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Spinal-Exercise Prescription in Sport: Classifying Physical Training and Rehabilitation by Intention and Outcome

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Context: Identification of strategies to prevent spinal injury, optimize rehabilitation, and enhance performance is a priority for practitioners. Different exercises produce different effects on neuromuscular performance. Clarity of the purpose of a prescribed exercise is central to a successful outcome. Spinal exercises need to be classified according to the objective of the exercise and planned physical outcome.

Objective: To define the modifiable spinal abilities that underpin optimal function during skilled athletic performance, clarify the effect of spinal pain and pathologic conditions, and classify spinal exercises according to the objective of the exercise and intended physical outcomes to inform training and rehabilitation.

Design: Qualitative study.

Data Collection and Analysis: We conducted a qualitative consensus method of 4 iterative phases. An exploratory panel carried out an extended review of the English-language literature using CINAHL, EMBASE, MEDLINE, and PubMed to identify key themes and subthemes to inform the definitions of *exercise categories*, *physical abilities*, and *physical outcomes*. An expert project group reviewed panel findings. A draft classification was discussed with physiotherapists (n = 49) and international experts. Lead physiotherapy and strength and conditioning teams (n = 17) reviewed a revised classification. *Consensus* was defined as unanimous agreement.

Results: After the literature review and subsequent analysis, we defined spinal abilities in 4 categories: *mobility*, *motor control*, *work capacity*, and *strength*. Exercises were subclassified by functionality as *nonfunctional* or *functional* and by spinal displacement as either *static* (neutral spinal posture with no segmental displacement) or *dynamic* (dynamic segmental movement). The proposed terminology and classification support commonality of language for practitioners.

Conclusions: The spinal-exercise classification will support clinical reasoning through a framework of spinal-exercise objectives that clearly define the nature of the exercise prescription required to deliver intended physical outcomes.

Key Words: spine, back, classification

Key Points

- The spinal abilities underpinning optimal function during skilled athletic performance have been evaluated, and a comprehensive framework of exercise and physical outcomes has been established.
- The framework provides a basis for clinical reasoning in spinal-exercise prescription and establishes a platform for shared understanding to enable interdisciplinary efforts within a diverse spectrum of musculoskeletal practice.

Injury epidemiologic data have suggested that the prevalence of back pain in athletes ranges from 30% to 50%.[1,2] Injury-surveillance data of Great Britain Olympic athletes collated by the Injury/Illness Performance Project under the auspices of the UK Sport/English Institute of Sport (EIS) between 2009 and 2012 across 11 Olympic sports have indicated that thoracic and lumbar spine injury (LSI) accounted for 14.2% of all injuries and resulted in 737 days missed from training and competition.[3] Injury is prevalent in sports that place substantial demands on the spine through intensive or repetitive directional loading,[4,5] including gymnastics, diving, weight lifting, cricket, and rowing. Identifying strategies to prevent spinal injury, optimize spinal rehabilitation, and enhance spinal performance is a priority for practitioners.

Spinal function has been defined as the ability to create, absorb, and transfer force and motion to the terminal appendicular segment during the performance of skilled motor tasks.[6] Theoretical definitions of *core stability* (CS), however, do not represent the relationship between passive anatomical structures and the complex neuromuscular system coordination required to maintain spinal integrity under varying loads and motion demands. The nature of spinal integrity during sport activity is task specific. Therefore, the theoretical basis of "optimal" movement efficiency is an expression of the coordinated interaction of numerous physical abilities underpinning spinal function.[7]

Specificity of training enables the development of targeted outcome measures to enhance performance. During rehabilitation, practitioners also must consider the

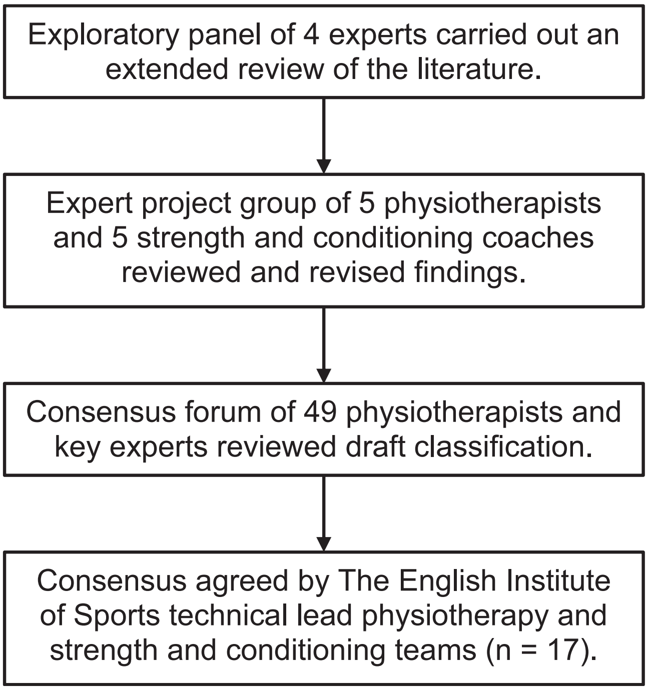

Figure 1. Flow diagram of consensus process.

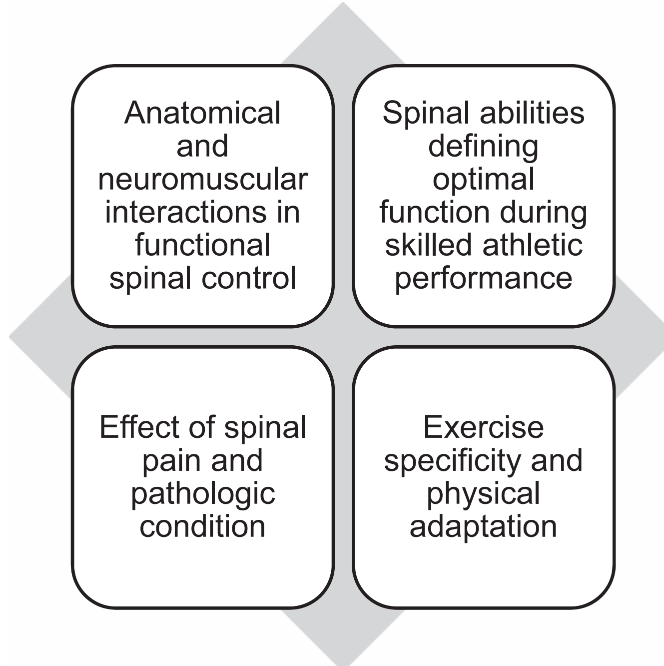

Figure 2. Conceptual framework underpinning the study methods.

effect of pathologic conditions and pain on specific physical abilities and identify effective strategies to address dysfunction. The use of exercise is accepted unequivocally as part of a multifaceted approach to training and rehabilitation.[8] Identification of suboptimal physical performance forms the basis of clinical reasoning to inform exercise prescription.

