

Table 4.4: Dependent Variables Means and Standard Deviations for Raw Data and Data Normalized by Body Weight, Change Scores and Statistical Significance level for the Change in Performance from Pre- and Post-Intervention

	Traditional		Power Stability	Pre	Change Score		
Dependent Variables	Pre	Post	Post		ET	PS	p-value
	Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd	Mean ± sd	(p ≤ .05)
Peak Throwing Velocity, mph	67.5 ± 11.6	67.3 ± 11.7	67.3 ± 13.4	70.7 ± 13.4	.21± .55	3.4± 1.1	< .001*
Peak Throwing Velocity/Kg Body Wt.	.85 ± .1	.85 ± .1	.90 ± .09	.95 ± .09	.00 ± .01	.04 ± .02	< .001*
Mean Throwing Velocity, mph	64.8 ± 11.5	66.4 ± 11.8	65.8 ± 13.3	69.5 ± 13.2	1.1 ± 1.6	3.7 ± 1.8	< .001*
Mean Throwing Velocity/ Kg Body Wt.	.82 ± .1	.83 ± .1	.88 ± .09	.93 ± .09	.01 ± .02	.04 ± .02	< .001*
Chop Output, watts	536 ± 202	557 ± 199	511± 206	616 ± 224	20 ± 78	105 ± 68	< .001*
Chop Output/Kg Body Wt.	6.5 ± 2.0	6.6 ± 2.0	6.6 ± 2.1	8.0 ± 2.2	.22 ± .91	1.3 ± .91	< .001*
Lift Output, watts	258 ± 126	308 ± 118	248 ± 128	362 ± 166	49 ± 62	114 ± 73	.003#
Lift Output/Kg Body Wt.	3.0 ±1.2	3.6 ± 1.0	3.1± 1.3	4.7 ± 1.6	.59 ± .67	1.4 ± .82	.001*
Prone Plank Hold-times, seconds	128 ± 41	154 ± 54	126 ± 32	151 ± 42	26 ± 33	25 ± 39	.98#
Side Plank Hold-times, seconds	75 ± 14	98 ± 24	72 ± 32	90 ± 24	23 ± 12	18 ± 16	.60#

Change Scores = Average change for post-intervention data minus pre-intervention data.
*= Independent Student T-Test.
#= Independent Sample Mann-Whitney U test.

Table 4.5: Pre-Intervention Between Group Differences for Dependent Variables

Dependent Variables	Group	N	Mean Differences	Standard Deviation	p-value ($p \leq .05$)
Peak Throwing Velocity/Kg Bwt., mph	ET	21	.85	.11	.08*
	PS	25	.91	.09	
Mean Throwing Velocity/Kg Bwt., mph	ET	21	.83	.11	.46*
	PS	25	.88	.09	
Chop Output/Kg Bwt., watts	ET	21	6.5	2.03	.84*
	PS	25	6.6	2.17	
Lift Output/Kg Bwt., watts	ET	21	3.0	1.29	.78*
	PS	25	3.1	1.35	
Prone Plank Hold-times, seconds	ET	21	1.6	.59	.78#
	PS	25	1.7	.55	
Side Plank Hold-times, seconds	ET	21	.92	.21	.98*
	PS	25	1.0	.41	

ET= Traditional Training Intervention Group.

PS= Power Stability Intervention Group.

*= Independent Student T-Test.

#= Independent Sample Mann-Whitney U test.

Table 4.6: Correlation Coefficient and Level of Statistical Significance (p≤ .05) for Throwing Velocity/Kg of Body Weight and Performance Dependent Variables at Post-Intervention

Dependent Variable N= 46	Mean Throwing Velocity/Kg Bwt., mph	Chop Outputs/ Kg Bwt., watts	Lift Outputs/ Kg Bwt., watts	Prone Plank Hold-times, seconds	Side Plank Hold-times, seconds
Peak Throwing Velocity/ Kg Bwt., mph	.99 (.001)*	.69 (.001)*	.73 (.001)*	.31 (.007)*	.39 (.001)*
Mean Throwing Velocity/ Kg Bwt., mph	1	.64 (.001)*	.58 (.002)*	.50 (.006)*	.47 (.016)*
Chop Output/Kg Bwt., watts		1	.81 (.001)*	.45 (.002)*	.29 (.04)*
Lift Output/Kg Bwt., watts			1	.22 (.151)	.23 (.13)
Prone Plank Hold-times, seconds				1	.58 (.001)*
Side Plank Hold-times, seconds					1

*=Correlation significant at .05.

Table 4.7: Training Session Compliance Means and Standard Deviations

Groups	N	Mean ± Sd

Power Stability Group	25	91 ± 9*
Traditional Training Group	21	92 ± 8*
Total	46	91± 8*

*=Exceeded the pre-establish compliance requisite of 66%.

Table 4.8: Mean Repetitions to One-Repetition Maximum for the Chop and Lift Test

Time	Group	N	Repetitions Mean ± sd
Pre-intervention	PS	25	3 ± .9
	ET	21	3 ± 1
Post-intervention	PS	25	3 ± 1
	ET	21	3 ± 1

ET= Traditional Training Intervention Group.
PS= Power Stability Intervention Group.
Repetitions = Number of maximum efforts needed to reach the 1-RM for the Chop and Lift Maximum Power Test.

Chapter 4: Figures

Figure 4.1: Study Subject Allocations

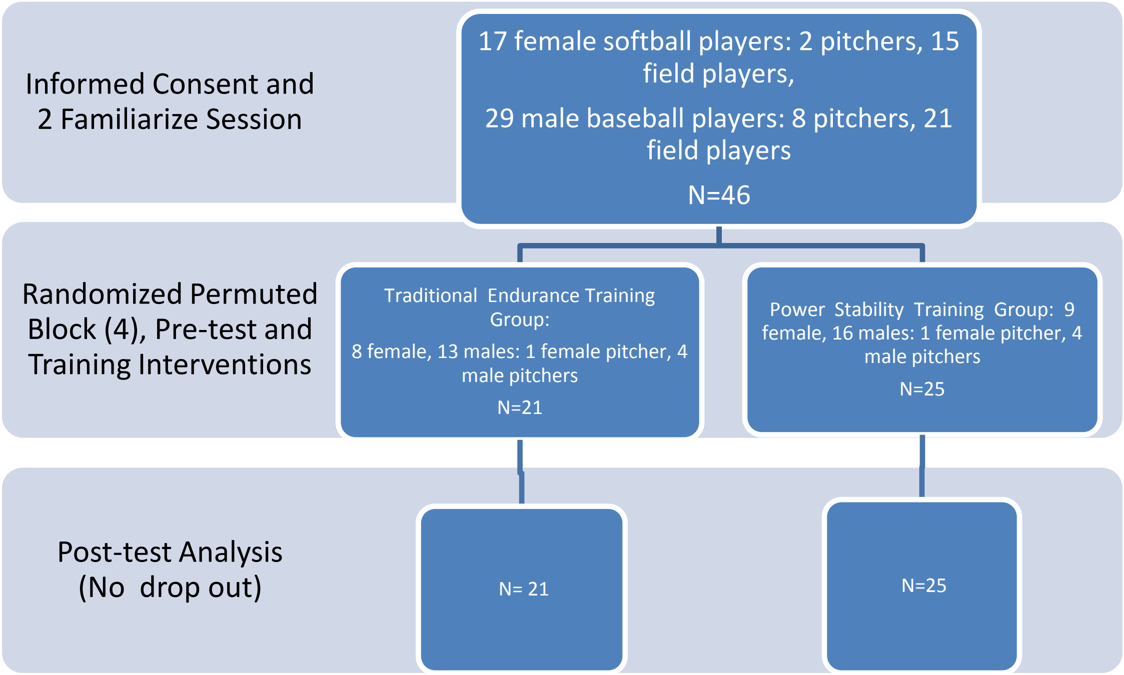
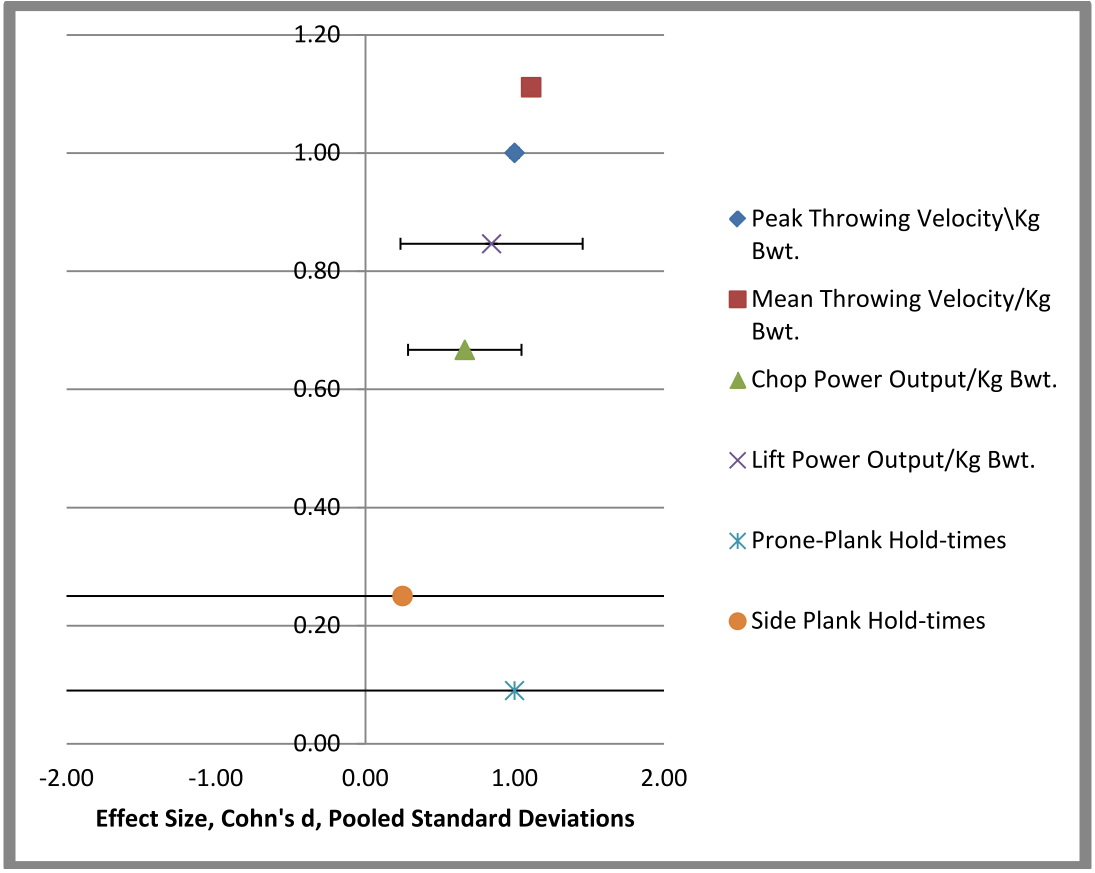


