

EFFECTS OF STRENGTH TRAINING ON SQUAT AND SPRINT PERFORMANCE IN SOCCER PLAYERS

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ABSTRACT

Styles, WJ, Matthews, MJ, and Comfort, P. Effects of strength training on squat and sprint performance in soccer players. *J Strength Cond Res* 30(6): 1534–1539, 2016—Researchers have demonstrated that increases in strength result in increases in athletic performance, although the development of strength is still neglected in some sports. Our aim was to determine whether a simple in-season strength training program would result in increases in maximal squat strength and short sprint performance, in professional soccer players. Professional soccer players ($n = 17$, age = 18.3 ± 1.2 years, height = 1.79 ± 0.06 m, body mass [BM] = 75.5 ± 6.1 kg) completed 1 repetition maximum (1RM) back squat and sprint tests (5, 10, and 20 m) before and after a 6-week ($\times 2$ week) in-season strength training (85–90% 1RM) intervention. Strength training resulted in significant improvements in absolute and relative strength (before = 125.4 ± 13.8 kg, after = 149.3 ± 16.2 kg, $p \leq 0.001$, Cohen's $d = 0.62$; 1RM/BM before: 1.66 ± 0.24 kg·kg⁻¹, after = 1.96 ± 0.29 kg·kg⁻¹, $p \leq 0.001$, Cohen's $d = 0.45$; respectively). Similarly, there were small yet significant improvements in sprint performance over 5 m (before = 1.11 ± 0.04 seconds, after = 1.05 ± 0.05 seconds, $p \leq 0.001$, Cohen's $d = 0.55$), 10 m (before = 1.83 ± 0.05 seconds, after = 1.78 ± 0.05 seconds, $p \leq 0.001$, Cohen's $d = 0.45$), and 20 m (before = 3.09 ± 0.07 seconds, after = 3.05 ± 0.05 seconds, $p \leq 0.001$, Cohen's $d = 0.31$). Changes in maximal squat strength seem to be reflected in improvements in short sprint performance highlighting the importance of developing maximal strength to improve short sprint performance. Moreover, this demonstrates that these improvements can be achieved during the competitive season in professional soccer players.

KEY WORDS sprint times, back squat, acceleration, in-season training, correlation

INTRODUCTION

Although the total distance covered in an elite soccer match can total as much as 8–12 km (5,15), it is the short high-intensity sprints that represent the crucial game-changing moments. These sprints typically last from 2–4 seconds over distances of 10–30 m, with players performing 17–81 sprints per game, accounting for up to 11% of the total distance covered during a match (5,15,27,31). Moreover, sprinting ability (both acceleration and maximum sprint speed) is able to distinguish soccer players from different standards of play, in both adult (27) and youth soccer (9).

Strong correlations have been reported between short sprint performance and lower body strength, assessed using free weight back squats (7,10,18,21,25,35). Wisloff et al. (35) reported a very strong relationship ($r = -0.94$) between absolute back squat strength and sprint performance in soccer players, whereas McBride et al. (21), Meir et al. (25), and Comfort et al. (7) reported good relationships between short sprint performance and relative strength (1 repetition maximum [1RM]/body mass [BM]). Authors of a recent meta-analysis concluded that improvements in lower body strength transfer to improvements in sprint performance (<30 m) (30). This is likely due to stronger athletes developing higher peak ground reaction force and impulse, which have been shown to be strong determinants of sprint performance (11,32,33). Good associations are also reported between maximum ground reaction force and maximal sprinting velocity ($r = 0.60$) (32), suggesting that increasing strength, or maximal force production, may also improve acceleration and maximal sprinting velocity.