Historically, the nature of spinal-exercise prescription has been subject to widespread debate[9,10] centered on the relative understanding and importance of CS and driven by its role in the management of chronic low back pain (LBP).[11] Whereas researchers[12–15] have made substantial progress in detailing the components of spinal stability and its relationship with spinal mobility, unidimensional paradigms of exercise prescription persist. For example, attempts have been made to isolate groups of core muscles or their function despite the important synergistic contributions of many different muscles to balance stability and movement demands.[16] Furthermore, given that different exercises produce different effects on neuromuscular performance, use of the term *CS* is problematic, as it does not adequately define the intent of an exercise, and it often is used by practitioners attempting to deliver several different training or rehabilitation outcomes. Therefore, spinal exercises, and often exercises in general, are frequently described by name, equipment used, or place performed (eg, Pilates/core exercises, mat exercises, gymnasium exercises) rather than by intent, loading, and execution. If exercise intention is not delineated, miscommunication may occur among practitioners. Therefore, the purpose of our study was 2-fold: (1) to define the modifiable spinal abilities that underpin optimal function during skilled athletic performance and clarify the effect of spinal pain and pathologic conditions and (2) to classify spinal exercises according to the objective of the exercise and intended physical outcomes to inform training and rehabilitation.

METHODS

We used a qualitative consensus method of 4 iterative phases (Figure 1). A conceptual framework was defined to underpin the study methods (Figure 2). The framework formed an analytical tool that was used in phase 1 to organize the ideas emerging from the literature. It provided a structure of starting principles and assumptions that illustrate a broad concept.

Phase 1

An exploratory panel consisting of 2 senior physiotherapists and 2 senior strength and conditioning coaches (S.S., A.W., and 2 nonauthors) with extensive experience in spinal training and rehabilitation at the EIS was formed to carry out an extended review of the literature to (1) identify modifiable spinal abilities defining optimal function during skilled athletic performance, (2) clarify the effect of spinal pain and pathologic conditions on specific physical abilities, and (3) define categories of exercise objectives and physical outcomes (Table 1). The literature search used sensitive topic-based strategies designed for each database. Search dates were from database inception to July 31, 2013, to inform phase 1. We subsequently updated the search to July 31, 2015, to reflect contemporary literature.

We searched the databases of CINAHL, EMBASE, MEDLINE, and PubMed. The search strategy consisted of search terms informed by the conceptual framework. For anatomical and neuromuscular interactions in functional spinal control, we used the terms *core*, *function (spinal)*, *neuromuscular (control),* and *stability (spinal)*. Search terms for spinal abilities defining optimal function during skilled athletic performance were *mobility*, *motor control*, *performance (athletic/sporting), power*, *rate of force development (RFD)*, *strength*, and *strength endurance*. For the effect of spinal pain and pathologic conditions, we used the terms *low back injury*, *LBP*, *lumbar spine*,

Table 1. Characteristics of Exploratory Panel and Expert Project Group Participants

Participant	Profession	Phase Inclusion	Level[a]	Experience Within Elite Sport, y	Geographic Region
1	Physiotherapist	All	Senior	11	National
2	Physiotherapist	All	Senior	15	South
3	Strength and conditioning coach	All	Senior	13	National
4	Strength and conditioning coach	All	Senior	10	London
5	Physiotherapist	2–4	Senior	8	Central
6	Physiotherapist	2–4	Senior	10	Central
7	Physiotherapist	2–4	Senior	7	North
8	Strength and conditioning coach	2–4	Senior	15	North
9	Strength and conditioning coach	2–4	Senior	13	South
10	Strength and conditioning coach	2–4	Senior	15	North

[a] Typically, senior practitioners have at least 1 full Olympic cycle (4 years) of experience of working in elite sport, hold leadership positions within the organization or within specific sports, and frequently hold higher degrees within their professional specialties.

pathology (spine), and *sport*. Search terms for exercise specificity and physical adaptation were *exercise*, *injury prevention*, *outcome measures, physical/physiological adaptation, rehabilitation*, and *training*. We excluded studies not written in English but did not place restrictions on study design. A total of 1614 studies were retrieved from the initial searches. Findings from studies were analyzed in the context of any methodologic limitations. Key themes and subthemes (eg, exercise objective grouping, subclassification requirements) were identified to inform the definitions of *physical abilities*, *exercise categories*, and *physical outcomes*.

Phase 2

An expert project group was convened to review and revise the exploratory panel findings. The group consisted of 5 physiotherapists and 5 strength and conditioning coaches holding national leadership positions within EIS and regularly engaging in spinal training and rehabilitation (S.S., A.W., and 8 nonauthors; Table 1). Independently, they identified areas for discussion and review. Collectively, they agreed on modifications to the definitions of *physical abilities*, *exercise categories*, and *physical outcomes* and formulated a draft classification informed by the conceptual framework of the study. An example of an area discussed and modified was the separation of *work capacity* (*WC*) and *strength* into 2 distinct physical performance variables.

Phase 3

A researcher (S.S.) presented the draft classification to all EIS physiotherapists (n = 49) at a consensus forum and sent it to key experts in the field for international expert review. Data were analyzed to inform emerging themes and subthemes that subsequently were integrated into a revised classification. Examples of themes included *understanding and managing practitioner bias*, *clarity of presentation*, and *agreed terminology/use of language*.

Phase 4

Two of the investigators (S.S., A.W.) presented the classification to members of the EIS technical lead physiotherapy and strength and conditioning teams (n = 17) for discussion. The discussion focused on the strengths of the framework and its potential application in elite sport.