Figure 4.2: Treatment Effect Using Cohn's *d* Conversion with Pooled Standard Deviations for Dependent Variables Between Groups



Chapter 5: Discussion

We hypothesized that a seven week comprehensive proximal stability training intervention would improve throwing velocity and proximal stability measures among Division III softball and baseball players when compared to a traditional muscular endurance training protocol. The most important finding of our study was that throwing velocity and performance measures of the pelvis, spine and trunk improved simultaneously following a sport specific training intervention which targeted the muscular power, strength, and endurance characteristics specific to spinal stability and active pelvis and trunk control. We also confirmed that the PS group improved exclusively on the power tasks, and not the endurance plank tests when compared to the ET group. This finding confirmed our hypothesis that a training program that focused on exercises emphasizing power movements at the proximal segments would have a specific effect on performance measures that require fast explosive movement patterns similar to sport. The PS group had a significant change in the power tasks of throwing velocity, the power chop and lift tests, but not the endurance prone and side planks when compared to the ET group. Interestingly, the ET group did not improve or decline in peak throwing velocity. However, improvements in the endurance measures of the ET group appeared to translate to a higher post-intervention measure of mean throwing velocity. We also proposed that throwing velocity would have a high correlation with the power chop and lift tests and a low correlation with the endurance plank tests. This was found to be true with regards to peak throwing velocity; however there was a moderate correlation between mean throwing velocity and the endurance plank tests. Our results suggest a sport specific training program can improve endurance and power measures of proximal stability which can be translated into faster overhead throwing velocity. Training techniques which target the muscular endurance, strength and power characteristics versus endurance only exercises for the proximal segments result in increases in throwing velocity.

Prior to this study there has been limited support that improvements at the proximal segments result in increases in sport performance. However, our results confirm a resistance training program that targets the sport specific muscular endurance, strength, and power contributions specific to the proximal segments can result in positive improvements specific to sport. Several training interventions have been reported to improve either sport performance[36,40-42] or measures of proximal stability,[33-35,37,38,43] but only one study has reported improvements in both.[36] The lack of empirical evidence is likely the result of the inconsistencies and limitations regarding the current training and assessment techniques reported in the literature. The use of sport specific proximal stability training and assessment practices in the current study should serve as a template for future investigations regarding proximal stability training interventions.

Proximal Stability Training Implications

The positive outcomes in the current study are due in part to the novel training design for the PS group. We combined undulating blocked periodization with endurance, strength, and power resistance training exercises which targeted the proximal segments and emphasized the development of sport specific power movements associated with overhead throwing. The undulating design calls for more frequent changes in training intensity and volume when compared to a traditional linear periodization. The rather quick alterations from high volume-low intensity to low volume-high intensity have been theorized to place a great deal of stress on the neuromuscular system which accounts for gains in strength.[174,194,195] It has been proposed that the undulating stimulus allows for more frequent periods of recovery resulting in the ability to work at higher levels of intensity.[202-206] We employed an undulating design that emphasized periodic adjustments for exercise intensity and volume primarily between the strength and power exercises on a weekly basis.[194] While this model has been purported to be superior to linear progressions and optimal for developments in muscular endurance, strength, and power; this is the first study to use an undulating design to target proximal stability.[174,194,195] Thus, it appears that emphasis on high intensity resistance and the program progression are accountable for changes seen in the PS group. The significant change between groups and the treatment effect for the proximal stability and throwing velocity measures indicate that this training progression may be superior to those previously reported.[36,40,42]

In contrast to the undulating design used with the PS group, a linear periodization design was used to guide the ET training sessions. Exercises were modeled from several studies that previously reported success in documenting improvements in muscular endurance at the proximal segments.[32,35] The change in the endurance plank measures for the ET group between the pre- and post-intervention time points were similar to those previously reported, indicating the program was effective.[32,34] However, the non-significant differences and treatment effects for the plank tests between groups indicates the separate training interventions had a similar effect regarding muscular endurance. Although the amount of endurance training for the PS group was much less than those who participated in the ET group, the treatment effects appear to have been nearly equal. It is difficult to determine why the effect on the endurance measures between the different training programs was so similar. While there remains limited evidence, the undulating design has been previously reported to have a greater training effect for improving strength and endurance measures for both lower and upper extremity movements when compared to linear progressions.[195] Alternatively, the popularity and previous use of plank and isometric endurance exercises by the subjects in this study may have influenced the endurance performance effect. The athletes may have already been well conditioned to endurance plank tasks, thus limiting the ability to have a training effect and significant differences between the groups.[44]

Previous proximal stability training interventions often lack sport specific movement(s) and do not target the muscle contributions from the spine, pelvis and trunk specific to sport.[34,37,41,43,44] As a result, there is limited evidence and no consensus regarding the most appropriate training techniques for the proximal segments needed to promote improvements in sport performance. Similar to our results, Pedersen et al reported a 3.5% ($p = .04$) increase in ball velocity from a non-approach soccer kick and a 33 – 50% ($p < .01$) improvement in pelvic stability in twelve 1st division Norwegian soccer players following a neuromuscular control training program.[36] In this study, a variety of linear and static sling and single leg balance training exercises were performed on stable and unstable surfaces. Due to the diversity of the training program and limited sport specific movements it is difficult to determine if the improvements in sport resulted solely from contributions of the proximal segments, other body segments or a learning effect. Others have also reported improvements in sport performance following a sling and unstable surface training, but have failed to implement power and strength stimuli specific to sport in addition to traditional endurance exercises.[40-42] The few studies that have reported implementing strength training often use static and or non-sport specific exercises[31,36,37,40,42] or test measurable outcomes that are not likely to change in response to the training stimuli.[37,43] Stanton et al employed an 8 week Swiss ball muscular strength training program targeting the proximal segments for football and basketball players, to determine the effect on running efficiency and maximum oxygen volume (VO2) uptake.[37] While important for these sports such outcomes are not likely to be influenced by static strength stimuli in conditioned athletes. Our protocol included several techniques that were similar to Pedersen et al and others, such as resistance training on the Swiss ball, however, we targeted the proximal segments with multi-planar, rotation, strength and power stimuli specific to overhead throwing. Based on our data and the findings from Pedersen et al,[36] and others[40-42,47,183] endurance, strength, and neuromuscular training stimuli seem to play a role in promoting improvements in performance. However, our study is the first to employ training stimuli that isolated sport specific contributions of proximal stability specific to muscular power.

