

Clinical Commentary/Current Concept Review

A Critical Review of Trunk and Hip Exercise Prescription: Applying Evidence for a Modern Approach

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Exercise targeting the trunk and hip (core) musculature is common practice in rehabilitation and performance training. Historical underpinnings of core exercise focus on providing stability to the spine, thus improving the function of the spine and extremities, while instability has been postulated to result in pathology and impaired performance. Mechanistic studies on the topic are often conflicting and indeterminate, suggesting the theoretical underpinnings of targeted core exercise may be over assumed in common practice. The best modes of intervention also remain undefined, with combined methods having potential to optimize outcomes. This includes moving beyond isolated exercise camps and being inclusive of both targeted exercise and progressive multi-joint movements. The purpose of this clinical commentary is to describe the historical mechanisms of the stability-instability continuum and the role of exercise intervention. A spectrum of ideologies related to core exercise are examined, while appreciating positive outcomes of exercise interventions across healthy and pathological populations. Finally, exercise summaries were compiled to improve critical reasoning within current practice and inspire future investigations.

Level of Evidence

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INTRODUCTION

Therapeutic and performance-based exercise prescription directed at the musculoskeletal structures of the trunk, hip, and lumbopelvic region have commonly been labeled “core” exercise due to the central proximity of the anatomy related to the central location about the axial skeleton and nearly associated appendicular skeleton. The core is compromised of the spine, hip and pelvis, proximal lower extremity, and abdominal structures.¹ Also notable are the prime movers for the extremities (i.e. latissimus dorsi, pectoralis major, trapezius, gluteal, hamstring, and quadricep groups, and iliopsoas) which attach to the axial skeleton and lumbopelvis.¹ In unison, these muscular components help to sustain trunk stiffness which is defined as the ability of the spinal column to respond to an applied perturbation or loss of spinal stiffness.^{2,3} Much attention has been paid to spe-

cific musculature such as the transversus abdominis, multifidus, and more global anterior abdominal and posterior extensor musculature.^{2,4} The hip musculature is also often included due to its function affecting the lumbopelvic region.^{2,5}

A comprehensive view of the core consists of several different musculoskeletal structures and their neuromotor function that acts to provide adequate axial stiffness required for the generation and application of force throughout the kinetic chain during physical activity. Located about the center of mass, of which is a fulcrum of movement outputs to the distal segments, one can view the core as a central force creator, absorber, and distributor for distal movement that's performed in sporting activities such as running, jumping, cutting and throwing.³ This clinical commentary will describe the historical mechanisms of the stability-instability continuum and the role of exercise in-

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tervention. A spectrum of ideologies related to core exercise are examined, while appreciating positive outcomes of exercise interventions across healthy and pathological populations. Exercise summaries were compiled to improve critical reasoning and application within current practice and inspire future investigations.

HISTORICAL CONCEPTS OF STABILITY & INSTABILITY

Due to the early recruitment of the local, segmental muscles, the global primary moving muscles about the spine, and the associated stiffness created about the axial skeleton, it is easy to label core exercises as targeting spinal stability.^{2,3} The theories of spinal stability can be dated back to Knutsson and Barr in 1940s and 50s⁶ and progressed through Panjabi's multi-system approach to stability, of which the neutral zone function of the spine relies on the passive (inert spinal tissue), active (spinal musculature), and control subsystems (neural recruitment) where "ideal" stability is contingent upon interdependence between all.⁴ Musculoskeletal instability consists of excessive joint motion without inert and/or muscular protective control. Various scales have been proposed to identify a balance of tissue stiffness and compliance for maintaining health,⁷ which would be similar for a stability-instability continuum. Despite the broad spectrum of spine pathology classified as discogenic, spondylitic, facet-related, and non-specific low back pain, some have proposed the overarching relationship to the absence of spinal stability, otherwise known as spinal instability, as the causative agent to injury.⁸ Core exercise has been proposed to be a solution to spinal instability.^{4,9}

However, definitions of spine instability are not agreed on and the wording has resulted in significant consequences that include, but are not limited to, dogma, nocebo, and faulty pathoanatomic clinical reasoning and application of interventions.^{2,6} For example, when the concept of instability is applied to the appendicular skeleton, it is often in the context of a subluxation or dislocation incident, and resultant joint level damage (i.e. glenohumeral dislocation with Bankart/Hills-Sachs lesions, tibiofemoral dislocation with ligamentous disruption). If similarly applying the definition of mechanical instability within the spine, a case of instability would likely result in similar tissue damage and neurologic involvement.¹⁰ Yet this presentation is inconsistent in the majority of cases spine,¹¹ particularly when implicating the utilization of core exercise and its historical application to instability.

CHALLENGES TO THE THEORY OF INSTABILITY & STABILITY

To fully understand the presence of proposed stability or instability within a human, there needs to be valid and reliable diagnostic tests, referenced to a gold standard. The current gold standard to assess for clinical instability is diagnostic imaging, which includes dynamic radiography,

magnetic resonance imaging, ultrasound and fluoroscopy.¹² Intraoperative assessment of instability by a physician has also been proposed as alternative gold standard and has been shown to correlate with pre-operative radiographs, but is invasive and limited by operator bias.¹³ Imaging methods related to spine pain and instability have been inconsistent regarding their relationship to pain and pathology. High numbers of asymptomatic individuals having pathologic images^{14,15} and consistent false-positive findings in tests such as flexion-extension radiographs.^{16,17}

Context is required with diagnostic imaging, requiring the utilization of clinical tests to correlate with clinical instability.¹⁵ Unfortunately, systematic reviews on clinical tests have shown only limited availability to diagnosis instability¹⁸ and have identified questions the validity of common tests.^{19,20} Common clinical tests include active and passive motion assessment, aberrant movement, the active straight leg raise, prone instability, and passive lumbar extension (PLE) tests. The relationship of these tests to segmental instability have not been consistently shown to be valid when compared with gold standards. This is especially challenging considering that there is not strong agreement on the gold standard of segmental instability.^{16,17}

Unfortunately, the identification of pain on clinical exam is not confirmation of pathokinematics. For example, the prone extension test has been shown to have the best relationship to segmental motion on radiography in pathologic population^{16,18,20,21} when compared to other clinical tests. However, when comparing positive findings of instability in these papers, defined instability on the PLE and radiographs defined by positives was matched in only in 17/39 cases.²¹ The PLE may be most appropriate in groups of how have established lumbar fracture and segmental shifting (spondylolisthesis),²¹ thus becoming more predisposed to segmental motion. The assumption that there is heterogeneous application to this form of clinical assessment of instability is yet to be established.²⁰