Definition of Consensus

Consensus was defined as unanimous agreement and was achieved at each phase. The classification was accepted by unanimous agreement with minor amendments. We present the definitive classification in the Results section.

RESULTS

Objective 1

Objective 1 was the identification of modifiable spinal abilities that underpin optimal function during skilled athletic performance. Spinal abilities were defined in 4 distinct categories: *mobility*, *motor control*, *WC*, and *strength*.[12,17–19] The extents to which each category contributes to spinal neuromuscular control,[6] the effect of pain and pathologic conditions, and how exercise interventions are used to influence targeted physical outcomes were important to consider. The modifiable spinal abilities that underpin optimal function during skilled athletic performance are summarized in Figure 3 and defined in the Appendix.

Mobility. *Mobility* was defined as freedom of movement at spinal segments. It provides the basis for the development of motor control[20] and optimal spinal function.[21] Furthermore, the relationship between axial mobility and athletic performance has been established.[22,23]

Deficits in spinal movement have been identified in athletes with a history of LBP,[24–26] for whom changes in mobility are a product of the interaction between soft tissue and articular dysfunction. It is plausible that abnormal movement patterns or repetitive directional loading result in the consistent absence of mechanical tension associated with connective tissue remodeling and eventual loss of muscle fiber length.[27,28] Loss of mobility could also represent an adaptive or maladaptive mechanism by which the body attempts to achieve active stability and maintain a level of function in the presence of pain, physical stress, or failed motor control.[29]

A myriad of therapeutic interventions are used to influence the neurophysical mechanisms associated with loss of mobility (hypomobility), such as focal articular or tissue restriction, pain, and altered muscular tone.[30]

Spinal Displacement	Physical Ability			
	Mobility	Motor Control	Work Capacity	Strength
Static	Not applicable	Segmental stabilization (NF) Spinal dissociation (NF)	Pillar work capacity (NF)	Pillar strength (NF)
	Not applicable	Spinal dissociation (F)	Pillar work capacity (F)	Static rate of force development (stiffness; F)
Dynamic	Mobility	Segmental movement control (NF)	Segmental work capacity (NF)	Not applicable
		Whole-body coordination (F)	Segmental work capacity (F)	Dynamic rate of force development (power; F)

Figure 3. Classification of modifiable spinal abilities positioned within the context of physical ability. Abbreviations: F, functional; NF, nonfunctional.

Exercise is frequently used to influence spinal motion, and mobility exercises can also be performed in combination with limb movement to augment tissue elongation throughout a continuous myofascial line.[31] Reliable assessment of spinal motion has been established,[32–35] and effective restoration of spinal range of motion after flexibility training has been demonstrated in participants with LBP.[36,37] Support for including this component within the classification is primarily based on clinical concepts.

Motor Control. Maintenance of spinal integrity during skilled movement tasks depends not only on muscular capacity but also on the ability to process sensory input, interpret the status of stability and motion, and establish strategies to overcome predictable and unexpected movement challenges.[38] The spinal stability required during athletic performance is task specific and governed by the nature of the intended movement, the magnitude of imposed load, and the perception of risk associated with the activity.[39] The central nervous system, therefore, determines the requirements for stability and coordinates contraction of deep and superficial core muscles using both feed-forward and feedback control mechanisms.[8,40] In the presence of pain, the relationship between task demand for stability and muscular recruitment becomes disrupted, resulting in delayed trunk-muscle reflex responses and excessive outer-core muscular activation.[41–43] Classification systems have been developed to establish the nature of adaptive motor responses in the presence of pain and identify maladaptive motor-control impairments contributing to spinal pain disorders.[44,45]

Motor adaptation to pain has been demonstrated in athletes with LBP[46] and groin pain[47] after recovery from a recent occurrence of LBP[48] and is observable in patients with recurrent LBP during periods of remission.[49] Furthermore, reflex response latencies can preexist within a healthy athletic population, substantially increasing the risk of sustaining an LSI.[50] Evidence has suggested that motor adaptation to pain can be influenced through exercise-based intervention. Segmental-stabilization exercises first described by Richardson and Jull[51] focus on retraining coordinated cocontraction of the deep trunk muscles through simultaneous isometric cocontraction of the transversus abdominis and multifidus in a static-neutral spine position. Exercise has been shown to effectively restore delayed or reduced activation of the transversus abdominis[52] and multifidus,[53] with positive effects persisting after cessation of training.[54] Despite its scientific foundation and widespread anecdotal support, impaired feed-forward activation of local stabilization muscles in patients with LBP has been challenged.[55] Furthermore, evidence also led researchers to question the ability to better influence anticipatory muscle patterning after the performance of segmental-stabilization exercises[56] aligned with the preferential effect on pain and dysfunction than after any other form of active exercise.[57]

The ability to dissociate spinal and appendicular movements provides a static platform for force absorption and transference and is a product of mobility and neuromuscular control of the limbs and maintenance of a static-neutral lumbar position. During sporting activities imparting high loads through the spine, forces need to be distributed evenly to minimize loading of vulnerable tissues in the spine.[58,59] The inability to control a neutral position increases the potential for tissue damage, especially during repetitive-loading activities. Clinical tests reliably identify the performance of dissociation tasks under both low- and high-load conditions,[60] with movement-control deficits identified in patients with LBP.[61] Hodges[62] hypothesized that failed load transfer during low-load conditions is primarily due to inadequate motor-skill competence or altered mechanical behavior associated with pain or the threat of pain or injury. Failure under higher loads may be attributed to other factors (eg, insufficient muscular capacity), requiring detailed assessment to establish the nature of the movement-control loss.

Spinal Displacement/Functionality[a]	Physical Outcome			
	Mobility	Motor Control	Work Capacity	Strength
Static – NF Exercises	Not applicable	Segmental stabilization (NF)	Pillar conditioning (NF)	Pillar strength development (NF)
		Spinal dissociation (NF)		
Static – F Exercises	Not applicable	Spinal dissociation (F)	Pillar conditioning (F)	Stiffness development (F)
Dynamic – NF Exercises	Mobility development (NF or F)	Segmental movement control (NF)	Segmental conditioning (NF)	Not applicable
Dynamic – F Exercises		Whole-body coordination (F)	Segmental conditioning (F)	Power development (F)

Figure 4. Spinal-exercise classification with exercise objectives positioned within the context of intended physical outcome. Abbreviations: F, functional; NF, nonfunctional. [a] Exercise objectives are subclassified by spinal displacement and functionality.