During sprinting, contact times of ≥ 200 milliseconds (222 ± 18 milliseconds) have been observed during the initial acceleration phase, reducing to <200 milliseconds (169 ± 7.9 milliseconds) during the maximal velocity phase (12), illustrating that high rates of force development (RFD) are essential for effective acceleration during sprinting. Importantly, maximal strength is reported to be the most important factor in maximizing power output when ground contact time or movement duration is >200 milliseconds (11,32,33). When increasing maximal strength, an athlete's BM will normally show minimal change; therefore, if a higher force is applied to a similar mass, acceleration increases. In

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addition, higher strength levels are associated with higher RFD (3,22,23,37). This is likely to be the case for team sport specific sprint distances of ≤ 20 m; however, the relationship between maximum strength and sprint performances is likely to diminish as the distance increases. As the sprint distance increases, it has been proposed that performance is affected more by the stretch-shorten cycle (SSC) and that the relationship between maximal strength and sprint performance is less apparent (4).

Despite these factors, there is limited research documenting whether changes in strength are associated with changes in sprint performance (6,8,29). Chelly et al. (6) observed an improvement in back squat strength, jump, and sprint performance in junior soccer players after a 2-month back-squat training protocol. Similarly, a study by Ronnestad et al. (29) reported significant improvements ($p \leq 0.05$) in half squat strength (before = 173 ± 4 kg, after = 215 ± 4 kg), 10 m (before = 1.78 ± 0.02 seconds, after = 1.75 ± 0.01 seconds), and 40 m (before = 5.43 ± 0.05 seconds, after = 5.37 ± 0.05 seconds) sprint performances, after 7 weeks of combined strength and plyometric training. More recently, Comfort et al. (8) investigated whether changes in maximal squat strength were reflected in changes in sprint performance. Preseason training resulted in 17.7% improvement in maximal squat strength from before training (170.6 ± 21.4 kg) to after training (200.8 ± 19.0 kg), and decreases in sprint times over 5 m (7.6%), 10 m (7.3%), and 20 m (5.9%).

With numerous studies reporting that stronger athletes perform better during short sprint performances (4,7,10,11,18,21,25,35,37), it may be that increasing lower body strength, through a simple training intervention, is likely to result in improved performance during short sprints and may therefore enhance soccer performance (5), as recently concluded in a meta-analysis (30). To date, although studies have reported associations between squat strength and short sprint performance in soccer (10,35), only 1 study has reported that preseason strength training improved short sprint performance (29). The aim of the investigation, therefore, was to implement a basic in-season strength training program and determine whether any resultant increase in maximal squat strength is accompanied by an improvement in short sprint performance. It was therefore hypothesized that the training program would improve subjects' absolute and relative 1RM back squat performance, which would be reflected by a concurrent increase in sprint performance over 5, 10, and 20 m.

METHODS

Experimental Approach to the Problem

To determine whether a basic in-season strength training program results in an increase in 1RM back squat performance and whether these increases are reflected in a concurrent improvement in sprint performance, a squad of professional soccer players were tested (1RM squat and 5, 10, and 20 m sprint) before and after a 6-week in-season strength training intervention using a repeated measures experimental design.

Because this was an in-season intervention in a professional team sport environment, it is acknowledged that other sessions over the intervention period (agility and speed) may have influenced sprint performance. It would not have been practical to remove such sessions from the training week of this group of professional athletes; however, this increases the ecological validity of the study.

Subjects

Seventeen elite level professional soccer players (age = 18.3 ± 1.2 years [range: 16–20 years], height = 1.79 ± 0.06 m, BM = 75.5 ± 6.1 kg, 1RM back squat = 125.4 ± 13.8 kg, and 1RM/BM = 1.66 ± 0.24 kg·kg⁻¹) participated in the study. The institutional review board approved the project, and all the participants provided written informed consent and parental or guardian consent where required. The subjects were considered to be moderately trained in regard to maximal strength training interventions and relative strength levels, with an experience of resistance training of approximately 1 year, with a primary focus on strength endurance. The subjects had not been exposed to a strength training intervention of this nature (high intensity and low volume), having previously completed a general preparation phase that focused on muscle hypertrophy and strength endurance. All participants were accustomed with the testing methods, as they formed part of the on-going assessment and evaluation of their athletic development. All participants were free from injury and undertook a standardized warm-up before each testing session. The study conforms to the Code of Ethics of the World Medical Association (approved by the ethics advisory board of Swansea University) and required players to provide informed consent before participation.

