Vertical force production in soccer: mechanical aspects and applied training strategies

Abstract

Vertical force production (VFP) is widely recognized as a critical determinant of performance in a series of soccer-specific activities, such as sprinting, jumping, and changing direction. Therefore, practitioners are constantly seeking better and more effective strategies to improve VFP in professional soccer players. This article analyzes the mechanical aspects associated with the actual role played by VFP in elite soccer, and also examines and highlights the training considerations related to its appropriate and effective development during modern soccer seasons.

Introduction

In elite soccer, the capability to generate force in the vertical direction has been associated with successful performance in numerous match tasks, such as vertical jumps, maximum sprints, and change-of-direction (COD) maneuvers (45, 71, 87). Superior performance in explosive tasks such as vertical jumps and sprints is achieved by applying great amounts of force into the ground, in order to quickly accelerate the body and achieve higher velocities in the initial phases of the movement (51, 52). The VFP is especially important when it is considered that these actions typically occur during decisive game situations (e.g., a short sprint when scoring a goal) (27, 28, 76). Wisloff et al. (87) indicated that professional soccer players with superior levels of strength in the half squat exercise could sprint faster (in 10 and 30 m sprints and in the 10 m shuttle run test) and jump higher than their weaker counterparts. Accordingly, several investigations have shown that, independently of the training sequence or methodological approach used during the interventions, increases in VFP are normally accompanied by significant increases in the physical performance of soccer players (7, 14, 47, 54, 55). As a result, practitioners are constantly seeking more accurate and applied information regarding the actual role played by VFP in elite soccer, as well as the most effective strategies to enhance this ability throughout the competitive season. One logical way to better understand how player performance can be affected by higher or lower levels of VFP is by examining in detail its possible associations with some soccer-specific motor-skills, such as jump and speed-qualities. In this context, this article discusses the importance of VFP in soccer and presents some considerations about the effects of different training elements (e.g., exercise type and loading intensity) on the physical performance of elite soccer players.

Literature Search

Coaches are encouraged to take an evidence-based approach in choosing the most appropriate training interventions and part of this involves an analysis of experimental studies that have investigated the development of VFP and its effect on the physical performance of soccer players. To facilitate this, a PubMed search was carried out using the following keywords: “soccer” or “football” or “team-sports” or "team sports" and "strength training" or "power training" or "resistance training" or "jump training" or "explosive training" or "optimum power load" or "optimal power load" and “vertical force” or “vertical force production” or “vertical force performance” or "vertical jump" or "squat jump" or "countermovement jump" or “sprint” or “sprinting” or "sprinting speed" or "sprint velocity" or "velocity" or "sprint time" or "change of direction" or "change-of-direction" or “COD” or "COD time" or "COD velocity" or "COD speed" or "jump squat" or "half-squat" or "half squat", published until 2018. This search resulted in

22 studies, which are discussed throughout the article and which allowed an analysis to determine the potential of different training strategies to increase vertical jumping ability, linear speed, and COD speed in elite soccer players (**Table 1**).

The close relationship between VFP and vertical jump performance

Throughout official soccer matches, vertical jumps are generally executed during vigorous offensive or defensive maneuvers, to score or prevent goals (27, 60). Although the number of jumps during a match may be relatively low (~ 10 jumps) (60), this action accounts for 22% and 11% of goal situations for scoring and assisting players; respectively (27), confirming its importance to soccer performance. Despite the multifaceted nature (64) of jumping tasks, there is little doubt that VFP plays a key role in vertical jump performance. Indeed, a previous study (42) showed that the ability to produce higher peak and instantaneous forces (i.e., forces at 50, 90, and 250 ms) during an isometric mid-thigh clean pull is closely related to vertical jump height and to smaller differences between "weighted (with a 20 kg barbell) and unweighted (without overload) jump heights" in collegiate athletes (including soccer players). In the same way, Requena et al. (71) reported significant correlations between half squat one-repetition maximum (1RM) measures and unloaded squat and countermovement jumps in soccer players from the Estonian Soccer First Division. Accordingly, Loturco et al. (53) observed that two different vertically-oriented 6-week training schemes comprised of squats and loaded jump squats (i.e., traditional periodization regime) or solely loaded jump squats (i.e., optimum training load regime) were equally effective in simultaneously increasing the maximum squat strength and countermovement jump height of professional soccer players. From these data, it is possible to deduce that soccer players able to apply greater amounts of force in and through vertically-directed exercises (43, 51, 89) (e.g., squat variations and loaded vertical jumps) are potentially able to perform better in different vertical jump tests, under loaded or unloaded conditions. For some authors, these strong relationships may be explained by the mechanical similarities and resemblances in movement patterns between squat-based movements and vertical jumps (42, 71, 72). Interestingly, these close correlations and positive effects of VFP on player performance have also been observed for other relevant soccer-specific physical capacities such as maximum sprinting speed (43, 45, 70, 87).