During dynamic spinal movement, coordinated neuromuscular control of intersegmental articulation is provided by precise coordination of the surrounding musculature.[63] Proximal-to-distal segmental sequencing is critical for performing skills that demand maximum speed to be produced at the end of the distal segment in the kinetic chain, such as kicking or throwing.[22] Failed load transfer during segmental motion results in aberrant motor patterns, which hypothetically could result in tissue damage through uneven load distribution and focal tissue stress.[45,64] Conversely, changes in motor control in some subgroups with LBP have been associated with a compromised ability to coordinate spinal motion due to excessive aberrant muscular cocontraction, resulting in an inability to perform controlled segmental movements.[65] Sequential segmental-control exercises, such as dynamic pelvic tilting, are intended to establish or retrain appropriate muscular recruitment, coordinated dynamic motor control, and proprioceptive awareness.[66]

Facilitation of skilled motor learning during rehabilitation requires autonomous engagement in the learning process.[67] When the participant is motivated to learn a

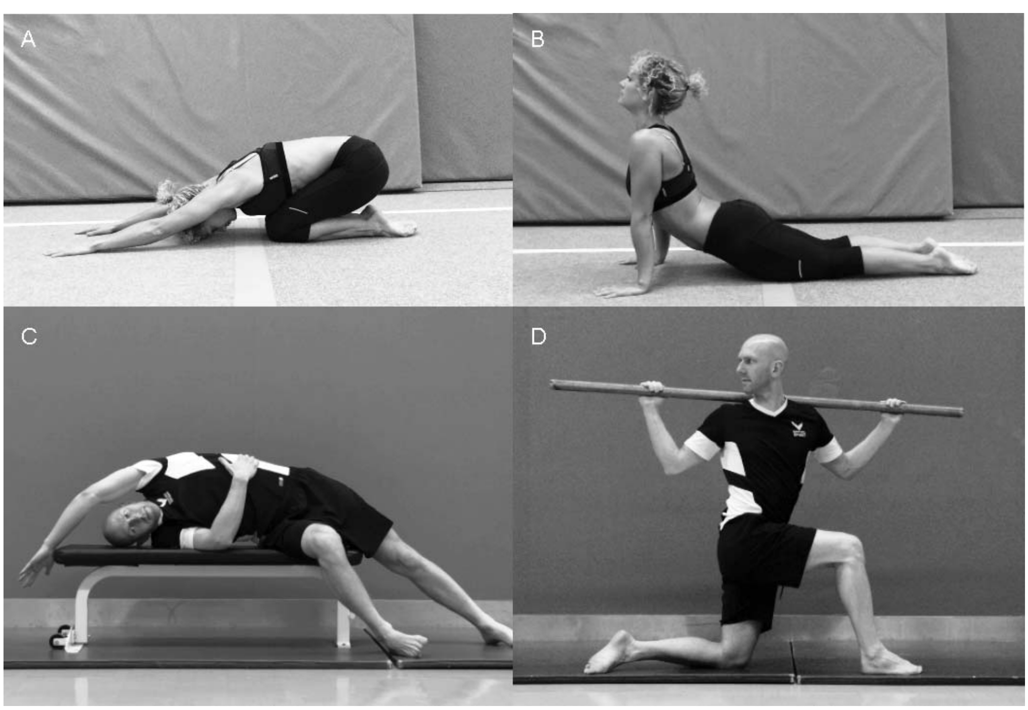

Figure 5. Examples of mobility development exercises. A, Flexion. B, Extension. C, Lateral flexion. D, Rotation.

Table 2. **Exercise Objective Definitions Positioned Within Context of Intended Physical Outcome**

Physical Outcome	Spinal Exercise Objective	Definition
Mobility	Mobility development (NF or F)	Exercises intended to develop, maintain, or restore global spinal range of movement through a specific range of motion (Figure 5).
Motor control	Segmental stabilization (NF)	Exercises intended to retrain coordinated recruitment of the deep abdominal and back muscles through a submaximal voluntary isometric cocontraction performed in a neutral spine position (Figure 6A).
	Spinal dissociation (NF)	Neuromuscular patterning exercises intended to develop the ability to maintain a neutral spine through the appropriate recruitment of abdominal musculature while resisting forces created by movements of the appendicular skeleton during the performance of NF skilled movement tasks (Figure 6B).
	Spinal dissociation (F)	Neuromuscular patterning exercises intended to develop the ability to maintain a neutral spine through the appropriate recruitment of abdominal musculature during the performance of F skilled movement tasks (Figure 6C).
	Segmental movement control (NF)	Neuromuscular-patterning exercises intended to develop sequential segmental control of spinal movement through the appropriate recruitment of abdominal musculature during the performance of NF skilled movement tasks (Figure 6D).
	Whole-body coordination (F)	Neuromuscular-patterning exercises intended to develop coordinated movement sequencing between the axial and appendicular skeleton during the performance of F skilled movement tasks (Figure 6E).
Work capacity	Pillar conditioning (NF)	Conditioning exercises intended to develop the ability to maintain a neutral spine while enduring forces from movement through a specific plane of motion during the performance of NF movement tasks (Figure 7A and B).
	Pillar conditioning (F)	Conditioning exercises intended to develop the ability to maintain a neutral spine while enduring forces from movement during the performance of F movement tasks (Figure 7C through E).
	Segmental conditioning (NF)	Conditioning exercises intended to develop the ability of the spine to endure the production or absorption of forces during the performance of NF sequential segmental movement tasks through a specific plane of motion (Figure 8A and B).
	Segmental conditioning (F)	Conditioning exercises intended to develop the ability of the spine to endure the production, transference, or absorption of forces through the performance of F sequential segmental movement tasks (Figure 8C and D).
Strength	Pillar strength development (NF)	Strength exercises intended to develop the ability of the spine to maintain a neutral position during the performance of NF movement tasks while withstanding high-yielding forces through a specific plane of motion (Figure 9).
	Stiffness development (F)	Stiffness exercises intended to develop the ability of the spine to create an equal rate, magnitude, and directional resistance to segmental deformation against yielding forces to maintain a neutral spine or sport-specific F position (Figure 10).
	Power development (F)	Dynamic exercises intended to develop the ability of the spine to create a high-velocity sequential coordination of segments to augment global power production (Figure 11).

