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The Strength–Biomotor Nexus: Integrating Movement Velocity, Economy, Posture, Fatigue Tolerance and Recovery in Athletic Performance

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ABSTRACT

This conceptual review synthesises current evidence on the relationship between muscular strength and five performance-determining qualities: sport-specific movement velocity, movement economy, postural control, fatigue tolerance, and recovery rate. Drawing on force–velocity profiling research, strength-training intervention studies, and neuromuscular fatigue literature, the review argues that strength does not operate as an isolated fitness component but as a common physiological substrate that modulates the rate of force development, the mechanical efficiency of locomotion, the stability of the kinetic chain, the capacity to resist fatigue, and the speed of neuromuscular recovery between and within training sessions. Evidence indicates that greater relative strength is associated with superior sprinting, jumping, and change-of-direction performance; that strength training can improve running economy, particularly at higher running speeds and in athletes with high aerobic capacity; that trunk and lower-limb strength contribute to postural and core stability during dynamic sport actions; and that stronger, better-trained neuromuscular systems tend to tolerate high-intensity efforts with a more favourable fatigue and recovery profile. An integrated conceptual model is proposed in which strength functions as a central node connecting these otherwise distinct performance qualities. Practical implications for the periodisation of strength training within athletic development programmes are discussed, along with limitations of the existing evidence base and directions for future sport-specific, longitudinal research.

Keywords: Muscular Strength; Biomotor Abilities; Movement Velocity; Movement Economy; Postural Control; Neuromuscular Fatigue; Recovery; Athletic Performance

INTRODUCTION

Athletic performance is a multifactorial construct shaped by the interaction of several biomotor abilities, commonly classified as strength, speed, endurance, flexibility, and coordination. Among these, muscular strength has increasingly been described as the "foundational" or "ultimate" biomotor ability because of its pervasive influence on the expression of the others [1]. Strength, generally defined as the maximal force or torque produced by a muscle or muscle group, underlies not only maximal lifting tasks but also the rate at which force can be developed, the efficiency with which movement is produced, the stability of joints and segments during dynamic actions, and the capacity of the neuromuscular system to sustain repeated high-intensity efforts and recover between them [2].

A substantial body of research has examined the relationship between muscular strength and discrete performance outcomes such as sprinting, jumping, and change-of-direction speed [2]. However, comparatively less attention has been paid to synthesising how strength simultaneously relates to a broader cluster of performance-relevant qualities, namely sport-specific movement velocity and economy, postural control, fatigue tolerance, and recovery rate. These qualities are rarely trained or assessed in isolation in applied practice, yet the scientific literature addressing them has developed largely along separate lines: biomechanists have examined force–velocity profiles of sprinting and jumping exercise physiologists have examined the metabolic cost of locomotion and its response to strength training and neuromuscular physiologists have examined fatigue aetiology and recovery kinetics following different training modes [2-7].

The purpose of this review is to bring together evidence from these separate lines of enquiry in order to examine muscular strength as a common physiological determinant linking sport-specific movement velocity and economy, postural control, fatigue tolerance, and recovery rate. In doing so, the review proposes an integrated conceptual model that may be useful to coaches, sport scientists, and researchers seeking to understand why strength development is frequently prioritised within long-term athletic development frameworks, and to identify where the current evidence base remains incomplete [1].

Strength as a Foundational Biomotor Ability: Conceptual Framework

Within periodisation theory, biomotor abilities are frequently depicted as interacting components rather than independent capacities, with strength positioned as the quality from which speed, power, and muscular endurance are partly derived [1]. This conceptualisation is consistent with basic biomechanical principles: because force is a prerequisite for acceleration, and acceleration is a prerequisite for the attainment of velocity, an athlete's capacity to produce force underlies their capacity to produce and control movement velocity [8]. Strength therefore has a plausible mechanistic role not only in maximal-effort actions such as sprinting and jumping, but also in submaximal, repeated, and postural tasks that depend on the efficient and stable production of force over-time.

Suchomel reviewed the relationship between muscular strength and a wide range of athletic tasks, reporting that a large proportion of studies found moderate-to-large correlations between measures of maximal strength (for example, back squat or isometric mid-thigh pull performance) and jumping, sprinting, and change-of-direction outcomes [2]. Building on this, Suchomel argued that the practical value of strength lies less in its magnitude alone than in the neuromuscular qualities that accompany greater strength, including an enhanced rate of force development, improved potentiation responses, and a greater capacity to tolerate high training loads [9]. These training-consideration perspectives provide the conceptual bridge between maximal strength and the more dynamic, fatigue-related, and postural qualities considered later in this review.

