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Absolute and relative maximum strength measures show differences in their correlations with sprint and jump performances in trained youth soccer players

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Abstract

Speed strength performances are heavily dependent on maximum strength. However, various strength testing methods determined inconsistent relationships between absolute and relative strength and sprint and jump performances. The aim of the study was to calculate the one tailed correlation coefficients between both the One-Repetition Maximum (1RM) and 1RM in relation to body mass (1RM/BM) in parallel squats and different jump (squat jump and countermovement jump) and sprint performances (5-, 10-, 20-, and 30-m) in youth soccer players (n= 63, 17.9±2.1 years old). Relative strength showed significantly larger correlations with jump performances (r= 0.52 to 0.58) than absolute strength (r= 0.16 to 0.26, z= -1.81 to -1.90, p= 0.029 to 0.035). However, the r values between relative strength measures and sprint performances (r= -0.32 to -0.42) were of non-statistical difference to the correlations of absolute strength measurements with sprint performances (r= -0.19 to -0.3, z= 0.349 to 1.17, p= 0.121 to 0.363). The results of this study support findings in previous literature of enhanced speed strength performances by higher levels of maximal strength in youth soccer players, with faster and more powerful athletes being able to generate larger forces against their own body weight. The data suggests that strength expressed relative to body mass might be considered as a superior predictor of speed strength performance in general.

Keywords: *Squat, 1RM, linear sprint, jump, speed-strength, soccer*

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CORRELATIONS BETWEEN MAXIMUM STRENGTH, SPRINT AND JUMP PERFORMANCES
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Introduction

Team sports, such as competitive soccer, require a complex mix of technical, tactical, and conditional qualities (Stolen et al., 2005). Repeated changes between jogging, sprinting, jumping and rapidly performed directional changes add up to approx. 1300 diverse speed strength actions per player per game (Bangsbo et al., 2006; Stolen et al., 2005). These speed strength actions, according to detailed analyses, contribute substantially to the overall game performance. (Bangsbo et al., 2006; Reilly, 2006). Thus, to be successful, it is mandatory for soccer players to develop reasonably high levels of sprint and jump ability in addition to other technical, tactical, and conditional qualities (Reilly et al., 2000; Stolen et al., 2005).

The execution of sprints and jumps requires the generation of largest possible ground reaction forces by the neuromuscular system within short ground contact times (Hunter et al., 2005; Morin et al., 2012). Peak values of vertical ground reaction forces of up to 2 times body weight during push-off (Weyand et al., 2000) and 4 to 6 times body weight during landings are reported (Dempsey et al., 2014). Similarly, ground reaction forces during sprint starts and acceleration phase are reported with 2 to 5 (Bass et al., 2007; Lafortune et al., 2000) and 2 to 3 (Allmann, 1985; Joch, 1992; Schmidtbleicher, 2000) times the athlete's body weight, respectively. Therefore, these speed strength performances are heavily dependent on maximum strength (Schmidtbleicher, 1992) and consequently on relative strength as the athlete's body mass must be accelerated (Hunter et al., 2005). Numerous studies utilizing various strength testing methods have investigated these relationships. Consequently, small to large correlations between speed strength measurements and both absolute and relative strength have been determined utilizing dynamic free-weight squats in different sports (r= |0.26| to |0.60|) (Hori et al., 2008; Loturco et al., 2021).

These observed correlations between speed strength measurements and both absolute and relative strength are also true for studies analyzing soccer (r= |0.10| to |0.94|) (Boraczynski et al., 2020; Chelly et al., 2010; Comfort et al., 2014; Keiner et al., 2021; Keiner et al., 2014; McBride et al., 2009; Nuzzo et al., 2008; Rodriguez-Rosell et al., 2017; Wisloff et al., 2004; Wisloff et al., 1998). In detail, small to large correlations have been reported for absolute strength measures with various sprint performances (LS 5m to LS 40m) (r= |0.23| to |0.94|) (Boraczynski et al., 2020; Chelly et al., 2010; Comfort et al., 2014; Keiner et al., 2021; Keiner et al., 2014; Wisloff et al., 2004). Moreover, moderate to very large correlations have been reported for absolute strength measures with squat jump (SJ) and countermovement jump (CMJ) height, respectively (r= |0.39| to |0.78|) (Boraczynski et al., 2020; Comfort et al., 2014; Keiner et al., 2021; Rodriguez-Rosell et al., 2017; Wisloff et al., 2004; Wisloff et al., 1998)