A majority of the proximal stability training interventions have focused less on training specificity and more on the training stimuli.[33,35,47,183] Regardless of the sport, training programs have predominately consisted of linear or static isometric endurance exercises on stable and unstable surfaces, such as planks or balancing tasks on a Swiss ball.[44] While these training techniques have been reported to improve muscular endurance of the deep spinal stabilizers there is little evidence that these gains translate into enhanced sport performance.[33,35,38,43] Our results provide support for the importance of specificity of exercise. Although there were muscular endurance gains alone observed in the ET group there was no subsequent improvement in peak throwing velocity.[33,35,36,38]

However, the improvements in mean throwing velocity indicate endurance training may be warranted for maintaining consistency in throwing performance. However, more research is needed to confirm these results. These findings indicate endurance training alone is not sport specific and maybe inappropriate for establishing gains in the power movements and peak throwing velocity.

Muscular Endurance Training

Muscular endurance appears to play a role in performance, but likely has less influence than the strength and power contributions for peak overhead throwing velocity and power movements where active pelvic and trunk control and spinal stability are essential to movement. Muscular endurance training has been reported to increase muscular co-activation, recruitment of type I/slow-twitch, oxidative muscle fibers, and hypertrophy development specific to the deep spinal stabilizers. [10,32,56] As a result performance outcomes not focused on endurance movements have been limited.[33,35] Therefore, it is not surprising that several authors have reported isolated improvements in muscular endurance tasks, such as plank tests, but not in more dynamic or quick movements, such as a power ball toss following an endurance intervention.[33,52,53] Several authors[21,73,87,107] have reported muscular endurance as a primary contributor in maintaining spinal stability even during maximum efforts. There were significant improvements in muscular endurance for both the ET and PS groups and it can be surmised that gains in spinal stability may compliment the musculature supporting the pelvis and trunk during dynamic power tasks, such as throwing. To date there is no conclusive evidence that improved muscular endurance at the proximal segments can solely influence better performance in power sports.[10,32,52,87] For the most part our data seems to support this claim, however the improvements in mean throwing velocity indicates a potential need for endurance training. Muscular endurance training appears to have an essential, but limited role for power movements such as overhead throwing and should be trained accordingly. Based on our results it can be hypothesized that the endurance gains primarily contributed to spinal stability which enhanced the efficiency of energy transfer at the proximal segments, however the application to sport performance is limited without contributions of strength and/or power from the adjacent pelvis and trunk.

Motor Unit Recruitment Considerations

Motor unit recruitment is vital to sport specificity training and can influence performance outcomes. We attempted to mimic the intensity, movement pattern and velocity of overhead throwing within a resistance training program. The intensity or difficulty of a movement can influence muscle activation patterns at the proximal segments thus impacting the effect of a training stimulus. The deep spine stabilizing muscles have been reported to function predominately as static stabilizers and provide a proximal base of support prior to the activation of the torque producing muscles of the pelvis, trunk and extremities regardless of the intensity of the movement.[7,107] Low intensity movements using little to no resistance have been reported to isolate the recruitment and development of type I slow-twitch, oxidative muscles fibers specific to the deep spinal stabilizers; transverse abdominis, multifidi, quadratus lumborum, and internal oblique muscles.[5,21,87,107,112] High intensity movements using a resistance of > 60 - 80% of a 1-Repetition maximum or performing work at high velocities with less resistance have been reported to target the larger torque producing muscles of the pelvis and trunk.[9,44] Type IIa and IIx fast-twitch, non-oxidative or anaerobic muscle fibers are predominately active during explosive movements.[19,51] Tasks which require different intensities often require the predominant recruitment of different muscle fiber types to produce resistance or force specific to the external stimuli.[19,51] While not measured directly in this study, it can be speculated that the improvements noted in endurance and power performances were likely due to specific changes in muscle fiber recruitment and efficiency. Future study in this area may help to decipher the reason for performance improvements noted in this session.

While the average distribution of type I to type II skeletal muscle fibers in the human body is generally 50% some muscles tend to have higher endurance versus power characteristics.[51,207] Spinal stabilizers, such as the multifidi and transverse abdominis, are reported to have approximately 60% type I slow-twitch, oxidative fibers and nearly 40% of type IIa and IIx fast-twitch, anaerobic fibers.[207] It may be hypothesized that high intensity movements which contribute to the recruitment of type II muscle fibers could potentially stimulate type II fiber development within the deep spinal stabilizers.[19,51] Type II muscle fibers have been reported to have contractile velocities of 3 times greater than type I fibers.[19,51] It can be surmised that the incremental stabilization provided by the multifidi or transverse abdominis during overhead throwing may result from both the type I and type II fibers or exclusively by a sport specific contribution of the type II fibers. It seems reasonable that the improvements in average and peak throwing velocity from the current study were likely due in part to training specificity in muscle fiber type recruitment at all the proximal segments. The improvements in average, but not peak throwing velocity for the ET group indicates gains in muscular endurance may have contributed in establishing better postural control at the proximal segments resulting in more consistent and efficient throwing mechanics. Indirectly, our data supports that sports requiring explosive or high intensity movements, such as throwing may necessitate training that facilitates recruitment patterns specific to sport, resulting in an increased efficiency in the number and rate of fast-twitch recruitment.[3,19] Training programs which emphasize only muscular endurance training at the proximal segments neglect the development of type II muscle fibers causing a potential for disuse or decreased efficiency of recruitment for fast-twitch fibers which provide strength and power.[19,208-210] Previous research has indicated endurance training to increase the cross sectional area of the type I muscle fibers and not type II muscle fiber size.[208,209]Thus, training low and high intensity movements such as those used in the current study could prove to be beneficial if specific to the intensity and movement patterns of the proximal segments specific to sport.

Aim of Proximal Stability Training

A proximal stability training program should aim to be comprehensive and consist of exercises which target the muscle contributions from the pelvis, spine and trunk specific to sport. Our results indicate the combined training stimuli for muscular endurance, strength and power contributed to performance improvements and not exclusively muscular endurance. Improvements for the PS group in endurance planks and the chop and lift tests, demonstrate that throwing velocity was most likely influenced by a combination of gains in muscular strength, power and endurance at the proximal segments. Despite the limited endurance training performed by the PS group they still managed to demonstrate improvements in endurance measures. The significant training effect and the change scores for the power measures of proximal stability indicate the strength and power training stimuli were likely the primary influence on improvements in peak throwing velocity.[45,211]

The goal of our intervention was to focus on the development of strength and power movements reported to enhance the muscles that support the pelvis and trunk contributions specific to over-head throwing. Several biomechanical factors have been reported to influence throwing velocity.[12,106,181,212] We identified those movements associated with over-head throwing in order to develop sport specific resistance training exercises to improve throwing velocity. Specifically, taking a forceful forward step, the ability to rotate and tilt the pelvis forward at high velocities are several movement patterns reported to be associated with faster throwing velocities.[126,169,181] We incorporated these types of movements within our training program which required participants to perform exercises in a weight bearing position which mimics throwing. In addition, maximum voluntary efforts that incorporate moderate to heavy loads ranging from 30-90% of a 1 RM have been reported to facilitate the exclusive recruitment and development of type II muscle fibers resulting in muscular power gains.[171-175] Therefore, we employed a resistance training program with moderate and heavy resistance that emphasized multi-planar rotational movements from a standing position. Due to the power and motor control elements of over-head throwing we emphasized strength and power movements, as well as traditional muscular endurance training techniques.[149,155,165] Neuromuscular control and perturbation stimuli were also used as they have been reported to increase muscle strength and endurance.[31,35] This was the first study to utilize a sport specific muscular power training program to target the proximal segments. The isolated emphasis on training proximal stability with strength and power stimuli transferred into greater throwing velocity. Our findings support the use of a training program which mimics the endurance, strength and power needs specific to the proximal segments and sport.