Muscular Strength and Sport-Specific Movement Velocity

Movement velocity in sport is rarely a single, generic quality; it is expressed differently across acceleration, maximal sprinting speed, change-of-direction tasks, and vertical or horizontal jumping. The force–velocity (F–V) profiling approach developed by Samozino, Morin, and colleagues has provided a practical framework for characterising an individual athlete's mechanical capabilities along the force–velocity continuum during jumping and sprinting [2,3]. This approach describes each athlete's profile in terms of theoretical maximal force (F0), theoretical maximal velocity (V0), and maximal power (Pmax), and compares the athlete's actual profile against an individualised optimal profile for a given task.

Evidence from F–V profiling research indicates that many athletes exhibit an imbalance toward either force deficit or velocity deficit relative to their optimal profile, and that correcting this imbalance through individualised training often incorporating heavier-load strength work for force-deficient athletes can improve jump performance [4]. This suggests that the relationship between strength and movement velocity is not simply linear or universal, but depends on where an individual athlete sits on the force–velocity spectrum: for force-deficient athletes, increases in maximal strength are likely to transfer directly to improvements in velocity-dependent tasks, whereas for velocity-deficient athletes, additional strength training may yield smaller returns unless combined with higher-velocity training modes [3].

At a more general level, Suchomel reported that a majority of studies examining the relationship between maximal strength and sprint performance, and between maximal strength and change-of-direction performance, found moderate-to-large associations, although the magnitude of these relationships varied according to the strength test and performance measure used [2]. Collectively, this body of work supports the view that muscular strength is a necessary, though not solely sufficient, contributor to sport-specific movement velocity, and that its transfer to velocity-dependent tasks is best understood through the lens of an athlete's individual force–velocity characteristics rather than as a uniform dose–response relationship.

Muscular Strength and Movement Economy

Movement economy, most extensively studied in the context of running economy refers to the metabolic energy demand associated with sustaining a given submaximal speed or work rate, and is a key determinant of endurance performance independent of maximal aerobic capacity [6]. Because economical movement depends partly on the ability of the neuromuscular system to generate force with minimal energy cost per stride or cycle, strength training has been investigated as a means of improving movement economy through mechanisms such as improved musculotendinous stiffness, enhanced motor-unit recruitment efficiency, and reduced relative effort at a given absolute intensity [5].

A systematic review and meta-analysis by Balsalobre-Fernández found that strength training programmes produced small-to-moderate improvements in running economy among highly trained runners, with no consistent negative effect on maximal oxygen uptake [5]. Blagrove similarly concluded, in a systematic review of the physiological determinants of middle- and long-distance running performance, that strength training in its heavy-resistance, explosive, and plyometric forms tends to benefit running economy, time-trial performance, and maximal sprint speed, while leaving maximal oxygen uptake, blood lactate parameters, and body composition largely unaffected [6]. More recent, larger-scale meta-analytic work by Llanos-Lagos, Ramirez-Campillo, Moran, and Sáez de Villarreal refined this picture by showing that the effect of strength training on running economy is moderated by both training method and running speed: high-load strength training produced the clearest improvements in economy at higher running speeds and in athletes with higher maximal oxygen uptake, whereas plyometric training was more effective at lower running speeds, and submaximal-load or isometric strength training produced negligible effects [10]. A companion meta-analysis by the same research group further reported that combining two or more strength-training methods produced greater improvements in overall distance-running performance than any single method used alone [11].

These findings indicate that the strength–economy relationship is method- and context-dependent rather than uniform. Strength training appears capable of improving the mechanical and neuromuscular efficiency of locomotion, but the magnitude and even direction of this effect depends on the training method selected, the intensity domain in which economy is assessed, and the athlete's underlying aerobic capacity [10].

Muscular Strength and Postural Control

Postural and core stability refer to the capacity of the trunk, pelvis, and supporting musculature to maintain appropriate alignment, balance, and control during both static positions and dynamic sporting actions [12]. Because most sporting actions require force to be transmitted through the trunk between the lower and upper extremities, adequate strength and neuromuscular control of the postural musculature is considered a prerequisite for the efficient expression of strength and power at the extremities, as well as for maintaining balance during perturbation [13].

A scoping review by Zemková and Zapletalová found that postural stability was functionally related to performance in sports with high balance demands, including archery, biathlon, gymnastics, and shooting, and that core stability and strength were particularly relevant to performance in sports involving lifting tasks and trunk-rotational movements [12]. However, an earlier systematic review by Reed cautioned that, despite the popularity of core-stability training in athletic development programmes, direct evidence linking increases in core strength and stability to improved athletic performance measures was, at that time, relatively limited and inconsistent [13]. More recent systematic review evidence has offered a more differentiated picture: Bustos Carvajal and Arias Coronel found that core-muscle training produced improvements in trunk extensor strength, core muscular endurance, dynamic balance, and sprint speed among competitive athletes, but reported less consistent evidence for improvements in trunk flexor strength, jump height, and agility [14].