Greater mobility and the absence of hypomobility were shown to have the best relationship with segmental translation, which is more indicative of a sub-group of more mobile individuals, than it is of a pathoanatomic relationship, of which radiographic instability only could be related to 56% of the studied non-specific low back pain population.¹⁶ Further confounding the nature of these tests is that they are studied in an already injured population. Even if the clinician is confident that they can diagnosis the instability via the above tests and measures, it is uncertain if the instability is the cause or effect of injury, or if treatment of these findings will cause efficacious change.²²

Due to the still undetermined validity of tests to truly measure segmental instability^{18,19} tests such as aberrant motion, active and passive vertebral motion, passive extension, and prone instability tests, are more purely measures of pain provocation than an accurate confirmation of instability related pathomechanics.^{18,23} Taken simply for what they are able to provide within a clinical exam, provocation tests have been shown to identify the presence of pain, and are more reliable than segmental motion assessment

tests.²⁴ Understanding what constitutes a positive clinical test is also important, as inconsistencies in the definitions of positive pain provocation and instability tests have been researched and documented.²⁰

Exercise-based neuromuscular testing has also been proposed to assess functional core stability or instability. However, these tests are measures of neuromuscular performance, generally defined by strength, endurance, power or general motor control of a derived testing task.²⁵ There is limited efficacy that muscle performance tests have a predictive correlation to segmental movement about the spine or the extremity.²⁵ While core stability exercises and core strength have been linked to improved lumbar spine control,⁹ the direct relationship between core muscle strength tests (i.e. front plank, Biering-Sorenson endurance, curl-up assessment, etc) and stability-instability related segmental motion remains underexplored in the literature.^{25,26}

Because of the limitations of any one individual clinical test, clinical prediction rules utilizing logistical regression methods have been proposed better understand proposed clinical sub-groups impacted by lumbar stability and instability.²⁷ Again, while retrospective relationships to the pathological spine instability have been developed,²⁸ validation trials have not been successful in predicting diagnosis²⁷ or treatment outcomes.^{27,29}

Overall, testing techniques described have been identified as reliable measures,¹⁹ but they have not been shown to be causal to injury, or a valid proof of pathomechanic inter-segmental functional instability.^{23,30,31} The various testing procedures assessed, including diagnostic imaging and clinical testing, are generally limited by indeterminate internal and external validity^{16,19} and thus, utility, as it relates to inter-segment movement³² and resultant spinal impairment.^{22,30,33-35} While relationships are plausible, the literature is inconsistent in supporting the cause-and-effect relationships of spinal motion, motor function and injury.³⁶ Basing exercise selection purely on the idea of segmental or lumbopelvic instability is flawed due to the inability to first truly diagnose such instability and practically quantify such motion.²⁷

While one thought of instability is focused purely on the translation of spinal segments, others have defined spinal instability as the spines' inability to maintain its standard pattern of displacement under normal physiological loads creating a mid-range segmental motion abnormality.^{2,4} Functioning within the neutral zone has been proposed to place less stress on the passive structures of the spine and prevent submaximal injury.³⁷ Maintaining an optimal segmental and lumbopelvic position, known as the neutral zone, during functional movement have been accepted in clinical practice,^{1,38} despite conflicting support regarding the validity and outcomes of the mid-range aberrant movement phenomenon.

THE NEUTRAL ZONE

The utilization of core exercise to promote "neutral mechanics" and control of the axial and appendicular skeleton to perform task have been recommended^{9,39,40} as a result of

the defined construct of a neutral zone and purported bio-mechanical risk of related spinal movements (i.e combined flexion-rotation,⁴¹ repetitive flexion).^{42,43} The neutral zone has been identified as a segmental range of 1-2 degrees of lumbar flexion⁴⁴ and a total range of 5-9 degrees in cadavers.^{45,46} The neutral zone has also been shown to consist of a minimal portion of the available range of motion of the lumbar spine in vivo (roughly 11 to 20 degrees).^{47,48}

The plausibility and effectiveness of maintaining a neutral spine with common functional movements has been questioned.⁴⁹ Assessment of motion and maintenance of core neutral,⁵⁰ core stability,⁵¹ and motor control⁵¹ have been shown to be unreliable in a clinical setting. When performing basic compound movement tasks such as a deadlift or squat, in vivo and in vitro measures have identified significant and variable segmental vertebral motion beyond a "neutral" zone without harm.⁵²⁻⁵⁴ Beyond fundamental movement patterns and exercises, significant amounts of lumbar flexion have been identified in various sporting populations⁵⁵ and are a key motor requirement for various field sports. The spinal structures possesses a force tolerance that allows a considerable margin of safety than forces exposed to healthy spines when lifting in a flexed position.⁵⁶ Performing tasks outside of a neutral zone may not only be safe, but create a mechanical advantage for better performance in functional tasks.⁵⁵ Further, higher order tasks (sprinting, jumping, change of direction) require movement variability, requiring specific segmental motion within each given movement task, and are unlikely transferable from basic cardinal plane assessment.

FORCE TOLERANCE & PAIN

As described with the neutral zone, it has long been shown that the structures of the spine have a considerable margin of safety to tolerate significant flexion, compression, and shear loads.⁵⁶⁻⁵⁸ The upper limits of physiologic tolerance have been defined, both in ultimate failure and fatigue stress conditions.⁵⁸ Studies analyzing force capacities generally investigate heavy and/or light lifting tasks,⁵⁹ bio-mechanical modeling,^{60,61} and dynamic, combined motion simulations.⁶² Most investigations are concerned with maximal limits of force or minimizing force in functional tasks as opposed to an envelope of function of the spine.⁶³ Contradictory to the established upper limits of force tolerance to failure, are studies demonstrating that individuals can produce forces onto the spine two to four times greater in higher order tasks than established limits.⁵⁹

Even with established upper load limits, it remains challenging to extrapolate modeling and cadaveric load limits to human tissues, which can adapt to mechanical stimulus provided proper progressive loading and recovery. This ability to adapt to properly dosed loads continues to be discredited when assessing the upwards limits of spinal load tolerance, despite identifying tolerance to suprathreshold limits.⁶³ The consideration of tissue adaptation to progressive overload is essential to exercise principles that should be applied to the core anatomy, of which a continuum of pathology to healthy adaptation should be considered.⁶³⁻⁶⁵

Concepts of spinal instability have been kinetically and kinematically attributed to pain, as shear force would seem to be related to segmental translation, and exercise treatments are proposed to minimize or dissipate pathologic forces. Resultant shear force on spinal joints can be maintained at a relatively constant and safe level when assessing neuromuscular contraction during a squat.⁵⁹ However, with increasing external loading demands, muscular contractions have been shown to increase the shear forces imposed on the lumbar spine,⁶⁶ which conflicts with the theory that instability and neutral spine-based exercise will decrease local load on the non-contractile tissues. Further, these forces are not similarly dispersed across individual segments the spine.⁶⁶