Abbreviations: F, functional; NF, nonfunctional.

new motor skill, the new task needs to be clearly detailed (eg, through instruction, demonstration).[68] In addition, the process must provide neuromuscular challenge through progressive difficulty[69] and variability,[70] underpinned by regular deliberate practice[71] with appropriate knowledge of results and performance related to the task.[72]

Work Capacity. *Work capacity* is synonymous with local muscular endurance.[73] This can be defined as the ability to produce or tolerate variable intensities and durations of work and contributes to the ability of an athlete to perform efficiently in a given sport.[73,74] Work capacity is a training outcome and not a performance outcome. The accumulation of training over many weeks and months results in chronic local adaptation to muscle, tendon, and metabolic biogenesis.[75–82] This adaptation increases the ability of the system to produce more work during repeated efforts, allows the local musculature to tolerate or demonstrate resilience to a larger training volume of work,[74] and supports the performance of work closer to the intensity and duration required for sporting performance.

By comparison, strength endurance has been described as a performance-outcome test completed in isolation whereby the goal is to achieve a specific amount of work at a given intensity, such as maximum number of repetitions at 50% of 1-repetition maximum or at a specific submaximal load,[83–85] with less emphasis placed on the physiologic adaptation required for WC development. The American College of Sports Medicine[73] has also defined *strength endurance* as high-intensity endurance. Therefore, strength endurance can be used as a proxy measure of WC or as a training variable within WC.[73]

The inability to meet mechanical-loading demands due to insufficient neuromuscular capacity may result in loss of optimal motor control and in biomechanical inefficiency.[86] Trunk WC is underpinned by the ability to transfer, absorb, or dissipate repeated or sustained submaximal forces through appropriate strength endurance, providing a platform for the development and performance of specific strength qualities.

A reduction in trunk muscle endurance and changes in endurance ratios have been identified in patients with a history

Figure 6. Examples of motor control exercises. A, Segmental stabilization (nonfunctional). B, Spinal dissociation (nonfunctional). C, Spinal dissociation (functional). D, Segmental movement control (nonfunctional). E, Whole-body coordination (functional).

of LBP,[87–89] and insufficient abdominal muscular endurance has been identified as a risk factor for injury recurrence.[90] Furthermore, structural degeneration of the lumbar musculature in patients with LBP has been characterized by fatty infiltration, muscular atrophy, and fiber-type modification.[91,92] Static stabilization (pillar) exercises are frequently prescribed to produce sufficient muscular activation to develop spinal-endurance qualities during rehabilitation.[16] Targeted exercise has been shown to improve muscular strength,[93] endurance,[94] and cross-sectional area.[95]

Strength. *Muscular strength* can be defined as the ability to produce force, and maximal strength is the largest force the musculature can produce.[96] The *RFD* has been defined as the rate of rise of contractile force at the beginning of a muscle action and is time dependent.[97] The RFD from the trunk musculature can either augment global external power production (dynamic RFD) or protect the spine by "stiffening" against yielding forces (static RFD). The production of force or torque and stiffness depends on morphologic and neurologic factors in the neuromuscular

Figure 7. Examples of work capacity exercises. A and B, Pillar conditioning (nonfunctional). C–E, Pillar conditioning (functional).

system. Morphologic factors include cross-sectional area, muscle-pennation angle, fascial length, and fiber type.[98] Neurologic factors include motor-unit recruitment, firing frequency, motor-unit synchronization, and intermuscular coordination.[99]

For dynamic RFD and power, a growing body of evidence[100,101] has shown that athletes who produce the greatest external power are the most successful in their events. Peak RFD has a strong relationship with peak power and has been used as a proxy measure of peak power.[96] Watkins et al[102] suggested that the trunk musculature assists in stabilizing and controlling the load response for maximum power during movements, such as the golf swing. During a single movement, *maximum power* is the greatest instantaneous power for producing maximum velocity of movements, such as striking, kicking, jumping, or throwing.[103] All of these tasks require segmental sequential coordination to augment external global power output.

Static RFD or *stiffness* can be defined as the trunk's ability to resist deformation from yielding forces and maintain spinal posture.[104,105] Muscular trunk stiffness requires contractile forces equal to the rate, direction, and magnitude exerted against the trunk to minimize the transmission of force to the spine. The morphologic and neurologic qualities required for appropriate stiffness are similar to those needed for power production.[99,106,107] The demand of the task can require the trunk to brace against a rapid RFD under relatively low loads, biasing challenge toward the neurologic system.[108] By contrast, a high imparted force also challenges the neurologic system but requires the morphologic qualities of the trunk musculature