Of the above-mentioned studies analyzing soccer players only a small number considered the potential effect of body mass on speed strength performances by correlating strength measures relative to the athlete's body mass. However, expressed relatives of body mass, squats strength showed mostly moderate to large correlations with sprint performances (r= |0.44| to |0.67|), squat jump, and countermovement jump height (r= |0.35| to |0.69|), respectively (Boraczynski et al., 2020; Comfort et al., 2014; Keiner et al., 2014; McBride et al., 2009). Correspondingly, there is no consent on magnitude of correlation between various jump performances and maximum strength. Moreover, due to the lack of studies comparing both absolute and relative strength measures in relation to speed strength performance, sampling errors, and the diversity of strength testing methods and protocols, which is impeding the comparison of results between studies, it is still not apparent whether absolute or relative strength measures show greater correlations with speed strength performances.

However, Boraczynski et al. (2020) reported small to moderate correlations between absolute squat strength, short sprint (LS 5m) (r= |0.28|), and countermovement jump performance (r= |0.39|), but strong correlations between relative strength short sprint performance (r= |0.51|), and countermovement jump height (r= |0.60|). 30-m sprint performance showed similar correlations for both absolute (r= |0.57|) and relative (r= |0.57|) strength measures, respectively. Similarly, Loturco et al. (2021) found large correlations (r= |0.54| to |0.60|) between squat and countermovement jump height, 30-m sprint performance and maximum strength expressed relative to body mass, but non-significant correlations in absolute terms (r= |0.26| to |0.34|). In contrast, Comfort et al. (2014) reported comparable large to very large correlations for both absolute (r= |0.59| to |0.76|) and relative (r= |0.51| to |0.67|) strength measurements with speed strength performances.

Therefore, the aim of the study was to analyze whether absolute and relative maximum strength measurements of the 1RM parallel squat correlate differently with different jump (squat jump and countermovement jump) and sprint performances (5-, 10-, 20- and 30-m), respectively. It was hypothesized that, while both absolute and relative strength correlate moderately to highly with athletes' sprint and jump performances, correlations of relative strength performances to be higher (Loturco et al., 2021).

Methods

Experimental approach to the problem

The objective of the study was to analyze potential correlations between maximal strength measures (1RM parallel back squat) with jump performance (squat jump and countermovement jump) and linear sprint performance (5-, 10-, 20-, and 30-m times), respectively, in trained youth soccer players (n=63, weekly training frequency 3-4 times over the last 2-3 years). To account for the possible effects of body composition and absolute body mass on jump performance and sprint performances, strength measures were included in the correlation analysis both as absolute (kg) and relative values (kg/kg of BM). Study protocol is presented in Figure 1.

Participants

In this investigation, 63 male youth soccer players (height = 182.9±5.9 cm, body mass [BM] = 72.2±8.0 kg, age = 17.9±2.1 years old) participated during in-season training throughout the Covid-19 pandemic. None of the athletes reported any injuries at the time of testing. The subjects were recruited from three teams (U21 [under 21 years], U19, U17) of a youth elite training center associated with a professional club in the third division in Germany. The U17 and U19 youth soccer teams played in the highest (Junior National League) and the second highest (Bavarian League) league, respectively. The U21

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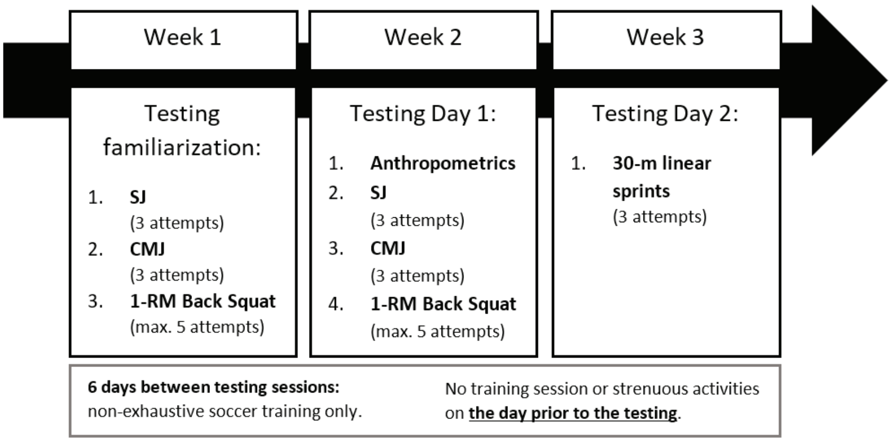

Figure 1. Study protocol. SJ – squat jump, CMJ – countermovement jump.

amateur team played in the 5th highest German league (Senior Bavarian League). The soccer players who were investigated had played soccer since early childhood. Their training during the period of testing consisted of 5 training sessions per week with competitions on weekends. The training sessions consisted of team and position specific soccer training, as well as athletic training including resistance training and plyometric exercises (i.e., jumping and sprinting). Based on their surpassing age-related training experience they were characterized as trained adolescents (3-4 times per week for 2-3 years).