Procedures

Maximal strength and sprint performances were assessed on separate days, 72 hours apart. Participants abstained from training for 24 hours before testing. Owing to testing being conducted on different days, all assessments were conducted at the same time of day and the participants asked to standardize their food and fluid intake before each testing session.

Maximal Strength Testing

One repetition maximum back squat was assessed by a standardized protocol, with warm-up loads approximated by individual training loads (3). During all attempts, the participants were required to squat to a depth where a 90° knee angle was achieved. This angle was gauged before the warm-up sets using a goniometer, with a bungee cord fixed at a height where it contacted the buttocks while the subject was in this position, which was also reinforced through verbal command. All participants achieved their 1RM within 4 attempts. Strength performances were reported as both absolute and relative (1RM/BM) strength.

Sprint Performance

After a standardized warm-up, the participants performed two 20-m sprints on an indoor artificial synthetic grass

TABLE 1. Example training program during the strength training intervention.

Exercise	High volume (sets/ repetition/load)	Low volume (sets/ repetition/load)
Back squat	4/5/85–90%	3/3/85–90%
Romanian deadlift	4/5/85–90%	3/3/85–90%
Nordic lowers	3/4–6*	3/3*

*Body mass (no external load).

surface, wearing standard training shoes. Sprints were interspersed with a 1-minute rest period in accordance with McBride et al. (21). Time to 5, 10, and 20 m was assessed using infrared timing gates (Speed Trap 2 Wireless Timing System; Draper, UT, USA). All subjects began from a two-point start, with their front foot positioned 0.5 m behind the start line, and were instructed to perform all the sprints with a maximal effort. Within-session reliability of sprint performances was assessed using the data from the 2 trials, during the preintervention assessments, whereas the best performances were used to compare preintervention to postintervention changes in performance.

Training Intervention

All subjects completed an individualized strength training program twice a week for 6 weeks (12 sessions in total) (Table 1). Loads were set as a percentage of the pretest values. The volume load of sessions was manipulated through the repetitions and sets performed to divide the sessions into a high volume and low volume day throughout the week, based on the competition schedule. This intervention formed part of the athlete's in-season conditioning program. Back squats were selected because of the strong associations with maximal strength in this exercise and short sprint performances (4,7,10,11,18,21,25,35,37). Romanian

deadlifts and Nordic lowers were implemented in light of the high incidence of hamstring strain injuries reported within soccer (36) and the injury prevention benefits of such strengthening exercises (1,2,26). In addition, the subjects were also familiar with these exercises.

Both maximal strength and sprint performances were reassessed at the end of the 6-week training intervention using the same protocols. Participants were asked to standardize their dietary intake and activity levels for the 24 hours before each testing session. All testing was performed at the same time of day to minimize the effect of circadian rhythms.

Statistical Analyses

Intraclass correlation coefficients (ICCs) were conducted to determine reliability of sprint testing methods within sessions. Paired sample *t*-tests were performed to identify the differences in sprint performances and 1RM back squat performance before and after 6 weeks of training. Effect sizes were determined using the Cohen *d* method and interpreted based on the recommendations of Rhea (28) who defines <0.35, 0.35–0.80, 0.80–1.5, and >1.5 as trivial, small, moderate, and large, respectively.

In addition, Pearson's product-moment correlations were performed to determine associations between the percentage change in sprint performances and the percentage change in relative strength. Correlation coefficients were interpreted as being weak (0.1–0.3), moderate (0.4–0.6), and strong (>0.7) in line with previous recommendations (17). Statistical analyses were performed using SPSS software (version 20.0; SPSS, Inc., Armonk, NY, USA). G-Power statistical software (version 3.1.9.2; University of Dusseldorf, Dusseldorf, Germany) (13) was used to determine that a minimum sample size of $n = 14$ was required for a statistical power ≥ 0.90 at an alpha level of $p \leq 0.05$.