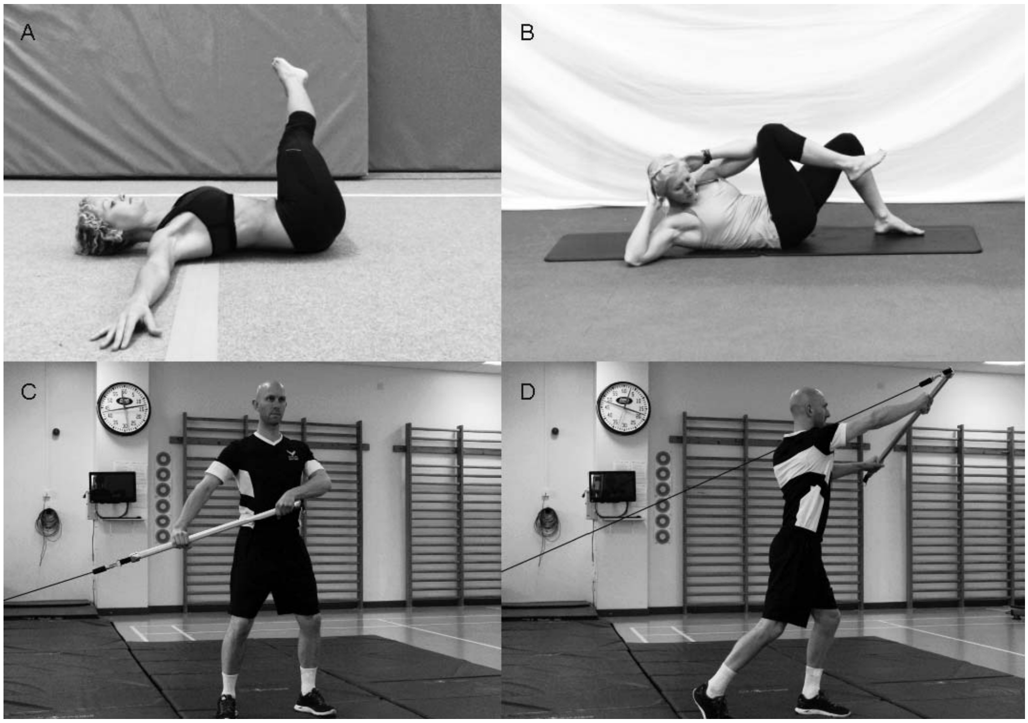

Figure 8. Examples of work capacity exercises. A and B, Segmental conditioning (nonfunctional). C and D, Segmental conditioning (functional).

to produce enough stiffness to protect the stability of the spine.[98,109]

The association between trunk strength and the presence of LBP remains unclear, with evidence to both support[110–113] and contest[114,115] the relationship. Despite the suggestion that trunk endurance provides greater prophylactic value,[116] strength and power are essential physical requirements for performance in many sports and represent the final stages of exercise progression for athletes during rehabilitation for LSI.[18] In addition, failing to redevelop sufficient trunk strength during the rehabilitation process may compromise the ability to maintain spinal integrity on return to sporting activity and increase the risk of injury recurrence.

Objective 2

Objective 2 is the classification of spinal exercises according to the objective of the exercise and intended physical outcomes. The classification of exercises was informed by empirical literature (eg, motor control, WC, and strength) and the application of research within clinical practice (eg, mobility development). Exercises were classified according to the objective of the exercise and the intended physical outcome. In addition, exercises were subclassified by functionality as *nonfunctional* or *functional* and by spinal displacement as *static* (maintenance of a neutral spinal posture with no appreciable segmental displacement) or *dynamic* (exercises involving appreciable dynamic segmental movement).

Subclassification 1: Functionality. Functional exercises have been described as a continuum of exercises that enable athletes to effectively manipulate their body weight in all planes of movement to achieve optimal athletic performance.[20] They are performed in weight-bearing (standing, single-legged standing, squatting, lunging) or sport-specific (multiple planes of motion involving multiple joints) positions. By contrast, nonfunctional exercises are typically performed in partial weight-bearing positions

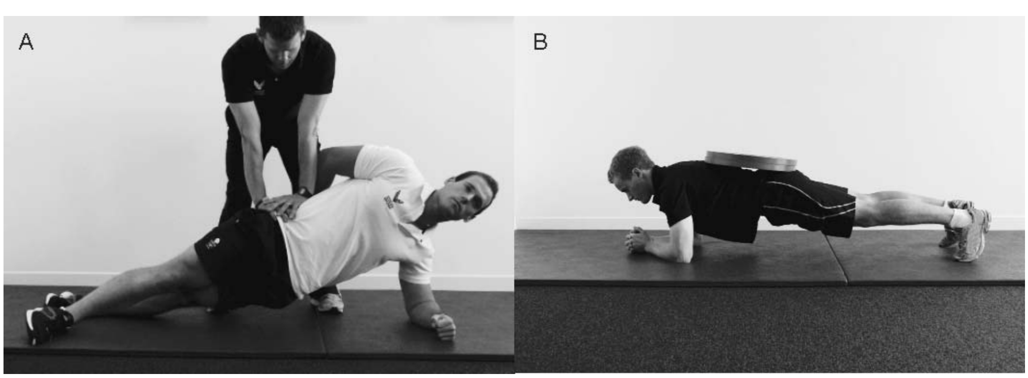

Figure 9. Example of strength exercises: A and B, pillar strength development (nonfunctional).