A review of in vivo and finite element studies have concluded that pathology such as disc degeneration, endplate fracture, and surgical resections significantly alter load transmission in the lumbar spine but are not explicitly explained by spinal instability.⁵¹ Pathologic spine mechanics demonstrate greater variability and inequality in segmental motion sharing,⁶⁷ making it challenging to utilize catch-all mechanics to classify individuals. As opposed to a traditional spinal segmental instability explanation,⁴ the reality of spine pathomechanics may be more accurately described by various dynamic processes resulting in alterations of stiffness and force transfer,³⁴ resulting in sensitized and/or injured tissue via unaccommodated dynamic overload.⁶⁵

The presence of pain around the structures involved about the core have been shown to have a significant impact on local (multifidi) musculature (i.e. cross sectional area, fatty infiltrate, motor recruitment, strength metrics), movement patterns, force distribution through the kinetic chain, and overall function.⁶⁸ Those who are in pain are exposed to differing loading patterns than from those not experiencing back pain.⁶⁹⁻⁷¹ These loading patterns happen at various degrees of motion and are not associated with end range mobility.^{72,73} Often these kinematic changes bring about less motion in the lumbar spine,^{73,74} which seems to be in contrast to an increase in instability. For example, people in pain tend to move with decreased speed, increased stiffness, and kinetic chain compensations during freestyle lifting tasks.⁷⁵ As with the clinical instability tests previously reviewed, it is important to emphasize that these deficits are consistently found in individuals already experiencing pain and have not been prospectively identified as causal.⁷³ Thus, many of the historical impairments attributed to spinal instability may be a result of pain, rather than a cause of it.^{75,76} An example of this limitation is demonstrated by altered motor patterns of the lumbar extensors in those with a history of low back pain, which have not been useful in identifying back pain patients in the absence of an acute bout of pain.⁷⁶

EXERCISE MODES TO ADDRESS THE CORE, STABILITY & INSTABILITY

Many of the numerous impairments traditionally associated with the stability/instability spectrum have been deemed modifiable, with exercise being a primary mode of

intervention. Despite the inconclusive evidence evaluating the validity and presence of segmental stability/instability,^{2,22,55,58,51} it cannot be discarded that exercise targeting the trunk and hip holds value in clinical practice.^{1,77-80} The positive effects of therapeutic exercise include analgesia,⁸¹ improvements in muscle, bone, tendon and ligamentous architecture,⁸² and development of functional attributes such as strength, power, speed, task performance,^{83,84} and global health and wellness.⁸² Specific to exercise related to the core, numerous methodologies are proposed to treat and prevent injury related to the spine and extremities, in addition to improving performance. There are numerous exercise variations that can be prescribed, and can be sub-categorized as isolated exercise (i.e. targeted abdominal/extensor movements with local motor control/hollowing,² or bracing,⁹ cues), multi-joint compound exercise,⁸⁵ general exercise,⁸⁶ sport-specific exercise,⁸⁷ among numerous others.

ISOLATED (LOCAL) MOTOR CONTROL EXERCISE

Isolated, local motor control exercises are primarily targeted at the transversus abdominis and multifidus musculature to improve the segmental function about the spine based on the instability theory previously reviewed. Often these drills are coached with a “drawing in” or “hollowing” maneuver (**Appendix 1 - Figure 1 & 2**) to localize the specific segmental musculature while minimizing the contraction of global movers (i.e. rectus abdominis), resulting in an increase in stiffness about the lumbopelvic region.⁸⁸ The cueing of spinal position with these exercises has shown to have a direct impact on the targeting of musculature, impacting the clinical reasoning for the application of each individual exercise. For example, a cued anterior tilt of the pelvis may increase multifidi activation compared to maintaining a neutral spine.⁸⁹

However, there is limited and conflicting evidence that local muscle performance and architecture is related to low back pain⁹⁰ nor are direct changes in the musculature related to improved clinical outcomes.⁹¹ The isolated and selective activation for segmental stability has been critically analyzed for an overreliance on electromyography studies and is lacking consideration of task-dependent specificity of co-contraction function that results in motor synergy across muscle groups.^{92,93} Beyond theoretical plausibility, selective training of local core muscles has not been shown to provide superior clinical outcomes when compared to other methods of exercise.³⁸ Due to the low intensity nature of these exercises, there is a possibility of underdosing to achieve optimal clinical outcomes. Adequate dosing parameters are not clearly defined for best application.⁹⁴ In other areas of the spine, greater durations and frequencies of motor control exercises have demonstrated greater improvements in desired outcomes.⁹⁵

ISOLATED TRUNK TRAINING WITH AND WITHOUT BRACING

Due to limitations of isolated training of local trunk muscles via motor control exercises,^{93,96} abdominal bracing

during selected exercises (**Appendix 1 - Figures 3-5**) has been promoted as an alternative strategy to create greater torso stiffness by achieving greater comprehensive recruitment of both global and local musculature about the core.^{2, 9,96} Bracing during activities has been shown to both increase stiffness,^{93,96,97} compression⁹⁸ and provide a more rapid kinematic response to perturbations.⁹⁸⁻¹⁰⁰ However, subjective reports of hollowing have been reported to provide more patient comfort compared to bracing,¹⁰¹ and may hold relevance when considering application of exercises when facing high irritability of pain.¹⁰² Hollowing has also been shown to acutely increase the size of the transversus abdominis, internal oblique, and lumbar multifidi, once again indicating that specific cues can be utilized to achieve a desired outcome.¹⁰³ It is important to note that when compared, both hollowing and bracing are able to actively increase muscle size on contraction, and were only different in two of seven exercises studied.¹⁰³ A comparison of the cues was repeated in an active population, with hollowing again showing greater increases in muscle size during exercise, while bracing cues demonstrated superior muscle activation.¹⁰⁴ It is clear that the different cues will produce different motor effects acutely and may impact in-session clinical reasoning based on a practitioners goals, yet the impact of these differences do not explain short or long-term outcomes (strength and morphology development, pain/injury outcomes, etc).²

The main benefits of the bracing techniques may be limited to greater muscle recruitment during specifically researched exercises⁹ and strength and endurance gains related to neuromuscular activation. Mechanistic changes in muscle morphology (thickness, hypertrophy, cross-sectional area) remain unclear¹⁰⁵ and may not achieve superior outcomes compared to multi-modal exercise programs¹⁰⁶⁻¹⁰⁹ or comparative programs.^{104,110,111} The carryover and benefit of bracing and hollowing during functional tasks has also yet to be conclusively shown.^{112,113}