Sprinting speed and VFP

In a classic study regarding sprinting mechanics, Weyand et al. (85) stated that runners reach faster speeds, not by repositioning their legs more rapidly in the air, but by applying greater vertical support forces against the ground. These authors concluded that, at any speed, applying greater forces in "opposition to gravity" will increase the vertical velocity at takeoff, reducing the foot ground contact times, and subsequently increasing the flight time and step length (85). Similarly, Nilsson and Thorstensson (65) reported that the transition from lower to higher velocities results in shorter support phases, with concomitant and progressive increases in vertical peak forces. As a consequence, it could be expected that improvements in VFP of soccer players will promote corresponding improvements in their ability to sprint over longer distances (e.g., ≥ 20 m). In fact, it has already been shown that a vertically-oriented plyometric training program able to increase vertical jump height and peak force is equally able to increase both 20 m speed and 10-20 m acceleration in high-level U-20 soccer players (52). However, these data should be interpreted with some caution, as: 1) in elite soccer, the majority of high-intensity running actions are performed over distances shorter than 10 m (3, 9, 22); and (2) there is a growing body of literature indicating that the ability to orient the resultant force vector horizontally while accelerating is a key determinant of sprint performance (12, 57, 58). Nonetheless, a recent study by Colyer et al. (16) examined some aspects of ground reaction force waveforms collected in maximal-effort sprints, establishing the specific mechanisms which allowed sprinters to continue accelerating beyond the soccer players' velocity plateau. According to previous results (57, 58), the "faster individuals" (i.e., sprinters; compared to soccer players) displayed a more horizontally-oriented force vector during the late braking phase, early propulsive phase, and the latter portions of the propulsive phase. Importantly, the authors also observed that, as athletes approached their velocity plateau and the ground reaction force vector becomes more vertical, the vertical component of force gradually acted as a critical performance indicator of maximum velocity (57, 58). Thus, the limits in the maximum velocities reached by soccer players might be related to (among other things) their "lower capacity" to generate the vertical impulse required to produce adequate (i.e., longer) flight times across the entire acceleration phase (15, 16). Together, these findings may have important implications for practice and research. Although elite soccer players predominantly sprint over short distances and rarely run close to their top-speeds (3, 9), improvements in maximum running velocity (through the appropriate development of VFP) could considerably increase their "speed reserve" (84), reducing the relative chronic workload (59) and, hence, the associated risk of injury. In addition, these positive effects seem to also be translated to more complex and mixed physical qualities, such as the COD ability (66, 79).

VFP: possible influences on COD performance

COD ability, defined as the set of skills necessary to change movement direction or velocity (66), is considered a key determinant action in modern soccer (5, 27). Even though during games COD mainly occurs in response to an external stimulus (e.g., ball movements, opponents and team-mates actions, changing game situations, etc.) (8, 36-38, 88), planned COD maneuvers provide the physiological and mechanical basis that underpin the ability to perform successive accelerations and decelerations in different directions and movement planes (66). Therefore, understanding and, subsequently, developing the physical qualities more associated with superior COD performances are of utmost importance for practitioners. Sheppard and Young (79) suggested that technique, straight speed, anthropometric characteristics, and leg muscle qualities (e.g., reactive and concentric strength) are sub-components of COD speed. Hence, it can be argued that the athlete's strength level and, consequently, VFP may have a possible influence on COD performance. Despite correlational research indicating a limited association between conventional maximum dynamic strength measurements (i.e., squat 1RM test) and COD ability (11), different longitudinal studies using vertically-oriented exercises (e.g., squat-based movements) have shown that enhancements in the VFP of soccer players may also result in positive adaptations in their COD performance (6, 21, 40, 80). Illustrating this idea, a study by Keiner et al. (40) concluded that an 8-week in-season periodized strength training program, incorporating the front and back squat exercises, resulted in increases in both maximum dynamic strength and COD speed in young soccer players, which was not observed in the control group that executed regular soccer training alone. Nevertheless, COD ability is a multifaceted phenomenon and, as such, factors other than strength could explain the increases in COD speed in soccer players (36-38, 49, 80). Irrespective of this, it is undeniable that for an athlete to effectively change direction, vertical and horizontal ground reaction forces of high magnitude must be applied to rapidly decelerate and re-accelerate the body (17, 24, 35, 77). This importance will depend on the mechanical characteristics of each specific COD maneuver. For example, in less aggressive directional changes (i.e., with angles ≤ 45º), deceleration is limited, and velocity maintenance is key (23, 35). In these situations, VFP seems to be a critical determinant of successful performances (77). In contrast, when sharper COD actions (e.g., 90º or 180º cuts) are executed, greater braking forces and more intense decelerations and re-accelerations are required (23, 31, 35). In this case, VFP may have a less prominent impact, especially when compared with the role played by the horizontally-oriented (braking and propulsive) forces (23, 24, 35). One final aspect to consider is that, for a given athlete, during every COD maneuver, a higher approach velocity will necessarily result in a greater sprint momentum (i.e., the product of body mass and running velocity) (2). Thus, increased loading on the knee joints (23, 61) and a resultant adjustment in body position during the directional change can be expected in faster and more powerful players. In this regard, lowering the center of mass (CoM) has been identified as a strategy related to superior COD techniques (66), which, from a mechanical standpoint, appears to be beneficial. A lower CoM may help an athlete with a greater momentum overcome the higher inertia naturally associated with the movement. Notably, if the propulsive phase of a COD maneuver starts from a more flexed position, the VFP is crucial to return the body to a more upright and sprint available posture. Finally, given that for COD maneuvers with similar movement patterns (e.g., more flexed angles) greater vertical ground reaction forces are related to faster completion times (77), practitioners might consider training strategies focused on enhancing the VFP of soccer players to also elicit positive adaptations in COD kinetic and kinematic variables.