A majority of our exercises were moderate to high resistance training on stable surfaces. Several authors have reported heavy resistance training to be more effective in targeting and strengthening the proximal segments when standing on a stable surface.[149,155,212] The support for training on unstable surfaces is inconsistent regarding influences on performance.[33,35,36,42] However, we incorporated the use of a Swiss ball and total body perturbation from a standing position as this has been proposed to improve co-activation, spinal stability, and contribute to improved performance in golf swing and weighted ball toss.[35,42,48] Our protocol emphasized the use of several positions to simulate a perturbation stimuli. For example, we combined maximum resistance and high velocity movements in a lunge or tall kneeling position which created a perturbation training stimuli.[172,200] Further, the use of plyometric throwing exercises and velocity specific movements at the proximal segments with heavy and light resistances has not been reported in studies targeting proximal stability and performance.[200] Throwing exercises have been reported to promote less muscular stiffness and more agonist muscle activation thus maximizing muscle recruitment.[172,173] Gains in the 1RM power chop and lift test and throwing velocity were likely to have occurred from an increase in recruitment and development of type II fast-twitch muscle fibers associated with the strength and power development necessary for the motion of throwing.[163,165]

There are limited studies that have trained the musculature responsible for proximal stability with heavy resistance strength and power training.[37,41,213] This is likely due to the emphasis on endurance training or the lack of resources necessary to train the proximal segments with exercises emphasizing power, such as weighted medicine balls. While these techniques seem to be very effective in promoting improved proximal stability and throwing velocity, caution should be practiced when training with heavy resistances and high velocity movements.[19] We feel confident that training with heavy resistances allowed for a proximal synergy of the pelvis, spine and trunk resulting in strength/power gains. Our results indicate coupling explosive strength-power exercises with spinal stability movements which target the proximal segments is effective in the development of throwing velocity over a relatively short 7 week training period.[172,173,214]

Proximal Stability Assessment Considerations

Similar to the training interventions, proximal stability assessment techniques used to monitor improvements in sport and performance have been limited in measuring maximal strength or power associated with sport. A majority of the studies focus on measuring static linear tasks often isolated to one plane of motion that require long sustained isomeric positions that are not sport specific. In addition, assessment tests are often identical to the training stimuli used in the reported intervention. Likewise, these tests are associated with having a high learning effect, but are often described in the literature without a familiarization session.[32-36,38,43,185] The ability to actively control or stabilize the proximal musculature during functional movements and sport requires more than muscular endurance or static stability.[9] The significant changes in peak throwing velocity and the power chop and lift tests within the PS group versus the ET group support a more balanced approach to assessment. It has been suggested there is a need for a comprehensive assessment technique that incorporates movements sensitive to the different muscular contributions of endurance, strength and power commonly associated functions specific to sport. For example, in certain circumstances an athlete may require a greater need to develop power at the proximal segments such as when performing a task that is more mobile and multi-planar versus a static and linear.[18,30,53] As proposed in previous reports static muscular endurance stimuli result in isolated muscular activity to the deep spinal stabilizers, where as multi-planar strength and power movements are exclusive to muscles actively controlling the pelvis and trunk.[7,9,10,31,59,86,100,215] However, previous studies have not considered testing muscle contributions for both spinal stability and active control of the pelvis/trunk. To our knowledge this is the first study to utilize a comprehensive assessment technique which accounted for both muscular endurance and power gains specific to proximal stability and sport.

The methodology of our study improved upon earlier assessment techniques in several ways. Primarily we measured both isometric endurance and multi-directional power muscle contribution about the spine, pelvis and trunk. While isometric endurance plank tests and a novel 1 RM chop and lift tests were used in our study, we incorporated two familiarization periods prior to testing all the dependent measures to account for a learning effect. Previous literature has reported excellent reliability (r= .80 to r=.90) with no learning effect for the power 1 RM chop and lift tests.[18] The novel use of combining both the stability-endurance task (plank test) and a mobility-power task, (chop and lift tests) provided a more comprehensive methodology of detecting changes in proximal stability and sport. Indirectly, these measurements may offer insight into the types of muscle contractions that are responsible for movement at the proximal segments specific to sport.

The relationship between the endurance and power performance measures may assist in understanding how the muscles that support the proximal segments contribute to improvements in throwing velocity. The moderate to high correlations (r= .58 -.73, p< .002) between the proximal stability power measures and throwing velocity indicate there are specific attributes shared by these power movements. The chop and lift assessment technique seems appropriate for measuring multi-planar movements that engage the proximal segments during power movements, such as throwing.[18,61] Similar to previous reports we recorded low correlations when the endurance and power tests were compared (r =.23 - .29). The low correlations between the chop and lift power tests with the prone and side planks signified these tests are potentially assessing different muscles and/or characteristics of proximal stability, such as power versus endurance. Previous reports have demonstrated that power movements are more likely to focus on muscle activation at the larger muscles supporting the pelvis and trunk while endurance movements are generally static and isolate the smaller spinal stabilizers. However, not all the correlates between power and endurance measures were low. There were moderate correlations (r= .45, p= .002) between the prone plank and chop test. These finding seem reasonable as both these tasks engage similar muscles to support the anterior pelvis and trunk.[10,18,145] The moderate correlations between the mean throwing velocity and the prone plank (r =.50, .002) and the side plank (r =.47, p=.016) endurance measures offer insight that the ability to maintain a static muscular endurance hold is important for throwing performance. Previous literature suggests that isometric endurance training may facilitate selective recruitment of postural stabilizers thus improving the efficiency of movement about the kinetic chain.[1,3Cholewicki, 1996 #300,32,87] The ability to maintain a more stable proximal base of support at the proximal segments for a longer period of time may contribute to the efficiency in movement thus impacting the mean throwing performance. These findings may be more applicable for pitchers as they are asked to maintain throwing velocities for longer periods of time.

Both muscular endurance and power at the proximal segments had a positive relationship with overhead throwing and likely have different roles specific to different skills or positions. The diverse relationships between the static plank measures and the dynamic chop and lift measures indicates that they are likely measuring different muscle contributions specific to throwing.[9,18] The Fishers Z transformation analysis indicates that the significant correlations between peak throwing velocity and the power measures of proximal stability are significantly greater than that of the endurance measures. Therefore, assessing change in ballistic performance activities which necessitate the proximal segments, such as, throwing velocity should include performance measure of power.

Previous authors have reported low and/or non-significant correlations between static muscular endurance measures of proximal stability and dynamic multi-planar strength/power sports.[9,18,30,52,53] However, these studies did not implement a power assessment similar to the athletic event being tested. We attempted to bridge this gap in the literature by using the 1RM chop and lift test which has a closer association with the power movement of throwing. A recent study by Shinkle et al[30] identified a power medicine ball toss to have moderate positive correlations (r =.47-.50, p= .02) with power field tests, such as the 1RM vertical jump and squat. Thus, power measures such as a medicine ball toss for may serve as a field assessment test that accounts for power contributions of the proximal segments. The comprehensive nature of the endurance and power measures offers the clinician additional information regarding proximal stability and sport.

Stability and Mobility Continuum

Common to the strength and conditioning literature the SAID principle or specific adaptation to implied demands is a foundation for many training and rehabilitation protocols.[19] It is this foundation on which the specificity to muscle over load is specific to training or performance outcome measures. The muscles that support the pelvis, spine and trunk are reported to have specific activation patterns exclusive to tasks that require stability versus those that require mobility. Previously reported the muscle activation patterns of three ballistic movements: a rapid isometric abdominal contraction, a rapid punch, and throwing a baseball, were reported to have different on-off and peak muscle contractile sequences.[9] It has been proposed that as the mobility demands change about the proximal segments there appears to be a progression of muscle activation that controls movement specific to the task. The proximal muscles work collectively to provide incremental degrees of muscle stiffness based on the magnitude or degree of mobility, force, and speed of the movement required.[19] For example, the external oblique muscle has been reported to provide selective on-set and peak muscle contractions before that of the rectus abdominis during the mobility task of throwing a baseball.[9] In contrast, during an isometric rapid abdominal tightening the onset and peak contractions for the external oblique and the rectus abdominis muscles occurred jointly with the proximal muscles. The identification of different sequences in muscle contraction specific to the stability and mobility requirements at the proximal segments for a task has been described as a the stability and mobility continuum, Figure 5.1a, Figure 5.1b.[9] We have drafted a model to depict the description by McGill et al[9] that represents the different muscle contributions at the proximal segments specific to the stability versus mobility demands of sport.