EFFECTS OF BRACING DURING FUNCTIONAL TASKS

It is clear that abdominal bracing will increase overall trunk stiffness when performing targeted core exercises, and has been shown to create comparable stiffness to passive orthosis.¹¹⁴ While achieving the greatest spinal stiffness achieved via bracing is often the goal of these isolated exercises, performing during specific movements of sport and reactive tasks^{115,116} may not have similar advantageous effects. Focusing on stiffness of the trunk during tasks has been shown to change kinetic and kinematic outputs.^{113,117} This may be deleterious to performance¹¹⁸ and increase injury risk at differing joints beyond the lumbar spine. Interestingly, decreased control (stability/stiffness) of the trunk has been related to improved change of direction performance,^{118,119} and may also be related to lower extremity injury risk¹²⁰ or prior history of injury.¹²¹ It may also not be feasible to focus on trunk stiffness when unconsciously reacting to competitive sport conditions.¹¹⁵ This again indicates a balance on the stability-instability continuum of lumbopelvic performance, and questions the direct carryover of these applied exercise techniques to dy-

namic movement. Further, sport specific tasks may provide a greater stimulus to the trunk and hip musculature that could create superior adaptations when compared to local, isolated trunk exercises (**Appendix 1 - Figures 6 & 7**).^{87, 122,123} It has been shown that competitive demands in field-based tasks require significant trunk flexor-extensor force production. Core musculature has been shown to be acutely fatigued by sporting competition,¹²⁴ indicating the feasibility of appropriate dynamic overload for adaptation. It remains unclear if isolated training via cued bracing or hollowing of the trunk, or specific movement training (**Appendix 1 - Figure 8**) via change of direction tasks alters movement quality or performance of a sporting task in a similar manner to sport. While much attention has been paid to purely increasing the stiffness of the spine to create stability, optimal function is more likely to depend on a balance of stiffness and compliance,³² which requires motor coordination,¹¹⁸ muscle timing/recruitment, comprehensive physical capacity, overall load tolerance,^{87,125} and task specificity.¹²⁶

ISOLATED TRAINING WITH HEAVY LOADS

While targeting the multifidi, transversus abdominis, and oblique musculature through isolated exercise and cueing methods has garnered much attention when studying core exercise, other exercise modes are available for prescription. These consist of additional isolated movements of the trunk and hip and compound movements which may or may not fall into the studied category of "general exercise." Heavy isolated trunk training¹⁰⁹ (**Appendix 1 - Figures 9-11**) has been compared to isolated motor control and compound movement strategies, and has been shown to produce favorable outcomes in both general low back^{109, 127} and radiculopathy cases, of which often have poorer prognosis.¹²⁸ It has been suggested that isolated extensor resistance training intervention consisting of limb stabilization, low frequency (1x/week), high intensity effort (to muscular failure), utilized with either full or limited range of motion can achieve reductions in pain, while improving muscle strength and morphology.¹⁰⁹ Training specificity appears applicable with high intensity extensor training, as it has been shown to improve strength but not endurance in a healthy military population.¹²⁹ Isolated heavy dynamic training of the trunk flexors may be less common in clinical practice, likely due to historical factors related to a neutral pelvis^{4,55} and modeling of repetitive flexion.^{42,43} However, a variety of focused trunk flexor training has been shown to be effective when applied,^{9,38,130} and the risk reward value of trunk flexor training on the injury-performance continuum remains unclear.^{53,131}

Beyond isolated extensor training, comprehensive resistance training of the posterior chain (both isolated joint and compound movements) with heavy loads (i.e. >70%1RM) have been shown to have superior clinical results when compared to general exercise as related to pain, strength and functional outcomes.⁸⁵ It could be hypothesized that comparable high intensity loading could occur in heavy compound movements.^{109,132}

COMPOUND EXERCISES WITH INCLUSION OF THE HIP MUSCULATURE

In addition to the trunk extensors, the gluteal and hip musculature have been included in the posterior chain. Due to the hips' inert¹³³ and dynamic¹³⁴ relationship with the lumbopelvic region, exercises targeted at the hip have been included in core exercise programs. With the gluteal muscle group being of great interest in investigations and clinical practice, the adductor musculature has been a historically overlooked hip muscle group¹³⁵ that has shown promise in training in an isolated^{136,137} and compound¹³⁸ fashion in concert with the lumbopelvic region and trunk.

A micro¹³⁹ and macro¹⁴⁰ motor relationship has been established identifying the complementary nature of the hip and trunk. Correlational relationships of the hip-spine interaction are plausible as it relates to injury,¹⁴⁰ rehabilitation and performance,¹¹⁸ but causal relationships to injury¹⁴¹ or outcomes^{142,143} are yet to be validated. When progressing targeted hip exercises, it is worth noting that many compound movements have been identified as achieving greater hip recruitment (**Appendix 1 - Figures 12-14**) compared to isolated hip exercises.^{5,144} These hip strength gains can also be achieved in sporting activities such as running,¹⁴⁵ sprinting,¹⁴⁶ and hopping/plyometrics.¹⁴⁷⁻¹⁴⁹ Resolving episodes of pain and injury have also been shown to improve hip strength without isolated training of the hip, but with compound, dynamic exercises and time.¹³⁸

Compound movement exercises, particularly those involving the hip, offer the benefit of combining significant motor recruitment,^{5,150} co-contraction,^{150,151} force output,¹⁴⁴ power generation,¹⁵¹ and multi-planar movement while simultaneously involving the trunk, lumbopelvic region, hip and lower extremity.^{2,5} Compound exercises are often included in general exercise programs, making it challenging to delineate which means are most effective, as some crossover is inevitable in practice. Studies comparing general exercise programs to specific core/trunk/hip exercises programs often demonstrate improvement in both study groups with unclear outcomes in the superiority of methods as it relates to performance¹⁵² and rehabilitation outcomes.¹⁵³ Challenges exist in comparing exercise programs due to the common bundling of various lower extremity exercises into core programs, and inconsistent description¹⁵⁴ and targeting¹⁵⁵ of exercise prescription.