Taken together, this literature suggests that muscular strength contributes to postural control primarily through the trunk and hip musculature that stabilises the kinetic chain during force transmission, and that this contribution is more clearly established for balance-dependent and running-based outcomes than for jump height or agility, where the relationship with core strength appears weaker or less consistently demonstrated [13,14].

Muscular Strength and Fatigue Tolerance

Neuromuscular fatigue is defined as an exercise-induced reduction in the maximal voluntary force that a muscle or muscle group can generate, arising from a combination of central (neural) and peripheral (muscular) mechanisms [15]. The capacity to tolerate fatigue that is, to sustain force and movement quality across repeated efforts or prolonged competition is influenced by an athlete's underlying strength and neuromuscular training status, since stronger, better-trained neuromuscular systems tend to operate at a lower relative intensity for a given absolute task demand [9].

Thomas directly compared the fatigue and recovery responses of trained athletes following heavy-resistance, jumping, and sprint-training sessions matched for maximal effort, finding that all three modes produced significant reductions in neuromuscular function that required up to 72 hours to fully resolve, but that this fatigue was not primarily attributable to impairment of central nervous system function, implicating peripheral, muscular-level mechanisms as a major contributor [7]. This finding is relevant to fatigue-tolerance considerations because it suggests that the muscle's own contractile and metabolic characteristics which are themselves adaptable through strength training play a substantial role in determining how quickly performance capacity is restored after high-intensity efforts.

At the applied, team-sport level, Alba-Jiménez reviewed the tools used to monitor neuromuscular fatigue in training and competition, noting that countermovement jump and sprint-based tests are widely used because reductions in jump height or sprint speed provide a practical proxy for reduced force- and power-generating capacity [15, 16]. The authors highlighted that fatigue monitoring is essential for regulating training load and reducing injury risk, reinforcing the view that an athlete's baseline strength and rate of force development capabilities interact with the volume and intensity of competition and training to determine the fatigue profile observed across a micro- or meso-cycle.

Muscular Strength and Recovery Rate

Recovery rate refers to the time course over which neuromuscular performance capacity, and the physiological systems that underpin it, return to baseline following a fatiguing bout of exercise. The study by Thomas is again instructive here: heavy-resistance, jump, and sprint sessions matched for maximal effort each required up to 72 hours for neuromuscular function to fully recover, with the aetiology of this fatigue attributed predominantly to peripheral rather than central mechanisms [7]. This has direct implications for how strength and power sessions are sequenced relative to competition and other high-intensity training within a micro-cycle.

Alba-Jiménez et al. similarly noted that incomplete restoration of force-generating capacity between sessions can accumulate across a competitive schedule, particularly in team-sport contexts with congested fixtures, and that systematic monitoring of neuromuscular status is required to manage this risk [15]. From a strength-training perspective, Suchomel argued that athletes with a higher underlying strength capacity, and consequently a lower relative intensity for a given absolute training or competition demand, are likely to exhibit more favourable recovery kinetics than weaker athletes performing the same absolute task, although this proposition would benefit from further direct, sport-specific longitudinal testing [9]. Considered alongside the fatigue-tolerance evidence in Section 6, these findings support the inclusion of strength development as a component of long-term athlete management strategies aimed at improving both the tolerance of, and recovery from, repeated high-intensity efforts [1].

An Integrated Conceptual Model

The evidence reviewed above suggests that muscular strength should not be conceptualised merely as one biomotor ability among several, but as a physiological substrate that partly underlies the expression of the other four qualities examined in this review. Sport-specific movement velocity, through its influence on force–velocity characteristics and rate of force development [2,3].

- Movement economy, through neuromuscular and musculotendinous adaptations that reduce the relative energy cost of submaximal locomotion [5,10].
- Postural control, through trunk and hip strength that stabilises force transmission through the kinetic chain [12-14].
- Fatigue tolerance, through a lower relative intensity of effort and more favourable neuromuscular fatigue characteristics at a given absolute workload [7,9,15].
- Recovery rate, through peripheral muscular adaptations that may influence the speed of restoration of force-generating capacity following fatiguing exercise [7,15].

Importantly, this does not propose that strength is the sole determinant of any of these five qualities. Movement velocity also depends on technical, coordinative, and elastic factors; movement economy is shaped by anthropometry, biomechanics, and aerobic conditioning; postural control depends on proprioceptive and vestibular contributions in addition to strength; and fatigue tolerance and recovery rate are influenced by nutritional, sleep, and psychological factors that lie outside the scope of this review. Rather, the model proposes that strength represents a common, modifiable node that interacts with and partly constrains the ceiling of adaptation available in each of the other four domains, which is consistent with its description in the periodisation literature as foundational biomotor ability [1].