Figure 5.1a: Stability and Mobility Continuum Described by McGill et al[9]

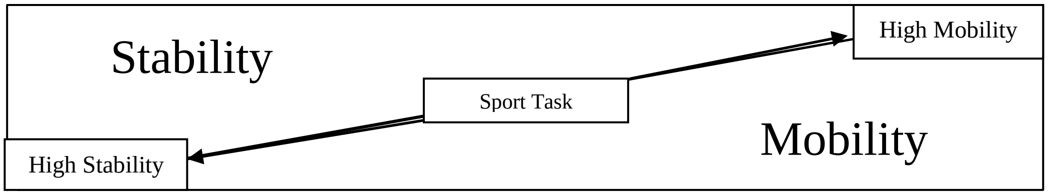
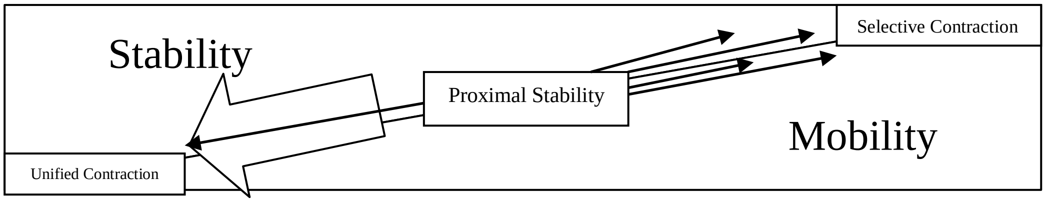


Figure 5.1b: A description of the unified and selective muscle contractions for stability and mobility tasks, respectively.[9]

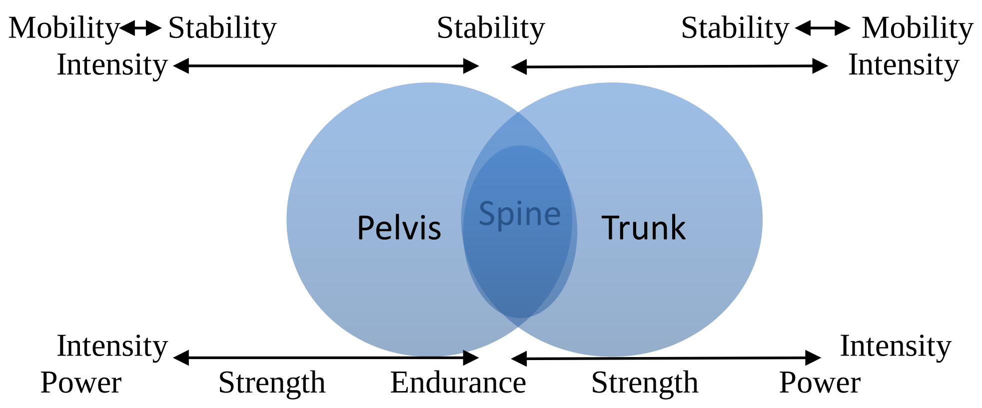


The distinct differences regarding the mobility of a task and the specific muscle stiffness contributions likely have a potential impact on training and assessment of performance outcomes.[9,19] Previous literature has reported the muscles that support the pelvis, spine and trunk function synergistically. However, the separate roles with regards to movement support the theory that stability and mobility are integral for motion but require different activation patterns specific to demands.[3,7,14,22,67,72,77,78,100,183] Several authors have reported the deep spinal stabilizers, such as the transverse abdominis and mutifidus have an exclusive role as stabilizers of the spine regardless of the task.[6,7,10,27,55]

Specifically, low intensity and linear isometric endurance training has been reported to isolate and promote improvements in muscular hypertrophy, endurance, and motor unit recruitment exclusive to the deep spinal stabilizers in healthy athletes and pathological subjects.[32] Conversely, dynamic and multi-planar training interventions which incorporate perturbation, strength and power stimuli have been reported to improve strength and balance measures specific to the muscles that support the pelvis and trunk.[47,100,183] Further, isometric and explosive assessments of proximal stability have been proposed to be more appropriate for exercise or sport tasks which mimic the isometric or explosive movements, respectively.[18,30,52,53] Therefore, it seems reasonable that proximal stability training and assessment practices should consider a continuum of exercises and assessment techniques that take into consideration differences in activation patterns specific to a sport or task.

While we did not measure muscular activation patterns directly, we trained and assessed contributions of muscular endurance, strength, and power specific to sport. We based much of our training on the concept that different sports require specific muscle contributions of endurance, strength and power along a stability and mobility continuum. As baseball requires very little endurance or static tasks, a majority of our proximal stability training consisted of strength and power movements at the proximal segments that were similar to the act of throwing. It appears that the different muscle activation patterns for stability versus mobility tasks described by McGill et al are supported by contributions of muscular endurance, strength and power characteristics specific to sport. As a result, we have proposed the sport specific proximal stability and mobility continuum model that accounts for the demands of movement and associated force production requirements specific to the proximal segments for a given skill, Figure 5.2.

Figure 5.2: The Sport Specific Proximal Stability and Mobility Continuum Model



Our data suggest that proximal stability training that accounts for sport specific muscle contributions may be more appropriate for improving sport performance. Our model provides a depiction of the stability and mobility requirements compared to the endurance, strength, and/or power contributions specific to sport and the proximal segments. For example, during throwing it is assumed that the spine has less mobility than the pelvis and trunk and predominately acts as a stable column.[7,108,146] The spine functions primarily as a static endurance stabilizer while the pelvis and trunk predominately create, absorb, and transfer forces of strength and power to and from the extremities.[7,8,77,212,216] Recognizing that different muscular activation patterns exist based on the type of movement patterns which require more stability versus mobility and the different muscle contributions specific to a task can be used when developing training and assessment practices.

Stability tasks predominately require static muscular endurance at the proximal segments. As the intensity and mobility requirements of a task increases muscle strength and power may be required to adequately complete the task. Tasks which necessitate explosive dynamic movement will predominately use muscular power. If speed is the goal of the movement the necessary increase in mobility can elicit higher levels of muscular strength and power needed to complete the task.[171,211] More controlled or slower movements will require in increased amount of muscular strength.[171-173] Thus, strength movements are most commonly associated with all tasks thus assisting with those skills that require degrees of static and/or dynamic function.[9,16,18,45,148] Overall, movements that are strength and power oriented will predominantly be handled by the muscles that support the pelvis and trunk, while all three segments likely contribute to endurance tasks.

As suggested by McGill et al., assessing changes that account for different stability and mobility tasks appear to offer insight regarding the specificity of the proximal stability.[18,148] The integration of this concept with consideration to the contributions of muscular endurance, strength, and power will enhance the practical application of both training and assessment practices. Using the proximal stability sport specific stability and mobility continuum will allow clinicians to evaluate and administer exercise interventions which. For example, throwing velocity requires a great deal of multi-planar movement, intensity, and muscular power at the proximal segments. Training or assessment techniques which emulate similarities to the specific movement schemes are likely more appropriate and informative in identifying potential contributions to performance. Our data suggests that both training and assessment practices should target static and mobile tasks which mimic the sport specific muscular endurance, strength and power contributions of the proximal segments when evaluating sport performance.

Limitations

Although the current study had positive effects we did have some methodological limitations. The lack of a true control group limited our abilities to compare our results to a group that did not receive any treatment. A true control would have made the interpretations regarding the cause and effect relationship between the interventions and various performance measures more definitive. Due to the inclusion of both males and females in each group there was a large amount of measurement variance, especially in the power measures. As a result, the generalizability of the data may be limited. As is true in most intervention studies the participants were not blinded to the intervention, however the members for each group did receive a treatment and were strongly encouraged not to participate in additional strength training for the proximal segments. Although there were no signs of a contamination bias there was a potential for some crossover as many of the athletes trained and resided in close proximity. The primary investigator performed all training sessions for both intervention groups and assisted with the chop and lift test assessment for pre- and post-test evaluations. However, all the evaluators were blinded to the members' group allocation, the primary investigator did not record or independently make final decisions on performance measures and was blinded to the group allocations at baseline testing.