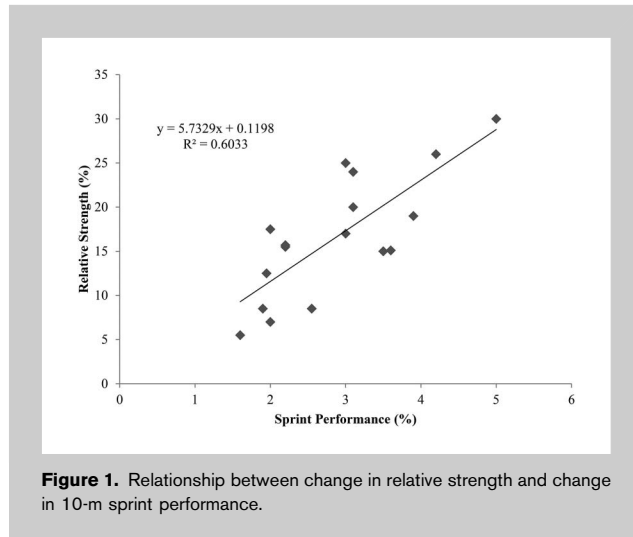
RESULTS

Examination of ICCs revealed varied but high within-session reliability for the 5, 10, and 20 m sprints during testing ($r = 0.86$; $r = 0.89$; $r = 0.92$).

TABLE 2. Descriptive statistics (mean \pm SD and 90% confidence intervals) for performance variables before and after training.

Performance variable	Before	After	Effect size, <i>d</i>
5-m sprint (s)	1.11 \pm 0.04 (1.09–1.13)	1.05 \pm 0.03* (1.04–1.06)	0.55
10-m sprint (s)	1.83 \pm 0.05 (1.81–1.85)	1.78 \pm 0.05* (1.76–1.80)	0.45
20-m sprint (s)	3.09 \pm 0.07 (3.06–3.12)	3.05 \pm 0.05* (3.03–3.07)	0.31
Absolute (kg)	125.4 \pm 13.78 (119.9–130.9)	149.3 \pm 16.62* (142.7–155.9)	0.62
Relative (kg \cdot kg ⁻¹)	1.66 \pm 0.24 (1.56–1.76)	1.96 \pm 0.29* (1.84–2.08)	0.45

* $p \leq 0.001$.



Body mass was increased over the 6-week training period, although the effect size was trivial (before = 75.5 ± 6.1 kg, after = 76.3 ± 5.9 kg, $p \leq 0.001$, Cohen's $d = 0.07$). Similarly, both absolute and relative strength increased significantly ($p \leq 0.001$) between baseline and after the 6-week in-season strength training protocol although the effect sizes were small (Table 2). Small but significant ($p \leq 0.001$) increases in sprint performance were also observed over each distance (Table 2) between before and after the 6-week strength training program.

Strong correlations were also observed between the percentage change in relative 1RM and 5, 10, and 20 m sprint times ($r = 0.62, 0.78, 0.60, p \leq 0.001$, respectively) (Figure 1).

DISCUSSION

We have demonstrated that a simple in-season strength training program resulted in an improvement in maximal back squat performance, which was reflected in improvements in short sprint performance, as identified by a decrease in sprint time over 5, 10, and 20 m, in professional soccer players, in line with the hypotheses. Furthermore, the changes in relative 1RM squat strength demonstrate strong associations with the changes in 5 ($r = 0.62$), 10 ($r = 0.78$), and 20-m ($r = 0.60$) sprint performances.

The in-season strength training intervention resulted in significant and moderate improvements in both absolute (19%) and relative (16%) strength. There were also significant ($p \leq 0.001$), yet small improvements in sprint performance over 5 m (~5%), 10 m (~3%) and 20 m (~1%) (Table 2). Despite moderate increases in squat strength, the effect sizes demonstrate that 5-m sprint performance showed small improvements, with progressively smaller effect sizes and percentage improvements as sprint distance increased, despite being statistically significant. The greater changes in short sprint performance are likely due to the requirement

to overcome inertia during the initial 5 m, with the RFD rather than maximal force production becoming more important as distance and running velocity increase. The absolute 1RM squat performances (before = 125.4 ± 13.78 kg; after = 149.29 ± 16.2 kg) before training are comparable with values previously reported in soccer players participating in a similar level of competition (129.1 ± 11.4 kg) (24).