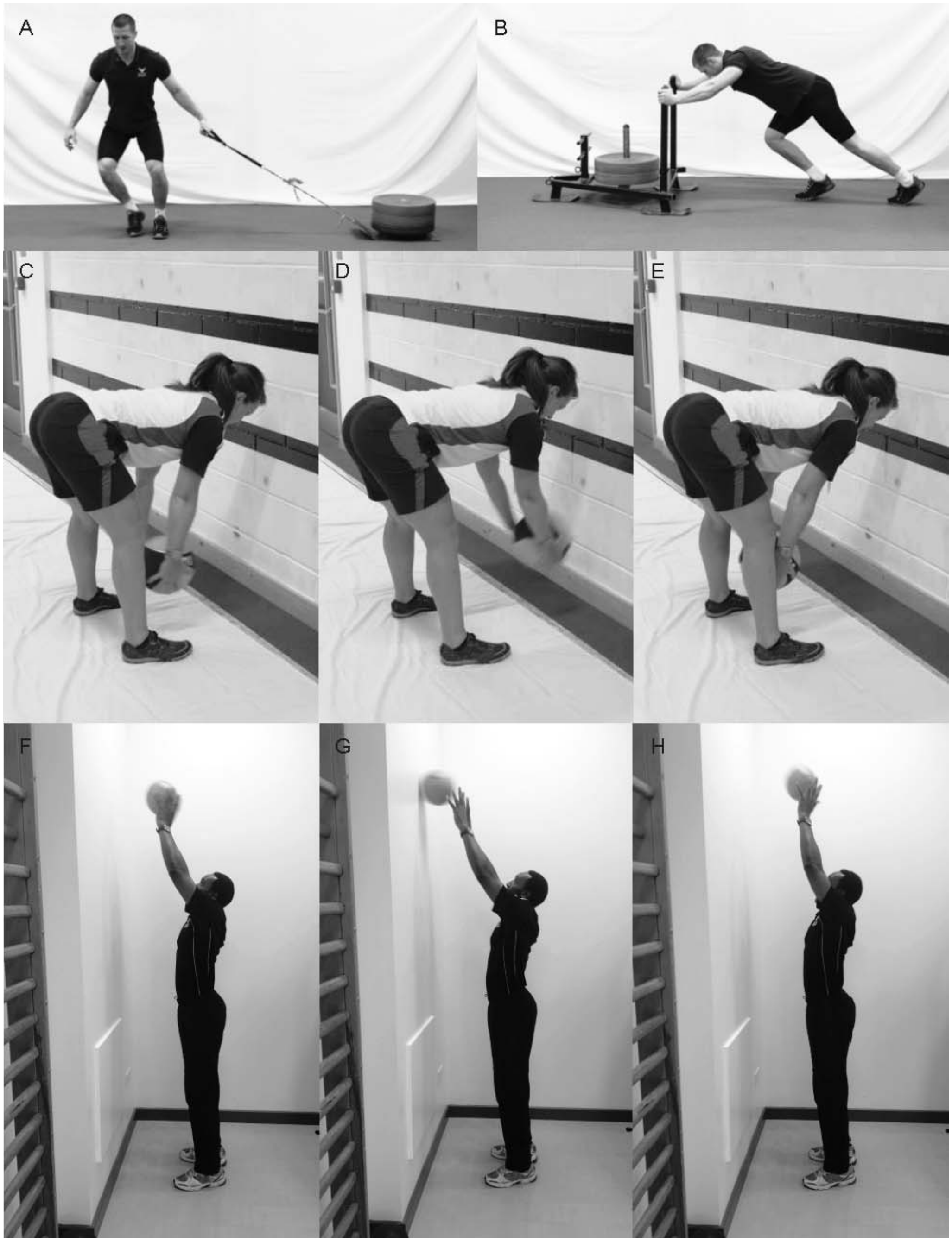

Figure 10. Example of strength exercises: Stiffness development (functional). Note that the exercise selection is biased toward, A and B, morphologic adaptation and, C–H, neurologic adaptation.

(sitting, kneeling, prone kneeling, lying) across a single plane of motion with movement isolated to fewer joints.[117] An advantage of nonfunctional spinal exercises is the ability to influence mechanical loading within specifically targeted muscle groups through the use of gravitational force, lever length (by manipulating body position), and superimposed load.[118] Both functional and nonfunctional spinal exercise prescriptions can be used to develop effective interaction (dynamic correspondence[119]) among physical abilities into sport-specific performance.

Subclassification 2: Spinal Displacement. During athletic activity, spinal function provides a static platform for force absorption and transference or a dynamic contribution to whole-body motion. The need for these abilities depends on the movement demands of the sport, which frequently require both components. During activities that involve high-loading characteristics, the central nervous system uses stiffening strategies by cocontracting the antagonist trunk muscles with little or no appreciable segmental displacement. In contrast, during tasks requiring appreciable dynamic segmental movement, the central nervous system controls this motion through the precision of timing and pattern of muscle activity.[12] The ability to dissociate spinal and appendicular motions and perform sequential segmental spinal movement represent 2 discrete skill-based movement competencies.

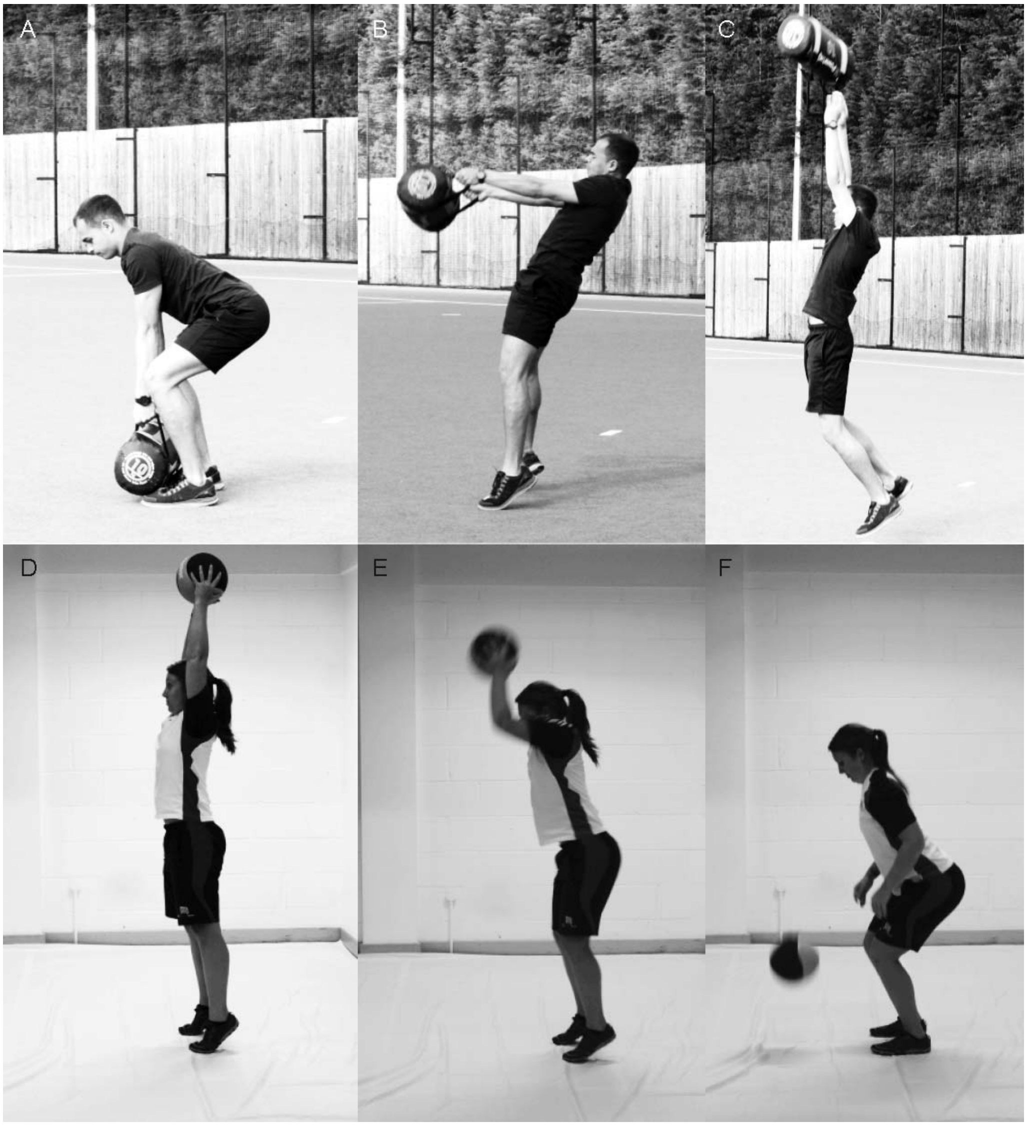

Figure 11. Example of strength exercises: A–F, power development (functional).