UNSTABLE SURFACES

Overall, compound movements have been established to train hip and trunk complexes at comparable or greater ability compared to targeted and specific core exercises.^{2,5} Adding an unstable surface has been proposed to further core recruitment and response to perturbations as another means of traditional core training.¹⁵⁶ Suspension training systems and BOSU ball plank progressions have been demonstrated to increase muscle activation of the trunk musculature, increasing the demand of prescribed exercises.¹⁵⁷ (**Appendix 1 - Figure 15**) Greater muscle recruitment and postural stability has been established on unsta-

ble surfaces,¹⁵⁸ however generally at the sacrifice of pure strength, power and endurance gains.^{156,159} Reduced, power, strength, speed/rate of force outputs are consistently found during training in unstable versus stable conditions^{160,161} and are a reminder that muscle activation is only one component of clinical reasoning in exercise prescription.¹⁶² Performing trunk exercises on an unstable surface may increase compression forces via increased motor recruitment demands, but comparisons of increased loading demands have not been shown to be detrimental to pathologic populations.¹⁶³ Training specificity is a driving factor of outcomes and limits the application of unstable surfaces.¹⁶⁴

ISOLATED, ENDURANCE-DOMINANT ISOMETRICS

Endurance-based isometric strengthening is possibly the most commonly prescribed form of core exercise.^{1,9,38,165} (**Appendix 1 - Figure 15 & 16**) Previously described bracing and hollowing techniques are often incorporated into isometric training, with favorable effects found on motor recruitment, endurance and strength tests, and pain. However, it remains unclear whether these methods are superior to dynamic exercises, both about the trunk,^{109,127} compound resistance training¹²³ plyometric movements¹⁶⁶ and general exercise.³⁸ Heavy back squatting has been shown to have equivalent abdominal muscle recruitment with greater total body co-contraction compared to planking.¹³² Endurance is not likely to be the only quality required for successful outcomes of trunk training.¹⁶⁷ While endurance may be one attribute that has value in baseline training capacity and trunk stiffness,¹⁶⁸ building a comprehensive physical profile that encompasses overall recruitment, strength, power,^{25,169} in addition to endurance, may be more indicative of favorable outcomes across specific performance and injury variables.^{25,170,171} For example, force-velocity characteristics are less studied aspects of core exercise, despite numerous applications to sporting injury and performance.²⁵ Variations of medicine ball throws, kettlebell swings,¹⁷² and/or Olympic movements¹⁷³ have been shown capable of developing both trunk and hip musculature, in addition to sporting qualities such as power development. These exercises can have value in comprehensive core exercise programming (**Appendix 1 - Figures 17-20**). Specificity of exercise selection continues to be related to specific outcomes, as isolated trunk exercises result in greater strength gains, while targeted endurance exercise results in superior endurance gains.¹⁷⁴

COMBINED EXERCISE PROGRAMS AND AVENUES FOR THE FUTURE

A vast array of exercises have been established to be adequate in targeting the hip and trunk.¹⁷⁵ When choosing which exercise is superior for a client, a clinical comparison is likely similar to the open (isolated knee extension) versus closed chain (compound movements) debate in anterior cruciate ligament rehabilitation, where outcomes are improved when both are included in programming as opposed to isolating only one form of open or closed kinetic chain

training.^{176,177} Specific outcomes of exercise intervention (endurance versus power, etc) will likely depend on training specificity within program design versus transference of a single exercise to functional or sporting movement and related clinical outcomes.¹⁷⁸ Exercise prescription that includes both progressive, isolated local and compound exercise have been shown to be superior to targeted traditional exercise.¹⁷⁹ Combined methods of intervention such as utilizing compound and isolated training methods has been shown the ability to improve both local lumbar spine morphology, physical qualities, and quality of life.^{85,180} Isolated motor control and heavy isolated training have been shown to achieve better outcomes when compared to a general exercise plan when the goal is to specifically target trunk musculature.¹⁸¹ A combined exercise program has also been shown to improve outcomes when adequate subgroup selection has taken place,¹⁸² highlighting the ability to broadly apply, yet individualize programming for improved outcomes. The authors advocate for greater fidelity in defining, testing, educating, and applying the reviewed core exercise programs. An updated approach that is inclusive of multiple constructs may be applied in practice across rehabilitation, prevention and performance spectrums discussed in the upcoming sections.

EVIDENCE & ROLE OF TARGETED EXERCISE IN LUMBAR SPINE INJURY MANAGEMENT & PREVENTION

MANAGEMENT

Exercise for low back pain (LBP) is an essential component of medical care due to the pathoanatomical context of the core,⁴ pain-related impairments,^{51,68} and the success as an intervention.^{58,183} LBP is one of the most common musculoskeletal conditions that individuals seek care for, with a documented prevalence of at least 80%¹ and high recurrence rates.¹

Common residual issues with an acute episode or chronic case of LBP include recurrent pain, disability, fear avoidance and disruption of quality of life. A subset of research has attempted to associate impairments such as motor recruitment, muscle morphologic changes, strength, spinal instability-stability, muscle performance (strength, endurance), and movement patterns with occurrence and outcomes in LBP events.^{22,35,51,68} Exercise has been found to be low risk, cost effective, and generally positive in improving pain, disability, and fear.¹⁸⁴ In the context of acute low back pain, exercise may have less of a positive impact on short-term outcomes.¹⁸⁵

Both general exercise and isolated exercise to the trunk and hip have been recommended for LBP management. The induced benefits may be largely related to analgesia and global improvements in function and disability¹⁵³ as opposed to pathomechanical mechanisms. Mechanical (tissue architecture) and performance (motor recruitment, strength, power, and endurance) changes due to targeted exercise have an uncertain relationship with their impact on low back pain outcomes.¹⁸⁶ For instance, while multifidi

morphology changes have been shown to be found in people impacted by low back pain,¹⁸⁷ these changes may be more related to pain, deconditioning and disability versus a causal factor to back pain.¹⁸⁸ Multifidus muscle changes after back injury are characterized by structural remodeling of muscle, adipose and connective tissue, but not always muscle atrophy.^{68,189} Multifidus changes have been related to post-operative low back pain outcomes but not in cases of non-specific low back pain. Changes in cross sectional area, fatty infiltrate, and other measured morphological changes within the paraspinal musculature can be found in virtually every type of low back pain, but the impact on outcomes remains uncertain.¹⁹⁰ The function transversus abdominis has not been shown to be predictive of low back pain outcomes.¹⁹¹ Other related trunk and hip musculature has not been as rigorously studied in low back pain treatment or prevention, but have shown similar outcomes when assessed.¹⁸⁶ Similar to musculature about the trunk, deficits in lower extremity muscle function have been identified after episodes of low back pain and/or chronic low back pain,¹⁹² but have not been prognostically associated to future episodes.

When pain-related morphological change such as fatty infiltrate is significant, changes may not be reversible through exercise.¹⁹³ Depending on exercise conditions (type, dosage), trunk muscle morphology may not change with exercise.¹⁰⁶ There is a lack of differentiation of morphologic changes in comparisons of isolated versus general training.¹⁹⁴ However, utilizing a combined exercise program that utilizes isolated core exercises along with loaded compound moments that provide an adequate resistance training stimulus, individuals with chronic low back pain have been shown to improve muscle morphology and performance, including movement patterns, endurance and pain and quality of life.¹⁸⁰

Psychologic and disability factors have been associated with future back pain episodes, but muscle morphology has not.¹⁹¹ With these findings, further investigation on the relationship of various determinants of health and musculoskeletal structure could be warranted as opposed to only a mechanical view on the topic. Following episodes of injury, exercise may improve the morphological and biomechanical function of the lumbar musculature, but those changes have not been shown to relate to clinical outcomes.¹⁹⁵ While physical attributes such as strength, endurance, power, and aerobic performance have been demonstrated to change through exercise and may improve disability outcomes, a relationship between morphology changes via exercise and clinical outcomes has yet to be proven.¹⁹⁶ Again, it is unclear if these neuromuscular changes of both function and structure are causal of LBP, or a result of LBP events and the comprehensive impact of pain and disability episodes.