Potential testing limitations reside in the fact that we did not include a self-reported measure or receive input from individual subjects regarding the effects of the training program. Recent pilot data indicates subject feedback to potentially influence performance outcomes and may be used to fashion more individualized training programs.[217] In addition, the chop and lift tests require expensive equipment and extensive practice time. The movements require adequate upper body strength and coordination. Thus, improved performance could result from strength or power gained in the arms. We did not measure arm contributions, but account for improvements in proximal stability as an extension of the kinetic chain and an inherent part of throwing or related tasks. The awkward motion of the lift movement may make it more susceptible to a learning effect. Although we incorporated two separate practice sessions and previous literature reports no learning effect for the lift movement, this may not be the case with skilled athletes.[18] The players in the current study may have been more responsive in developing neurological adaptations of strength/power than the general populations previously tested.[18,19] Thus, the significant improvement on the lift test may have been influenced by a learning effect. Lastly, the popularity of plank and static training stimuli previously used by all the athletes may have influenced the pre and post test endurance test measures as the athletes may have been well trained and familiar with that tasks.

Conclusion

A sport specific proximal stability training program for collegiate softball and baseball players produced significant improvements in power output during active trunk control measures and throwing velocity. The simultaneous improvement in proximal stability measures and throwing velocity indicates proximal stability training can positively influence sport performance. Our results suggest proximal stability function is not exclusively about stability during a maximal effort overhead throw. Muscular endurance, strength and power at the pelvis, spine, and trunk appear to have sport specific proximal stability functions. The stability, mobility, and intensity objectives of a task seem to dictate the necessary contributions of the proximal segments. Training and assessment practices that are designed to target proximal stability should consider the muscular endurance, strength and power contributions specific to the sport or task in question. We believe that using this novel approach to both training and testing of the proximal segments will offer insight to the specificity of sport and proximal stability contributions. Future research will foster the continued growth of this procedure thus providing additional evidence to better understand the specificity proximal stability may have in endurance versus power sports.

Appendix A

Tegner Activity Level Scale

Please indicate in the spaces below the HIGHEST level of activity that you can CURRENTLY achieve.

CURRENT Level of activity: __________

Level 10	Competitive sports- soccer, football, rugby (national elite/ Division I Athlete- Varsity starter)
Level 9	Competitive sports- soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball (Division I – non starter or Division II starter)
Level 8	Competitive sports- racquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing (Division II non-starter/ Division III starter)
Level 7	Competitive sports- tennis, running, motorcars speedway, handball (Division III – non starter) Recreational sports- soccer, football, rugby, bandy, ice hockey, basketball, squash, racquetball, running
Level 6	Recreational sports- tennis and badminton, handball, racquetball, down-hill skiing, jogging at least 5 times per week
Level 5	Work- heavy labor (construction, etc.) Competitive sports- cycling, cross-country skiing, Recreational sports- jogging on uneven ground at least twice weekly
Level 4	Work- moderately heavy labor (e.g. truck driving, etc.)
Level 3	Work- light labor (nursing, etc.)
Level 2	Work- light labor Walking on uneven ground possible, but impossible to back pack or hike
Level 1	Work- sedentary (secretarial, etc.)
Level 0	Sick leave or disability pension

This scale has been modified from: Y Tegner and J Lysolm. *Rating Systems in the Evaluation of Knee Ligament Injuries*. Clinical Orthopedics and Related Research. Vol. 198: 43-49, 1985.

Participant Identification: ______________________

Appendix B

Randomization Scheme

Plan randomizes patients in blocks of size 4 (2 in Intervention 2 in Control)

Stratified by gender and position

Block Number	Allocation Number	Sex	Position	Treatment Group
1	1	M	Pitcher	Intervention
1	2	M	Pitcher	Control
1	3	M	Pitcher	Intervention
1	4	M	Pitcher	Control
2	5	M	Pitcher	Intervention
2	6	M	Pitcher	Intervention
2	7	M	Pitcher	Control
2	8	M	Pitcher	Control
3	9	M	Pitcher	Control
3	10	M	Pitcher	Control
3	11	M	Pitcher	Intervention
3	12	M	Pitcher	Intervention
1	1	F	Pitcher	Control
1	2	F	Pitcher	Intervention
1	3	F	Pitcher	Intervention
1	4	F	Pitcher	Control
1	1	M	Fielder	Control
1	2	M	Fielder	Intervention
1	3	M	Fielder	Intervention
1	4	M	Fielder	Control
2	5	M	Fielder	Intervention
2	6	M	Fielder	Intervention
2	7	M	Fielder	Control
2	8	M	Fielder	Control
3	9	M	Fielder	Control
3	10	M	Fielder	Intervention
3	11	M	Fielder	Control
3	12	M	Fielder	Intervention
4	13	M	Fielder	Control
4	14	M	Fielder	Intervention
4	15	M	Fielder	Intervention

Block Number	Allocation Number	Sex	Position	Treatment Group
4	16	M	Fielder	Control
5	17	M	Fielder	Intervention
5	18	M	Fielder	Control
5	19	M	Fielder	Control
5	20	M	Fielder	Intervention
1	1	F	Fielder	Control
1	2	F	Fielder	Control
1	3	F	Fielder	Intervention
1	4	F	Fielder	Intervention
2	5	F	Fielder	Intervention
2	6	F	Fielder	Intervention
2	7	F	Fielder	Control
2	8	F	Fielder	Control
3	9	F	Fielder	Control
3	10	F	Fielder	Intervention
3	11	F	Fielder	Intervention
3	12	F	Fielder	Control
4	13	F	Fielder	Intervention
4	14	F	Fielder	Control
4	15	F	Fielder	Control
4	16	F	Fielder	Intervention

Appendix C

Training Exercise Figures

Figure 3.6: Warm up drills: high knees, strides, leg swings, bounds, squat/lunge

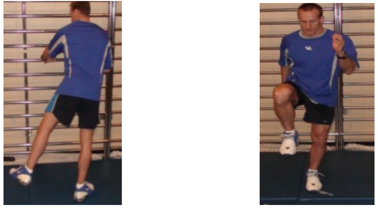
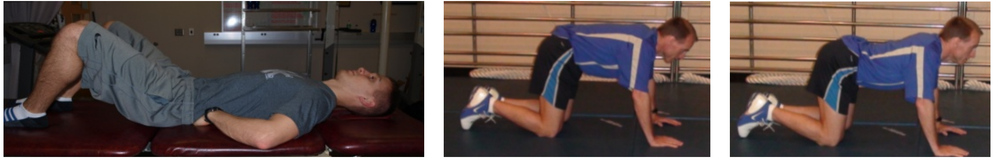


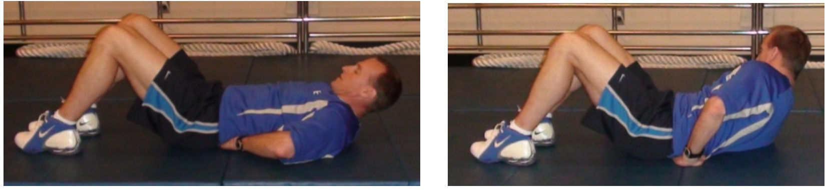
Figure 3.7: Endurance Training

Supine/Prone abdominal hollowing

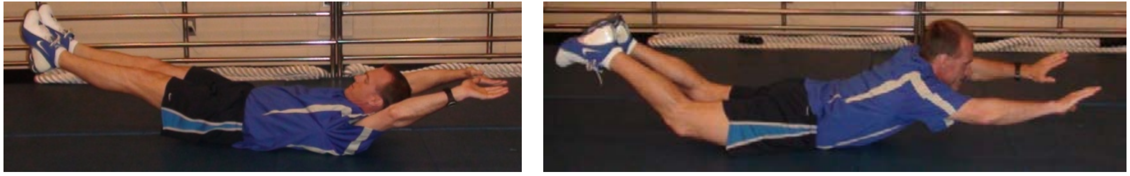


Birddog –four-point reaches ipsilateral/unilateral

Curl ups



Superman flexion to extension



Dead Bugs

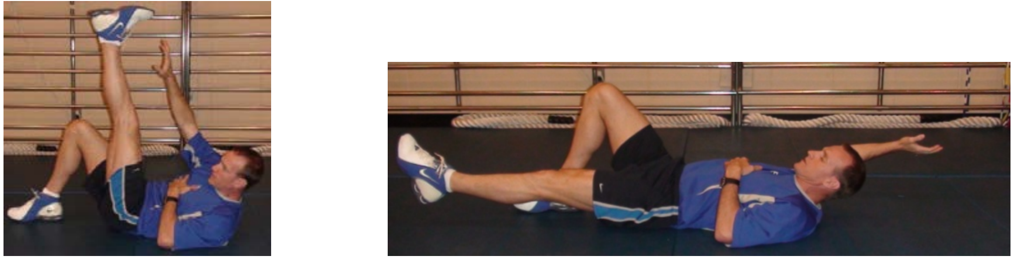


Figure 3.7: Endurance Training, Continued

Plank Series:

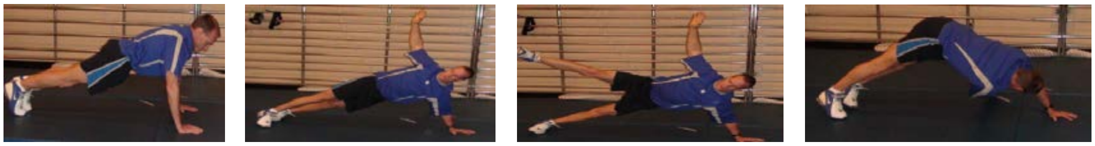
a. Prone Plank

b. Supine Plank

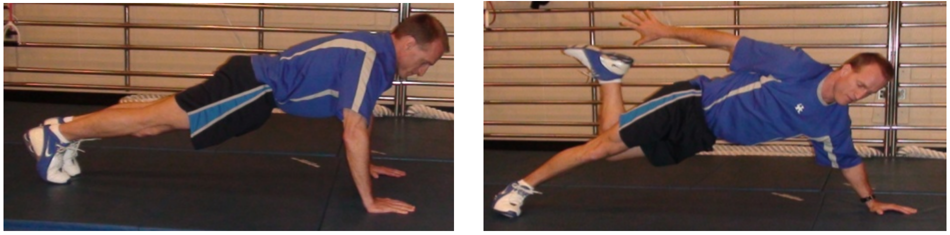
c. Supine Leg Extension

d. Lateral Plank

Plank Variations



Supine Plank- Heel Touches



Supine Plank Hip Heist –double to single leg

Side Plank with Hip Heist

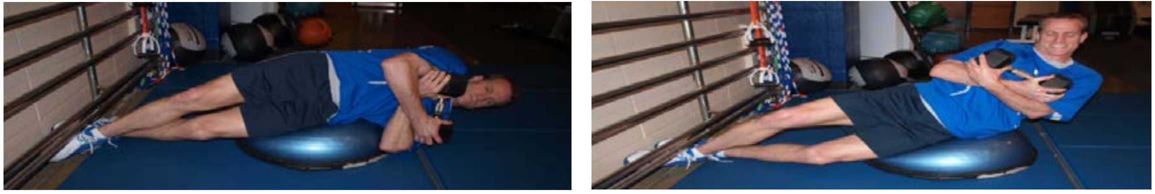
Figure 3.7: Endurance Training, Continued

Heals to the Heavens

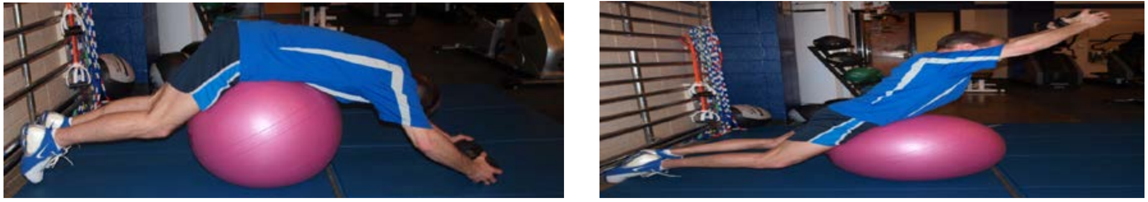
Figure 3.8: Perturbation/Heavy Resistance Exercises

BOSU –Back Extension

BOSU V-ups



Swiss Ball Weighted Back Extensions



Swiss Ball Weighted Flexion

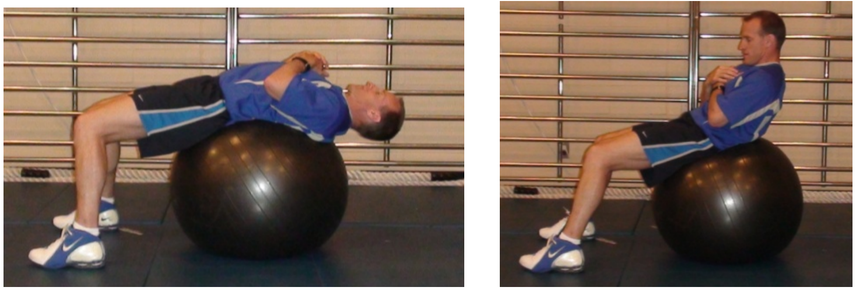
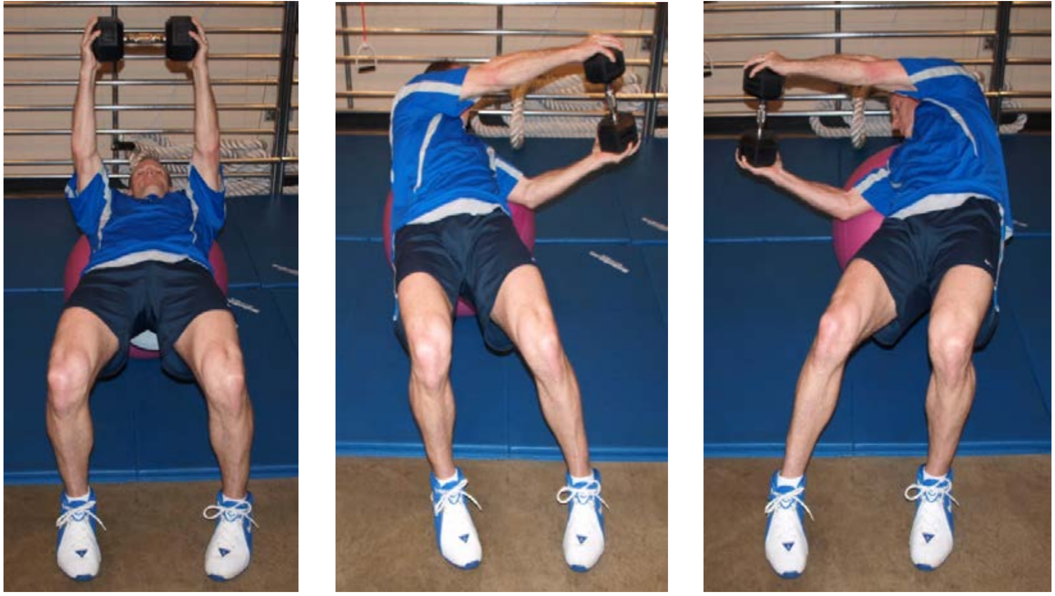


Figure 3.8: Perturbation/Heavy Resistance Exercises, Continued

Swiss ball T-Spine Rotations (High)



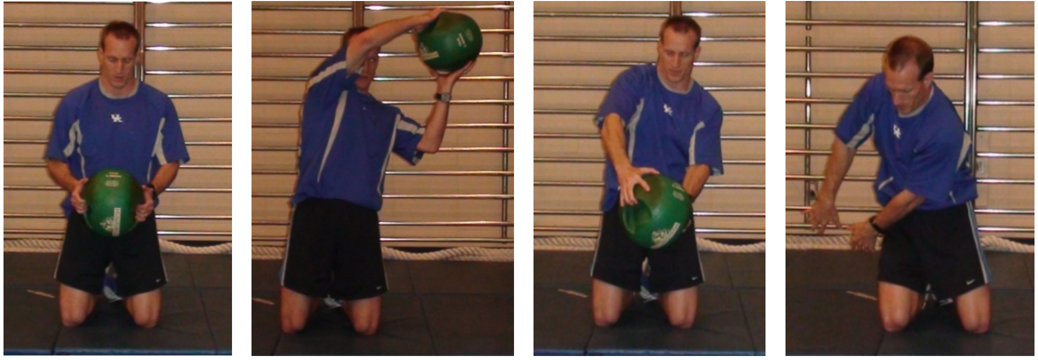
Swiss ball T-Spine Rotations (Low)