Practical Implications for Training and Periodisation

Several practical implications follow from the conceptual model outlined above. First, the individualisation of strength training appears important: force–velocity profiling suggests that athletes should be assessed to determine whether they present a force deficit, a velocity deficit, or a well-balanced profile before prescribing heavy-load strength work, ballistic or plyometric training, or a combination of both [3,4]. Second, when the goal is to improve movement economy in endurance athletes, the evidence favours higher-load strength training and/or plyometric methods over submaximal-load or isometric approaches, with the specific method selected informed by the athlete's competitive speed and aerobic capacity [10]. Third, trunk and hip strength and stability work appears warranted as a component of athletic development, particularly for sports with high postural or balance demands, while coaches should be cautious about assuming automatic transfer of core-training gains to jump height or agility outcomes, where the evidence remains less consistent [13,14]. Fourth, the finding that heavy-resistance, jump, and sprint sessions each require up to 72 hours for full neuromuscular recovery has direct implications for the sequencing and spacing of high-intensity strength, power, and speed sessions within a training micro-cycle, particularly in proximity to competition [7]. Finally, systematic monitoring of neuromuscular fatigue status using tools such as countermovement jump or sprint performance can help practitioners individualise training load and identify athletes who may benefit from additional strength development to improve their fatigue-tolerance and recovery profile [15].

LIMITATIONS

Several limitations of the reviewed literature warrant acknowledgement. Much of the force–velocity profiling and strength–sprint–jump correlational literature is cross-sectional or short-term in design, limiting causal inference regarding the direction and durability of strength-related adaptations [2]. The running-economy literature, while increasingly supported by high-quality systematic reviews and meta-analyses, continues to show heterogeneity in training protocols, athlete training status, and the running speeds at which economy is assessed, which complicates direct comparison across studies [10]. The core-stability and postural-control literature remains particularly mixed, with some outcomes (for example, sprint speed and dynamic balance) showing clearer benefits from core training than others (for example, jump height and agility) [14]. Finally, much of the neuromuscular fatigue and recovery literature has been generated using generic resistance, jump, or sprint protocols rather than sport-specific competitive tasks, and predominantly in male samples, limiting the generalisability of recovery-time estimates such as the 72-hour window reported by Thomas to other populations, sexes, and sporting contexts [7].

Directions for Future Research

- Longitudinal, sport-specific studies that track changes in strength alongside sport-specific movement velocity, movement economy, postural control, fatigue tolerance, and recovery rate within the same cohort of athletes, to test the integrated model proposed in Section 8 directly.
- Further investigation of how force–velocity profile status moderates the transfer of strength training to sport-specific velocity outcomes across a wider range of sports and playing positions.
- Expanded meta-analytic work on the strength–postural control relationship, particularly regarding jump height and agility outcomes, where current evidence is least consistent.
- Sport-specific and female-inclusive investigations of neuromuscular fatigue aetiology and recovery time course, extending beyond the generic resistance, jump, and sprint protocols that dominate the current literature.
- Research examining whether athletes with higher baseline relative strength demonstrate measurably faster recovery kinetics than weaker athletes performing matched absolute training or competition loads.

CONCLUSION

This review synthesised evidence indicating that muscular strength is meaningfully associated with sport-specific movement velocity, movement economy, postural control, fatigue tolerance, and recovery rate, and proposed an integrated conceptual model in which strength functions as a common, modifiable determinant underlying these otherwise distinct performance qualities. While the strength of the relationship varies across domains being most consistently demonstrated for sprint, jump, and change-of-direction velocity, and least consistently demonstrated for certain postural-control outcomes such as jump height and agility, the overall pattern of evidence supports the long-standing view within periodisation theory that strength constitutes a foundational biomotor ability. For coaches and sport scientists, this suggests that well-individualised, appropriately periodised strength training is likely to yield benefits that extend beyond maximal-force capacity alone, contributing to more efficient, stable, fatigue-resistant, and rapidly recovering athletic performance.

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CONFLICT OF INTEREST

The author(s) declare no conflict of interest.

DATA AVAILABILITY

No new data were generated for this conceptual review; all sources are cited in the reference list.

AUTHORS DECLARATION

The authors declare no conflicts of interest. All participants provided informed verbal consent prior to participation. Correspondence concerning this article should be addressed to Dr. Sandip Sinha, School of Physical Education & Sports Science, Arunachal University of Studies, Namsai, Arunachal Pradesh-792103 (India). Email:sandip.s@arunachaluniversity.ac.in

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