Using different training loads to improve VFP

The load used to develop VFP appears to play a key role in determining the direction and magnitude of the neuromuscular adaptations provided by a given resistance training program. In this regard, an 8-week study by McBride et al. (56) compared the effects of light- versus heavy-load jump squats (30 and 80% of half squat 1RM, respectively) on the development of strength, power, and speed capabilities of male athletic subjects, revealing contrasting responses between the two training schemes. For example, although both loads were equally effective at improving maximum squat strength, the "heavy-load group" presented significant decreases in short sprint performance (i.e., 5 m) (56), which in elite soccer can be considered a very problematic issue. Wilson et al. (86) observed that a substantial increase of 21% in squat strength (achieved after an 8-week squat training program comprising 4-6 sets of 6-10 "maximal effort repetitions") is necessary to produce a slight improvement of 2.2% in speed ability in exercise science students. Accordingly, in a recent review of the effects of strength training on highly trained soccer players, Silva et al. (80) reported that on average, these athletes need to increase their 1RM squat by 23.5% to achieve improvement of around 2% in sprint performance, from 10 to 40 m. Of note, the vast majority of studies analyzed in this specific section of the review used a range of loads ≥ 80% 1RM for the squat-based exercises during the whole (or for the most part of the) intervention period. Thus, it is highly probable that the "reduced levels" of transference from VFP to maximum sprint running are not only related to the vertical force orientation *per se*, but also, to the heavy range of loads typically used to develop this capacity. Nonetheless, this is a very conflicting theory, as previous research indicated that the intention to move a given resistance quickly is more relevant than the actual movement velocity to promote specific velocity adaptations in the neuromuscular system (4, 39). Even so, there is a compelling body of evidence suggesting that light to moderate loading ranges (i.e., 30% to 60% 1RM) and the "optimum power loads" (which typically occur between ~ 45 and 65% 1RM and can be easily determined by the barbell velocity) (30, 48, 53, 54, 62) may be more appropriate than heavier loads (i.e., ≥ 80% 1RM) to increase VFP and promote the transference of the VFP to sprinting ability in soccer players (25, 30, 50, 51, 69). Importantly, these improvements seem to occur at both ends of the force-velocity curve (i.e., low-load/high-velocity portion and high-load/low-velocity portion), without compromising (and even enhancing) the speed-related qualities of these athletes (53). Indeed, several studies have already reported meaningful increases in linear sprint speed and COD speed of elite soccer players after training interventions performed under light and optimum loading conditions (13, 20, 44, 46, 47, 50, 54, 67, 68, 73). In contrast, investigations using heavy loads have systematically failed to demonstrate substantial improvements in the speed and power performance of soccer players (10, 32-34, 41, 74, 75, 81, 83) (**Table 1**). It is essential to note that the positive responses to light and moderate loads are only obtained when soccer players are continuously required to execute the resistance training repetitions as fast as possible, thereby producing the highest level of force for each relative load (30, 53). Furthermore, light or moderate load training is generally better tolerated by professional soccer players than heavy load training, as the latter can generate a high level of fatigue, possibly impairing performance in the subsequent (and usually numerous) soccer-specific training sessions (e.g., technical and tactical training) and increasing the associated risk of injury (1, 25, 29, 30, 69). That said, from a practical point of view, practitioners are strongly encouraged to regularly implement strength-power training routines using light to moderate loads during both pre-season and in-season competitive periods, to safely and effectively develop VFP in elite soccer players. The proven efficacy and good tolerability of these loading ranges allows players to perform the resistance training sessions in a more frequent and regular manner than when using traditional heavy loads, which appears to be a key factor in determining the magnitude of VFP increases across different team-sports, and especially in professional soccer (78, 80).