Figure 3.9: Resistance/Plyometric Training

Weighted Medicine Exercise Balls

Seated Overhead Ball Toss

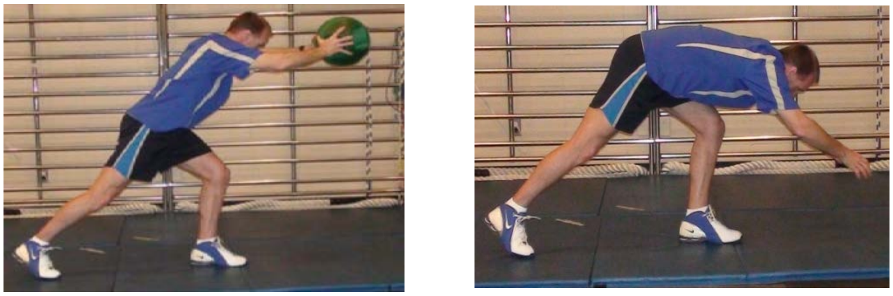
Tall Kneeling Over Head Throw Downs



Standing Over Head Throw Downs

Figure 3.9: Resistance/Plyometric Training, Continued

Standing Overhead Forward Toss



Standing Over back Ball Toss

Various Partner Exchange Ball Toss

Figure 3.9: Resistance/Plyometric Training, Continued

Russian Twist for Speed and Power

Russian Twist for Strength/Power

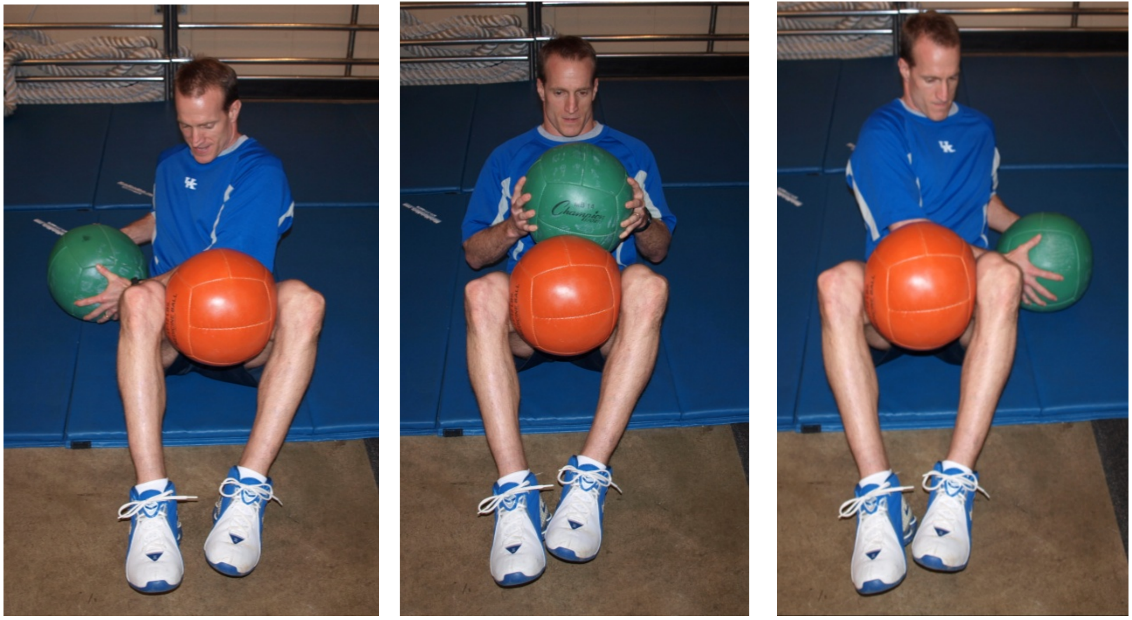


Figure 3.9: Resistance/Plyometric Training, Continued

Standing Ball Twists

Medicine Ball: Side Underhand Toss (Receive and Toss)

Figure 3.9: Resistance/Plyometric Training, Continued

Medicine Ball: Over Shoulder Front Throw (Side View)

Medicine Ball: Over Shoulder Front Throw (Anterior View)

Figure 3.10: Resistance Training

Standing Rotation –Fast and Slow

Lunge Rotation -Fast and Slow

Figure 3.10: Resistance Training, Continued

Lunge with Torso Lateral Bend

Lunge with Torso Lateral Bend/rotation

Figure 3.10: Resistance Training, Continued

Top Shelf

Russian Twist for Strength (Heavy Resistance)

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Vita

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Master of Science in Education, Emphasis in Athletic Training:
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Bachelor of Science in Physical Education, Instruction:
State University of New York at Cortland, 1992.

Certifications:

- Board Certified Athletic Trainer, ATC. Certification # 029402549. 1992 - present.
- Commission on Accreditation of Athletic Training: ACI/CI-Educator. 2000 - present.
- Commission on Accreditation of Athletic Training, Site Visitor. 2001 - present.
- National Strength & Conditioning Association, CSCS. Certification # 965560. 1994 - present.
- Orthotecnology Fabrication: semirigid, soft/hard foot orthotics. 1998 - present.
- Kinesio-Tape Specialist (1 & 2), National Kinesio-Tape Federation. April 2007 - present.
- American Red Cross Instructor, Professional Rescue/CPR. 1992 - present.
- National Teaching Certification: Physical Education K-12. 1992.

Professional Membership/Affiliations:

- National Athletic Trainers' Association, Member # 921748. 1992- present.
- Commission on Accreditation of Athletic Training, reform subcommittee. 2000 – 2006, 2009.
- National Athletic Trainers' Association, Annual Meeting Selection Committee. 2005- present.
- American College of Sports Medicine, Professional Member. 1997 - present.
- Greater Cincinnati Athletic Trainer's Association. 2007 – present.
- Kentucky State Athletic Trainer's Association. 2006 – present.
- Commission on Accreditation of Athletic Training, Review Committee. 2005 - 2008.
- Certified Test Examiner for BOC National Exam. 1996 - 2003.

Publications:

- Palmer, T.G., Howell, D., Mattacola, C.G. (2012) Self-perceptions of trunk stability as measured by the functional movement screen. Journal of Strength and Conditioning. (Approved, May 2012)
- Palmer, T.G. & Uhl T. (2011) Interday reliability of peak muscular power outputs on an isotonic dynamometer and assessment of active trunk control using the chop and lift tests. Vol. 6, # 2, 150 -159.
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- Morgan T, Stevens S, Palmer, T.G. (2007) Popliteus Dysfunction and Manual Therapy. Athletic Therapy Today, Nov. Vol. 12, # 6.

Professional Presentations:

International Professional Presentations:

- Palmer, T.G. Inter-test reliability of the chop/lift on the BTE Primus-RS to assess core stability. Canadian Sports Medicine Conference, Vancouver, Canada. June 2008.
- Palmer, T.G. PNF Technique and variations. Niagara Falls Sports Medicine Symposium, Niagara Falls, Canada. June 2005.

National Athletic Trainers' Symposium, Annual Meeting:

- Palmer, T.G., 63rd Annual Meeting & Clinical Symposia. Clinical Recommendations: Proximal Stability Assessment and Training. June 2012.
- Palmer, T.G., 63rd Annual Meeting & Clinical Symposia. Train the Chain: Rehabilitation Methods for Addressing Bio- mis chanics in the Kinetic Chain. June 2012.
- Grooms D, Palmer T, Grindstaff TL; The Effects of a Comprehensive Soccer Specific Warm Up Program on Lower Extremity Injury Rates. Summer 2010.
- Knowles, W., Palmer, T.G. Advanced rehabilitation techniques for return to sport progression. Summer 2009.

Southeast Athletic Trainers' Association, Annual Symposium:

- Palmer, T.G. Evidence support proximal stability assessment and intervention practices. March 2012.

Kentucky Strength and Conditioning Association, Annual Symposium:

- Palmer, T.G. Instrumentation of the functional movement screen. Spring 2010.

Kentucky Athletic Trainers' Association, Annual Symposium:

- Palmer, T.G. Defining core stability and appropriate measures. Spring 2010.
- Palmer, T.G. Instrumentation of the functional movement screen. Spring 2010.
- Palmer, T.G. Use of the chop/lift on the BTE to assess core stability. Spring 2008.
- Palmer, T.G. Neuromuscular training and rehabilitation. Spring 2007.
- Palmer, T.G. Core stability measurements: journal review. Spring 2007.
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