The previous study by Comfort et al. (8), which compared changes in back squat and short sprint performances across preseason training in rugby league players, demonstrated similar increases in relative strength (before = 1.78 ± 0.27 kg·kg⁻¹ vs. after = 2.05 ± 0.21 kg·kg⁻¹) when compared with this study (before = 1.70 ± 0.24 kg·kg⁻¹ vs. after = 1.97 ± 0.29 kg·kg⁻¹). Similarly, changes in 5-m sprint performance were comparable, although the increases in 10-m and 20-m sprint performances were greater in the previous study (8), which could be due to the differences in duration (6 vs. 8 weeks) and the time in the season (preseason vs. in-season). Similar changes in back squat strength were also observed by Ronnestad et al. (29), after a 7-week strength training intervention in youth soccer players, although they observed minimal changes in 10-m sprint performance.

This study was an in-season intervention with a group of elite level soccer players that was incorporated into the existing training and competition schedule of a professional club. As such, owing to the concurrent focus on multiple fitness attributes, it is possible that changes in maximum strength were less than would be achieved in a program where this was the primary focus. The incompatibility between strength and endurance training has long been recognized, with concurrent training resulting in reduced improvements in strength and power (14,19). Although other research has reported little to no decrements in strength training gains with the addition of endurance training (16), it appears that concurrent training when compared with solely strength training, compromises strength-related adaptations. Indeed, the conflicting findings may be explained by the study design, training status of the participants, the strength and endurance stimuli, and the recovery between bouts of exercise (20,34). A key point to consider is that in many of the highlighted studies, the participants had little or no strength training history and as such made performance improvements as a result of this novel stimulus. This could explain the results of this study, in that, another group of athletes with a longer training history may require a greater level of overload to stimulate adaptation and the improvements in strength (19% increase in 1RM), which may affect the overall training volume.

Although 1RM back squat performance has previously been correlated with sprint performance (7,10,18,21,25,35), it has been suggested that assessment of peak force or peak power during squat jumps or countermovement jumps may be a better predictor of sprint performances over distances specific to soccer (11). With jumps divided into slow and fast SSC performance, the countermovement jump is a measure

of slow (>250 milliseconds) SSC performance and the drop jump is a measure of fast (<250 milliseconds) SSC performance (37,38). Cronin and Hansen (11) highlighted that measures of slow SSC performance (countermovement and loaded jump squats) resulted in the highest correlations ($r = -0.43$ to -0.64) with sprint performance. It is suggested that in the initial phases of sprinting, where ground contact times are longer, measures of slow SSC are more important, whereas measures of fast SSC are more important during the maximal speed phase (11). Indeed, the relationship between first-step quickness (5 m time) and maximal speed is weaker than that of first-step quickness and acceleration. That is, a 5-m time accounts for less than 53% of the explained variance associated with maximal speed (30-m time). Jump analysis, therefore, may offer greater insight into the determinants of soccer-specific speed and allow for greater individualization in terms of assessment and exercise prescription. Future research may benefit from investigating whether 1RM back squats or assessment of jump performances are more closely related to short sprint performance, with regular assessment of jump performance easier to implement in-season. Additionally, as this study was only 6 weeks in duration, assessment of periodized strength and power training throughout the season is recommended.

PRACTICAL APPLICATIONS

The findings of this study are that a simple low-volume in-season strength training intervention in trained professional soccer players can increase maximal squat strength, which is reflected in improvements in sprint performance, albeit to a lower magnitude. This highlights not only the association between strength and performance in short sprints over distances regularly performed in competition but also that relatively simple interventions can produce meaningful improvements in a population that, although elite, is relatively untrained in strength. It is recommended therefore that strength and conditioning coaches not only try to maintain but increase strength in-season in competitive soccer players, with low-volume strength training, which should not negatively affect match performance.