*****INSERT TABLE 1 HERE*****

Developing VFP through ballistic or traditional resistance exercises

Another critical point to consider when developing VFP in elite soccer players is the appropriate selection of the training exercises (43-45). Resistance exercises may be divided into two distinct classes: ballistic and traditional (i.e., "non-ballistic") movements (**Figure 1**). Briefly, the most important difference between them is that the ballistic movements prevent any deceleration phase throughout the complete range of motion, whereas traditional exercises necessarily present a considerable period of deceleration during their execution (18). For many researchers, these mechanical characteristics are decisive in determining the level of transference from strength and power improvements to sport-specific performance, making the ballistic exercises potentially more useful and advantageous for preparing elite athletes from numerous sports (18, 19, 64). However, a previous study revealed that both exercise modes are efficient and may have different effects on the physical performance of professional soccer players (51). While the ballistic jump squat appears to be more effective at reducing acceleration decreases over very-short distances (which typically occur throughout a soccer preseason), the traditional half squat seems to be superior for increasing vertical jump performance (51). However, other investigations executed with senior and youth soccer players who exclusively performed jump squats or back squats, also reported significant improvements in multiple and complementary performance measures, such as maximum dynamic and isometric strength, jump and sprint abilities, and aerobic and anaerobic parameters related to fatigue

(7, 14, 46, 50, 55). Therefore, at least from this "mechanical perspective" (i.e., ballistic or non-ballistic), it is not possible to select, or even indicate, which exercise mode is more appropriate for enhancing VFP in elite soccer players. Considering the established effectiveness and popularity of both training strategies (18, 63), coaches are recommended to use the two exercise techniques in a varied and context-specific manner, which might follow, for example, some principles of training periodization or be adapted to the players' training background. In this sense, the non-ballistic squat movements (with moderate to heavy loads or optimum power loads) could be used during the earlier phases of the athletes' preparation (e.g., soccer pre-seasons) and be gradually replaced with their ballistic variations (using light to moderate loads or optimum power loads) throughout the competitive season (**Table 2**) (54). Likewise, soccer players with limited experience in resistance training may initiate the development of their VFP by using half or parallel squats during the strength foundation phase and, as their ability to execute these traditional (and easier) movements improves, they can progressively perform the explosive (ballistic) jump squats with light to moderate loads (53) (**Table 3**). As mentioned above, both exercise techniques have been widely suggested as potential strategies to elicit meaningful improvements in the VFP of soccer players and can be straightforwardly and safely applied to soccer training routines (18, 51, 63).

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Practical Applications

VFP is a critical component of physical and technical performance in soccer. Therefore, it is recommended that elite soccer players regularly perform ballistic and non-ballistic "vertically-directed exercises" in their training practices (43, 51, 89). The exercise selection (e.g., traditional half squat or loaded jump squat) should be based on different factors, such as players' training background or traditional periodization principles. Due to confounding factors, including the congested fixture schedules, the inherent risks, and the (potential) problematic by-products of using heavy loads (e.g., excessive fatigue and negative effects on speed-related abilities) in professional soccer, it is suggested practitioners prioritize the use of light and moderate loading intensities in their training programs. According to the current body of literature, soccer players with superior levels of VFP should also be able to jump higher, achieve greater COD speeds, and better tolerate the chronic match and training workload by increasing their speed reserve.

Summary and Conclusions

This article provides evidence that VFP is a very important capability for soccer players, as it is directly associated with successful performance in a diverse range of specific-soccer actions (e.g., jumping, sprinting, and COD tasks) which, in their vast majority, occur during decisive match situations (27, 28, 82). Factors such as exercise type (e.g., traditional or ballistic) and loading intensity (e.g., light or heavy loads) seem to be determinants for the development of optimal and suitable training strategies, which must be adapted to the real needs (e.g., match demands) (5, 27) and conditions (e.g., congested fixture schedules) (26) of modern soccer players. Similarly, the development of VFP must never be seen in isolation and ultimately the capacity to apply force in the context of the game must also be stressed, as this is the ultimate goal of the training program. Consequently, VFP development should be seen as part of a wider development program where technical aspects of performance, together with contextual application, are also stressed. Soccer coaches and sport scientists should be aware of this and take it into account when designing resistance training programs for professional soccer players. Future articles should also analyze the role played by VFP in injury prevention and in complementary physical fitness qualities (e.g., repeated-sprint ability) as well as examining the relationships between vertical and horizontal force production and their implications for improving speed and jump qualities.

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FIGURE CAPTION

Figure 1. Specific variations of vertically oriented exercises that can be easily performed by soccer players: (1) half squat, (2) dumbbell squat, and (3) hexagonal barbell squat, in both “traditional” (non-ballistic) and ballistic conditions. (A) initial position, (B) final phase of the traditional mode, and (C) final phase of the ballistic mode.