RISK

Retrospective findings of impairments after episodes of back pain continue to be recommended treatment targets in treatment and prevention programs. The characterization and targeting of these hypothesized, but not validated,

Table 1. Exercise Construct Summaries

Exercise Construct	Target Region	Target Theory	Cues	Recommended Exercise	Dosage	Advantage	Disadvantage	Example Figure
Isolated – Motor Control (Saragiotto)	Trunk	Instability, Neutral Zone	Hollowing/ Draw-In	Pelvic Tilt, Deadbug, Quadruped Variations	3-7x/wk 1-3x/day 1-3 sets 10-15 reps + 10" Isometric and/or Failure 3-12 wks	Tolerated by those in pain, may perform with greater frequency and lower loads	Limited carryover to tasks, limited morphology and strength improvement, ↓ motor recruitment compared to alternatives	1, 2
Isolated – Anti-Flexion, Anti-Rotation (McGill)	Trunk	Neutral Zone, ↑ Motor Recruitment Strength-Endurance	Bracing	McGill Endurance (Curl Up, Plank), Birdog, Pressing, & Carry Variations	3-7x/wk 1-3x/day 1-3 sets 10-15 reps + 10" Isometric and/or Failure	May perform decreased frequency, greater adaptations compared to motor control drills	May not change architecture and physical qualities as robustly as higher demand tasks. May impeded task completion, limited specificity to dynamic tasks (i.e drop jump, sport)	3, 4, 5, 15, 16
Isolated – Heavy (Steele, Fortin)	Trunk		Avoid Task Compensation beyond Spine	Glute-Ham, Back Extension Variations	1-3x/wk 1-3 sets 3x5-10 reps 10-6RM or 60-80%1RM to Failure	↑ muscle morphology, adequate load for strength and power	Studied mainly for extensor musculature, assessment required for those with injury. Not studied for functional task carryover. Equipment limitations	9, 10, 11

Exercise Construct	Target Region	Target Theory	Cues	Recommended Exercise	Dosage	Advantage	Disadvantage	Example Figure
Isolated – Hip (McGill, Welch)	Hip	Lumbopelvic Instability, Compensatory Mechanics of Extremity	Avoid trunk-lean compensation	Side Plank Gluteal Bridge Variations	3x/wk 3 sets 3x5-10 reps 10-6RM	May perform decreased frequency, greater adaptations compared to motor control drills	Time efficiency compared to compound exercise tasks	10, 14, 16
Unstable Training	Trunk, Hip, Extremity	Increase motor recruitment due to proprioceptive demands of unstable assistive device (suspension, BOSU, disc, etc)	Maintain body control with task completion	Supine, Quadruped, McGill Endurance Progressions (BOSU, Suspension), Compound Movements (Disc, Foam, etc)	1-3x/wk 1.5min-60min 50 to 100 % 1RM, ≥5 on the Borg Scale (CR-10) 6-12 wks	↑ muscle morphology, adequate load for strength and power More muscle groups trained. May be utilized to progress basic exercises	Sacrifice motor recruitment for sub-optimal strength, power, gains. Limited specificity	15
Compound (Behm)	Trunk, Hip, Extremity	Global Training, ↑ Co-Contraction and Motor Recruitment	Coaching specific movement technique with internal/external cues	Double & Single Leg Squat, Deadlift/Hinge Push, Press Variations	3x/wk 3 sets 3x5-10 reps 10-6RM 6-16 wks (Welch, Tataryn)	↑ muscle morphology, adequate load for strength and power ↑ motor recruitment More muscle groups trained. Time efficiency of training	Compensation to complete motor task may off-set gains to specific core musculature targets	12, 13, 17, 18, 19, 20
Sport-Specific	Trunk, Hip, Extremity	Specific Training, ↑ Co-Contraction and Motor Recruitment	Coaching specific movement technique & sport tasks with internal/external cues	Sport Participation (Individual, Practice, Competition) & Related Drills (SAQ i.e repeat sprints, 180, 90, 45 degree change of direction drills)	3-6x/wk Sport Specific Movement/ Playing + Matched Mechanical and Internal Loads 12-16 wks	↑ muscle morphology, ↑ motor recruitment, adequate load for strength and power More muscle groups trained while also training for sport	Compensation to complete motor task may off-set gains to specific core musculature targets	6, 7, 8

risk factors (aberrant movements, muscle morphology changes, motor recruitment patterns, etc) is common practice and well established in the public domain of popular culture. Unfortunately, this information may be over-utilized due to findings in retrospective studies as opposed to prospective investigations¹⁹⁷ and an overreliance on expert opinion in the absence of confirmatory evidence.⁶

Prospective risk factors for low back pain consistently identified in the literature include limited range of motion,^{198,199} poor general health, strenuous occupations, and physical and psychological stress.²⁰⁰ Typically tracked measures of core performance such as muscle morphology, endurance and strength have not been shown to be related to first time episodes of back pain according to systematic reviews and meta-analysis of prospective cohort studies.^{198,199} Exercise after an initial bout of low back may reduce the rate and number of reoccurrence.^{183,201} General exercise or specific core exercise as defined in above sections have not been accurately delineated in superiority for clear recommendations on the best mode of exercise for low back pain.^{94,201}

PREVENTION

Prevention programs often attempt to address these proposed risk factors despite the absence of mechanistic support. A limited body of exercise prevention programs have shown success in reducing episodes of low back pain in select populations such as office workers,²⁰² military candidates,^{203,204} and athletes^{78,205} and do not delineate between first time or recurrent low back pain. Limitations within the description and application of these programs are significant and do not allow practitioners to assume that the general or specific exercise intervention is improving specific pathoanatomic targets of which is related to the outcome (i.e multifidus structure and function improving spinal instability-stability and preventing injury). The studies also do not establish that local core exercises are superior to multimodal exercise groups and demonstrate either bias, small sample size, poor study design, inadequate descriptions of exercise intervention, and lack the differing modes of core exercise performed in comparison to one another and controls. Further, some of these programs are comprehensive exercise programs that include trunk and hip exercises, with the aim of preventing many types of injury.⁷⁸ There is a confounding effect of comprehensive multi-joint training impacting more than just local performance of the core musculature. Their inclusion conflicts with the findings that traditional core training is preventative of low back injury just by the simple inclusion of common isolation exercises within these programs. The effect of prevention measures via exercise has also been shown to reduce after one year.²⁰⁶