REFERENCES

1. Arnason, A, Andersen, TE, Holme, I, Engebretsen, L, and Bahr, R. Prevention of hamstring strains in elite soccer: An intervention study. *Scand J Med Sci Sports* 18: 40–48, 2008.
2. Askling, C, Karlsson, J, and Thorstensson, A. Hamstring injury occurrence in elite soccer players after preseason strength training with eccentric overload. *Scand J Med Sci Sports* 13: 244–250, 2003.
3. Baechle, TR, Earle, RW, and Wathen, D. Resistance training. In: *Essentials of Strength Training and Conditioning*. T.R. Baechle and R.W. Earle, eds. Champaign, IL: Human Kinetics, 2008. pp. 381–412.
4. Baker, D and Nance, S. The relationship between running speed and measures of strength and power in professional rugby league players. *J Strength Cond Res* 13: 230–235, 1999.
5. Bangsbo, J, Mohr, M, and Krstrup, P. Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci* 24: 665–674, 2006.
6. Chelly, MS, Fathloun, M, Cherif, N, Ben Amar, M, Tabka, Z, and Van Praagh, E. Effects of a back squat training program on leg power, jump, and sprint performances in junior soccer players. *J Strength Cond Res* 23: 2241–2249, 2009.
7. Comfort, P, Bullock, N, and Pearson, SJ. A comparison of maximal squat strength and 5-, 10-, and 20-meter sprint times, in athletes and recreationally trained men. *J Strength Cond Res* 26: 937–940, 2012.
8. Comfort, P, Haigh, A, and Matthews, MJ. Are changes in maximal squat strength during preseason training reflected in changes in sprint performance in Rugby league players? *J Strength Cond Res* 26: 772–776, 2012.
9. Comfort, P, Stewart, A, Bloom, L, and Clarkson, B. A comparison of performance characteristics in elite and sub-elite youth soccer players. *J Strength Cond Res* S1: 47–48, 2013.
10. Comfort, P, Stewart, A, Bloom, L, and Clarkson, B. Relationships between strength, sprint, and jump performance in well-trained youth soccer players. *J Strength Cond Res* 28: 173–177, 2014.
11. Cronin, JB and Hansen, KT. Strength and power predictors of sports speed. *J Strength Cond Res* 19: 349–357, 2005.
12. Cross, M, Brughelli, M, and Cronin, J. Effects of vest loading on sprint kinetics and kinematics. *J Strength Cond Res* 28: 1867–1874, 2014.
13. Faul, F, Erdfelder, E, Buchner, A, and Lang, A. Statistical power analysis using G*Power 3.1: Tests for correlation regression analysis. *Behav Res Methods* 41: 1149–1160, 2009.
14. Hakkinen, K, Alen, M, Kraemer, WJ, Gorostiaga, E, Izquierdo, M, Rusko, H, Mikkola, J, Hakkinen, A, Valkeinen, H, Kaarakainen, E, Romu, S, Erola, V, Ahtiainen, J, and Paavolainen, L. Neuromuscular adaptations during concurrent strength and endurance training versus strength training. *Eur J Appl Physiol* 89: 42–52, 2003.
15. Helgerud, J, Engen, LC, Wisloff, U, and Hoff, J. Aerobic endurance training improves soccer performance. *Med Sci Sports Exerc* 33: 1925–1931, 2001.
16. Helgerud, J, Rodas, G, Kemi, OJ, and Hoff, J. Strength and endurance in elite football players. *Int J Sports Med* 32: 677–682, 2011.
17. Available at: <http://sportssci.org/resource/stats/index.html>. Accessed August 05, 2015.
18. Kirkpatrick, J and Comfort, P. Strength, power, and speed qualities in English junior elite Rugby league players. *J Strength Cond Res* 27: 2414–2419, 2012.
19. Kraemer, WJ, Patton, JF, Gordon, SE, Harman, EA, Deschenes, MR, Reynolds, K, Newton, RU, Triplett, NT, and Dziados, JE. Compatibility of high-intensity strength and endurance training on hormonal and skeletal muscle adaptations. *J Appl Physiol* (1985) 78: 976–989, 1995.
20. Lundberg, TR, Fernandez-Gonzalo, R, Gustafsson, T, and Tesch, PA. Aerobic exercise alters skeletal muscle molecular responses to resistance exercise. *Med Sci Sports Exerc* 44: 1680–1688, 2012.
21. McBride, JM, Blow, D, Kirby, TJ, Haines, TL, Dayne, AM, and Triplett, NT. Relationship between maximal squat strength and five, ten, and forty yard sprint times. *J Strength Cond Res* 23: 1633–1636, 2009.
22. McGuigan, M and Winchester, JB. The relationship between isometric and dynamic strength in collegiate football players. *J Sports Sci Med* 7: 101–105, 2008.
23. McGuigan, MR, Newton, MJ, Winchester, JB, and Nelson, AG. Relationship between isometric and dynamic strength in recreationally trained men. *J Strength Cond Res* 24: 2570–2573, 2010.