Spinal-Exercise Classification. The definitive spinal exercise classification (SEC) is summarized in Figure 4. Definitions of each exercise objective and examples of exercises related to each intended physical outcome are displayed in Table 2 and Figures 5 through 11. Exercises can be delineated further by plane of motion or globally targeted muscular contraction (eg, sagittal-plane movement, anterior-chain muscular activation).[118]

DISCUSSION

Confusion has existed about CS, how it is trained, and its application to functional performance.[10] In addition, the most effective exercises for the treatment of LBP remain largely unknown, and researchers have been unable to direct a specific exercise prescription to patients in a given pathologic subgroup. During recent years, investigators have highlighted the complex interactions among anatomical, neurophysiological, and psychosocial factors influencing spinal control. Not synthesizing contemporary evidence can lead to reductionist opinion and unidimensional paradigms of exercise prescription when, in reality, the spine functions across a vast spectrum of movement demands, demonstrating complex interactions among many different modifiable physical abilities.

We used qualitative consensus methods for systematically defining the classification system to ensure acceptability to elite sport practitioners. The 4 phases worked well to ensure challenges to identified themes and subthemes, with conclusions drawn from individuals experienced in sport at the elite level. The definitive SEC consolidates approaches to spinal exercise to develop a practical, conceptual representation of rehabilitation options applicable within a diverse spectrum of musculoskeletal practice. Furthermore, the classification supports multidisciplinary team integration within the rehabilitation process, demonstrating validity for use by strength and conditioning professionals as the athlete transitions toward performance-focused training after injury.

The intention of the SEC is to encourage detailed clinical reasoning, with practitioners identifying specific physical dysfunction or dysfunctions and considering exercise prescription within the context of a clinical diagnosis or the prevailing circumstances (eg, sport-specific performance targets). When determined, targeted exercise objectives define the nature of the exercise prescription required to deliver an intended physical outcome. For practitioners to effectively use the SEC, spinal abilities need to be identified using outcome measures with established measurement properties. Moreover, athletes frequently compensate for suboptimal abilities in various aspects of physical performance. When the process of athlete evaluation identifies multidimensional physical dysfunction, restoration of mobility and fundamental motor control must precede the development of WC and strength.

The SEC provides a platform for further research. Future studies are required to establish patterns of physical dysfunction within specific pathologic subgroups, evaluate the efficacy of exercise prescription in the development of specific physical performance abilities, and assess the effect of targeted exercise within sporting populations that have pathologic conditions. The ability to exhibit a wide breadth of physical abilities enhances performance and supports the capacity to adapt to the variable nature of stress during sporting activity, contributing to the foundation of injury prevention.[120]

The strengths of our study were the attempts to define a common language; integrate a breadth of literature; and comprehensively evolve and incorporate, rather than replace or discredit, existing theoretical frameworks extrapolated from a rapidly expanding knowledge base. The key limitation of our study was the predominantly national focus of the consensus process, although international experts were included at key stages.

CONCLUSIONS

Maintenance of spinal integrity during skilled athletic performance requires precise neuromuscular control to balance task demands for stability and motion. Economy of motion is a function of discrete, interdependent physical abilities. When investigating intrinsic contributions to spinal injury, reductionist approaches may not accurately identify the factors associated with causality and predisposition. Furthermore, comprehensive restoration of physical abilities during rehabilitation is fundamental in attaining optimal athletic performance and mitigating injury risk on return to sporting activity. Exercise specificity forms the basis of targeted adaptation, in which the intended physical outcome must dictate the nature of the exercise prescription. The SEC contextualizes spinal function and provides a basis for clinical reasoning and targeted exercise selection in the prevention and management of spinal injuries in sport.

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Appendix. Spinal Abilities Underpinning Optimal Function During Skilled Athletic Performance

Physical Ability	Spinal Ability	Definition
Mobility	Mobility	The ability to demonstrate freedom of spinal movement through appropriate tissue extensibility and articular mobility.
Motor control	Segmental stabilization (NF)	The ability to appropriately recruit deep and superficial abdominal musculature during the performance of an NF neuromuscular-patterning task/skilled movement performed in a neutral spine position.
	Spinal dissociation (NF)	The ability to maintain a neutral spine during the performance of an NF neuromuscular-patterning task/skilled movement through the appropriate recruitment of abdominal musculature.
	Spinal dissociation (F)	The ability to maintain a neutral spine during the performance of an F neuromuscular-patterning task/skilled movement through the appropriate recruitment of abdominal musculature.
	Segmental movement control (NF)	The ability to demonstrate sequential segmental control of spinal movement through the appropriate recruitment of abdominal musculature.
	Whole-body coordination (F)	The ability to demonstrate coordinated movement sequencing between the axial and appendicular skeleton during the performance of F skilled movement tasks.
Work capacity	Pillar work capacity (NF)	The ability to maintain a neutral spine while enduring movement forces through a specific plane of motion during the performance of NF movement tasks.
	Pillar work capacity (F)	The ability to maintain a neutral spine while enduring movement forces during the performance of F movement tasks.
	Segmental work capacity (NF)	The ability of the spine to endure the production or absorption of forces during the performance of NF sequential segmental movement tasks through a specific plane of motion.
	Segmental work capacity (F)	The ability of the spine to endure the production, transference, or absorption of forces during the performance of F sequential segmental movement tasks.
Strength	Pillar strength (NF)	The ability to maintain a neutral spine while withstanding high movement forces through a specific plane of motion during the performance of NF movement tasks.
	Static rate of force development (stiffness; F)	The ability to create an equal rate, magnitude, and directional resistance to segmental deformation against a yielding force while maintaining a neutral spine or sports-specific F position (stiffness).
	Dynamic rate of force development (power; F)	The ability to create a rapid sequential coordination of segments augmenting global power production (power) with the aim of producing maximal velocity for the given movement.

Abbreviations: F, functional; NF, nonfunctional.

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