Overall, exercise has been established as a front-line intervention for treatment and prevention (primary, secondary, and tertiary) of low back pain. However, the exact mechanisms of efficacy remain unclear and do not seem consistent with impairments in impairments that are targeted via instability-stability based pathoanatomical models.^{75,180}

EVIDENCE & ROLE OF TARGETED EXERCISE IN LOWER EXTREMITY INJURY MANAGEMENT & PREVENTION

MANAGEMENT

The role of hip and trunk exercises in preventing and treating lower extremity injuries has followed a similar historical course as the utilization in low back pain. A traditional view that local exercise targeting the core and hip will cause kinematic change in the lumbopelvic region and throughout the lower extremity to either prevent or treat an injury.²⁰⁷ It has been hypothesized that deviations in lumbopelvic region related to neuromuscular instability cause biomechanical changes that predispose an athlete to injury implicating the hip, knee, and ankle/foot, and has resulted in core exercise for the treatment and prevention of lower extremity injury.²⁰⁸ These mechanistic assumptions lack consistent validation as it relates to isolated intervention and resultant biomechanical and clinical outcomes.²⁰⁹

For example, knee injuries are one of the most common conditions in which hip and trunk exercises are prescribed. A meta-analysis has identified that inclusion of core exercise in rehabilitation improves outcomes.²¹⁰ However, the combination of hip and knee dominant exercises have been shown to have superior outcomes via a more recent meta-analysis.²¹¹ Further challenging the impact of isolated hip and trunk exercise versus various exercise modes is demonstrated by a randomized controlled trial showed that replacing hip exercise with ankle dominant exercise can be just as effective for improving knee outcomes when treating patellofemoral pain syndrome.²¹² Overall, open kinetic chain hip strengthening may improve pain outcomes when added to a closed kinetic chain program, but the strength and function measures have not been shown to be superior between programs.^{213,214}

At the ankle, similar deficits at the hip have been shown post injury but may not be predictive of future injury. A common finding is that intervention to the trunk and hip may improve outcomes,²¹⁵ but still is unlikely to be a risk factor related to future injury.²¹⁶ As with the lower back, endurance, strength, and proprioceptive deficits of the core have been associated with injured populations, but have not been prospectively identified to be related to initial episodes of lower extremity injury.²¹⁷ Other major muscle groups of the lower extremity such as the quadriceps and hamstrings, which are not traditionally included in the core, have been weakly associated with lower extremity injury, while hip strength measures were found to have no relationship to future injury.²¹⁸

RISK

Trunk stabilization and postural control have not been shown to be predictive of future knee injury,²¹⁹ despite the relationship of trunk displacement in knee injury.²¹⁷ Different methods of trunk stabilization from unplanned perturbation showed that individuals who had less trunk displacement may be less likely to sustain future injury

Exercise Construct	Regression 2	Regression 1	Entry Level	Progression 1	Progression 2	Example Figure
Isolated – Motor Control	Pelvic Tilting Quadruped Pelvic Tilt	Bent Knee Deadbug Bent Knee Birdog	Deadbug Birdog	Resisted Deadbug Resisted Birdog	Change Construct	1, 2
Isolated – Anti-Flexion, Anti-Rotation	Curl Up Side Plank	Resisted Curl-Up Suitcase Carry	Plank Cable Press	BOSU Plank Med Ball Throw	Ab Rollout ↑ Resistance	3, 4, 5, 15, 16
Isolated - Heavy	Bierling-Sorenson	Hip Extension	Machine Extension	Glute-Ham Rows	↑ Resistance	9, 10, 11
Isolated - Hip	Clamshell DL Gluteal Bridging	Sidelying Hip Abduction SL Gluteal Bridging	Side Plank Hip Thrust	Copenhagen Adduction SL Hip Thrust	↑ Resistance ↑ Resistance	10, 14, 16
Unstable Training	Remove Device	DL Supported	Task with Device	SL Supported	↑ Resistance	15
Compound	Heel Elevated Squat Banded Hip Hinge	Counterbalance Squat Trap Bar Deadlift	Squat Barbell Deadlift	SL Squat SL Deadlift	Clean/Snatch KB Swing	12, 13, 17, 18, 19, 20
Sport-Specific	Linear SAQ Stationary Individual Drills	Multi Direction-SAQ Controlled Individual Drills	Global SAQ Full Individual Drills	Reactive SAQ Sporting Practice	Sporting Competition	6, 7, 8

Table 2. Construct Specific Progressions and Regressions

across four different studies.²¹⁷ Pure flexion and extension strength variables may have some utility as risk factors of initial injury but early research summarized in a recent systematic review has compared this mostly to lab based kinematic outcomes (i.e dynamic valgus) and not actual injury outcomes. When the goal is altering kinematics, utilizing external cueing and movement interventions achieves superior outcomes when compared to isolated hip and trunk exercises.²²⁰

Trunk endurance tests (i.e McGill, Bierling-Sorenson test batteries) have not shown utility in prospectively in identifying lower extremity injury.²¹⁷ No evidence was found for basic posterior and lateral trunk muscle endurance tests between injured and uninjured collegiate athletes, and conflicting evidence exists of anterior trunk muscle endurance being worse in subjects who developed injuries.²¹⁷ A review of 21 studies has shown that core muscle fatigue has not been shown to elicit theoretical detrimental biomechanical changes to jump landings aside from some increase in trunk flexion.²²¹ However, a modified Bierling-Sorenson test, with forces tracked through a fixed load cell, identified a prospective relationship between trunk and hip extensor strength (peak force) and strength-endurance (sustained peak force) and knee and hamstring injuries.²²² This indicates that more comprehensive testing and training of the posterior chain that includes both the trunk and hip may be more appropriate than basic clinical endurance assessment and training.

When considering the lower extremity as a whole, some studies have shown hip extensor^{222,223} and abductor²²⁴ strength as a prognostic risk factor at the ankle, hip and trunk extensor strength at the hip and knee,²²² hip abductor and external rotator strength knee,²²⁵ and hip abductor and external rotator strength for general lower extremity injury.²²⁵ However in larger trials, associations have been too small to significantly and correctly identify at-risk athletes, or consistently predict future injury with practical significance.^{218,226} The same research group, testing the same hip and core variables, found inconsistent findings and variable correlations across different populations.^{217, 225,227} With weak correlations and inconsistent findings, it

is challenging to successfully predict injury risk based on hip and core muscle performance.