24. McMillan, K, Helgerud, J, Macdonald, R, and Hoff, J. Physiological adaptations to soccer specific endurance training in professional youth soccer players. *Br J Sports Med* 39: 273–277, 2005.
25. Meir, R, Newton, R, Curtis, E, Fardell, M, and Butler, B. Physical fitness qualities of professional rugby league football players: Determination of positional differences. *J Strength Cond Res* 15: 450–458, 2001.
26. Mjolsnes, R, Arnason, A, Osthaugen, T, Raastad, T, and Bahr, RA. 10-week randomized trial comparing eccentric vs. concentric hamstring strength training in well-trained soccer players. *Scand J Med Sci Sports* 14: 311–317, 2004.
27. Rampinini, E, Coutts, AJ, Castagna, C, Sassi, R, and Impellizzeri, FM. Variation in top level soccer match performance. *Int J Sports Med* 28: 1018–1024, 2007.
28. Rhea, MR. Determining the magnitude of treatment effects in strength training research through the use of the effect size. *J Strength Cond Res* 18: 918–920, 2004.
29. Ronnestad, BR, Kvamme, NH, Sund, A, and Raastad, T. Short-term effects of strength and plyometric training on sprint and jump performance in professional soccer players. *J Strength Cond Res* 22: 773–780, 2008.
30. Seitz, LB, Reyes, A, Tran, TT, de Villarreal, ES, and Haff, GG. Increases in lower-body strength transfer positively to sprint performance: A systematic review with meta-analysis. *Sports Med* 44: 1693–1702, 2014.
31. Vigne, G, Gaudino, C, Rogowski, I, Alloati, G, and Hautier, C. Activity profile in elite Italian soccer team. *Int J Sports Med* 31: 304–310, 2010.
32. Weyand, PG, Lin, JE, and Bundle, MW. Sprint performance-duration relationships are set by the fractional duration of external force application. *Am J Physiol Regul Integr Comp Physiol* 290: R758–R765, 2006.
33. Weyand, PG, Sandell, RF, Prime, DNL, and Bundle, MW. The biological limits to running speed are imposed from the ground up. *J Appl Physiol* (1985) 108: 950–961, 2010.
34. Wilkinson, SB, Phillips, SM, Atherton, PJ, Patel, R, Yarasheski, KE, Tarnopolsky, MA, and Rennie, MJ. Differential effects of resistance and endurance exercise in the fed state on signalling molecule phosphorylation and protein synthesis in human muscle. *J Physiol* 586: 3701–3717, 2008.
35. Wisloff, U, Castagna, C, Helgerud, J, Jones, R, and Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 38: 285–288, 2004.
36. Woods, C, Hawkins, RD, Maltby, S, Hulse, M, Thomas, A, and Hodson, A. The Football Association Medical Research Programme: An audit of injuries in professional football—analysis of hamstring injuries. *Br J Sports Med* 38: 36–41, 2004.
37. Young, W, McLean, B, and Ardagna, J. Relationship between strength qualities and sprinting performance. *J Sports Med Phys Fitness* 35: 13–19, 1995.
38. Young, WB, James, R, and Montgomery, I. Is muscle power related to running speed with changes of direction? *J Sports Med Phys Fitness* 42: 282–288, 2002.