Combined measures of core muscle strength ratios, proprioception (Star Excursion Balance Test [SEBT]), and endurance have been able to prospectively identify those possibly at risk for lower extremity risk, but with a low relative predictive ability of 53%, which slightly better than chance.²²⁷ Static and dynamic stabilization, often related to core and hip performance, tested in similar movements has not been shown to be predictive of injury.²¹⁹ Similar constructs of proximal and lower extremity performance,²²⁸ and specifically, the SEBT²²⁹ have been previously identified as possibly related to injury risk. These studies have also appreciated the interaction and complex relationship of various physical attributes and their relationship to injury, and are more consistent with a complex systems approach.²³⁰ A recent study utilizing machine learning analysis of hip, core, and movement variables demonstrated low predictive ability of ACL injury. Despite possible indications of injury causation, these variables cannot currently be utilized in prediction.²³¹

PREVENTION

Successful prevention programs such as the FIFA 11+ include targeted trunk and hip exercises, but are also confounded by their comprehensiveness and inclusion of dynamic, multi-joint drills and eccentric exercise, single leg tasks, and plyometrics.⁷⁸ Similar complimentary programs have been shown to have an association with risk reduction in running related injuries in a trial compared to ankle and foot exercises or stretching.²³² Another recent review states that core exercise included in a hamstring prevention program is of benefit. However, this review does not identify the inclusion of the eccentric Nordic hamstring as a confounding variable all five studies analyzed, unless this drill is to also be considered a core exercise.²³³

It is unclear if the addition of the targeted core exercises is of added benefit due to the comprehensive nature of these programs. Yet conclusions are often made that the

core should be included to result in superior injury prevention without recognition of these confounding variables.²³³

When investigating the utility of hip and trunk exercise to prevent future injury, there is limited support of isolated strengthening and movement intervention.²⁰⁹ At multiple points over the past decade, deficits in hip strength have been most likely attributed to a result, not a cause of injury.^{234,235} Most variables of the hip and trunk were not identified as risk factors of future injury, and only hip external rotation and trunk proprioception/neuromuscular control have been identified as predictive of future knee injury.²⁰⁹ Isolated exercise to the hip has not been shown to change motor patterns proposed to reduce and treat injuries.²³⁶ Changes to motor patterns, such as dynamic valgus, are also likely to have varying success based on the interventions targeted pathology.²³⁷ External cueing and specific task training have been identified as more effective means of altering kinematics as opposed to isolated core exercise.^{220,237} Broadly defined core stability training has been identified to be impactful in changing jump landing strategy, but not change of direction movement patterns.²³⁸

In practice, clinicians have likely been applying the mechanistic effect of hip and trunk exercise too liberally and globally, overstating their effects on pathoanatomic, kinematic and injury outcomes. Lower extremity movement patterns and injuries are too complex to truly appreciate the impact of individual core exercise interventions, especially considering the likelihood of specificity required to each motor task.²³⁸ For example, simply improving hip strength²³⁹ and decreasing the occurrence of dynamic valgus²³⁷ in an isolated motor task do not guarantee as successful prevention outcome.

This does not necessarily mean that isolated trunk and hip exercises do not serve a purpose in the lower extremity. There is support for the utility of hip and trunk exercise in rehabilitation and prevention, but the described limitations and confounding variables must be appreciated. Increased local and global tissue capacity via exercise may provide protective qualities to athletes. It just may not be as straightforward or as protective as previously hypothesized (i.e. hip abduction strength gains changing dynamic valgus during a cutting or jumping task).^{236,240}

APPLICATION TO PERFORMANCE

Like injury management and prevention, there is a general belief that exercise directed at the hip and trunk will result in superior athletic performance. As with cases of rehabilitation and prevention of the back and lower extremity, results are often mixed and understudied.²⁵

It has been proposed that a stable core provided by hip and trunk exercises will allow better transmission of forces from the ground and lower extremity, through the trunk, and back through the extremities when performing multi-joint dynamic sport maneuvers (i.e. throwing, jumping, sprinting, etc). Performance in core endurance tests have been shown to be weakly and moderately related to performance in athletic performance, ranging from max strength

(squat, clean), jump and sprint performance.²⁴¹ Dynamic core exercise performance via medicine ball toss variations have shown a similar relationship between strength and power attribute outcomes, and may better mimic force transfer from the extremities to the trunk and vice versa.²⁴² These findings may also demonstrate that robust and high performing athletes will test well across a multitude of variables, as better athletes score better in speed, strength, power and endurance testing as a whole.^{241,242}

A chicken or the egg discussion can be had, as one cannot be sure of adaptations to the hip and trunk are from specific training or are developed through sport-specific adaptations from playing the sport. Across various sporting groups, improvements in postural stability and control have been found to occur from playing the sport itself.²⁴³ In adolescent populations with lower training ages, any means of training may be effective in improving performance proxies such as change of direction and agility. It remains unclear if general training versus an isolated core program exercise will improve these sport-specific qualities, or which program would be superior.²⁴⁴

Core exercise programs have also been related to sporting performance enhancement (i.e. throwing velocity, jumping, speed, sporting accuracy) across speed, accuracy, aesthetic, court/net, invasion, and combat based sports, of which programs lasted from 4-12 weeks.²⁴⁵ A major limitation in these findings is the lack of comparison of various forms exercise, both at the hip and trunk and specific to the sport.²⁴⁵⁻²⁴⁷ In comparison studies, global resistance training has been shown to have superior performance enhancement over a core exercise program, even though both modes of exercise improve performance.²⁴⁸

This bears consideration due to the findings that sport specific measures about the core may be required for programming and outcomes, especially when considering elite athletes⁸⁷ versus a younger population where any form of training may elicit outcomes.¹²⁵ Sport-specific adaptations may train trunk and hip muscles more advantageously than targeted, non-specific core drills, limiting the applicability for performance when comparing programs.²⁴³ Programs that include sport-specific, compound movement, and localized core training programs have been shown to have superior sporting outcomes then when the program components are performed in isolation.²⁴⁹

CONCLUSION

The broad, overarching benefits of targeted exercise to the hip and trunk (core) have likely been overstated and lack validation of historical and mainstream mechanisms. However, trunk and hip exercise still have shown value and hold a place in injury management, prevention, and performance attribute development. The view of which exercises best target the trunk and the hip should move beyond isolated exercises and cueing and be inclusive of both isolated and multi-joint movements that target multiple variables (recruitment, structure, strength, power, endurance, etc). Specific dosing parameters of mode, volume, intensity, frequency, and program periodization should be vigorously

tested and assessed. This programming analysis would help discern how to best combine all modes of training in practice and account for plausible interacting variables. This will require understanding the current evidence, as well as clinical decision-making skills, to make population-based decisions for the right exercise at the right time for the right person. More effort needs to be placed in critically questioning mechanisms and discerning the carryover of general and task specific exercise (or lack thereof) to health

and performance outcomes. With improved understanding, practitioners will be able to better prescribe interventions and educate athletes and patients regarding these interventions across a health and performance spectrum.

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SUPPLEMENTARY MATERIALS

Appendix 1. Exercise Figures and Clinical Reasoning

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Appendix 2. Example Weekly Programming

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