All participants and participants' parents, for those participants under the age of 18, read and signed written informed consent to participate approved by the local University's institutional Ethics committee (DHGS-EK-2021-002). All procedures complied with the principles outlined in the Declaration of Helsinki.

Procedures

Adequate familiarization with the tests was given through familiarization sessions and a pre-test one week prior to data acquisition. The actual test protocol was divided into 2 testing days with maximum strength and speed strength measures taken on one test day 1 week apart from linear sprint measurements. On the day prior to the respective test days, no trainings sessions were conducted, and participants were instructed to avoid strenuous activities. After completing a standardized warm-up, the subjects completed all tests in the order described below.

Maximal Strength Test

A 1-RM back squat measurement was taken to assess the maximum lower body strength in the participants after a standardized additional warm-up. The warm-up protocol consisted of multiple repetitions with submaximal loads (3 sets of squats with 6-8 repetitions). During all attempts, participants were required to squat to a standardized depth where the top of the thigh was parallel to the ground. Squat depth was visually assessed and verbally reinforced by the investigators while the subjects were squatting. The participants were familiar with back squats as they received a technical training twice a week for two weeks prior to testing. Attempts failed when the soccer players were not able to stabilize the bar with their backs, lost the bar, or were unable to hit required depth. Rest periods of at least 5 minutes were given between the trials. 1RMs were achieved within a maximum of 5 attempts. Considering the importance of body weight for speed strength performances 1-RMs were reported as both absolute (kg) and relative strength (kg/kg of BM). A high intraclass correlation coefficient (ICC) of 0.91-0.99, as measure of test-retest reliability, has been reported in previous research (Keiner et al., 2021; McMaster et al., 2014).

Jump Performance Tests

Squat jumps and countermovement jumps were tested using a portable contact mat [ALGE, Lustenau, Austria]. To ensure adequate familiarization the participants were granted 3 test trials for each jump type. After that, the participants completed 5 trails of each jump, with a 1-minute rest between jumps. All jumps were performed with hands fixed on the hips throughout the whole measurement. The best result was used for statistical analysis. A successful squat jump was initiated from squat position (approx. 90° knee angle) after a 2-second hold without momentum. The countermovement jump utilizes the momentum of a preceding squat movement (to approx. 90° knee angle) to initiate the immediate jump. Correct movement execution was visually assessed and verbally reinforced by the investigators while the subjects were jumping. ICCs of 0.87-0.98 and 0.94 have been reported for squat jumps and countermovement jumps, respectively (Keiner et al., 2021; Keiner et al., 2015).

Sprint Performances Test

A 30-m sprint measurement was taken to assess acceleration and linear sprint ability in the soccer players. Time measurements were initiated by the participants crossing the initial light barrier and sprint times were taken at 5, 10-, 20- and 30-m using four additional double-light barriers (wk7 time watch, Ditzingen, Germany). To avoid an early triggering of the system by hand movement or a tilted upper body position the participants started 0,75 meters ahead of the initial light barrier. Each participant completed three trials, with a 3-min rest between sprints. The best result after 30 meters was used for statistical analysis. ICCs of 0.91-0.97 has been reported in previous research (Keiner et al., 2021; Sander et al., 2013)

Statistical Analysis

Descriptive statistics were calculated for all data and reported as mean ± standard deviations. Shapiro-Wilk test was performed to analyze the data for normal distribution. The best performances in each test were used for the statistical analysis. Relationships between the performance variables were calculated for the normally distributed data using one-tailed bivariate Pearson correlations. If the data were not normally distributed, relationships between the test variables were calculated using one-tailed Spearman correlation coefficients. Correlations were interpreted according to the following thresholds: ≤0.1 = trivial, >0.1-0.3 = small, >0.3-0.5 = moderate, > 0.5-0.7 = large, >0.7-0.9 = very large, and >0.9-1.0 = nearly perfect/perfect (Hopkins et al., 2009). To statistically compare correlations of absolute and relative strength values with sprint and jump performances, Fisher's Z was calculated using the Pearson's correlation coefficients and sample size and tested for statistical significance (Z = (z1 − z2) / sqrt((1 / (n1 − 3) + (1 / (n2 − 3))). To assess the relative reliability of performances ICCs and 95% CI were calculated from familiarization and testing sessions for squats and jumps and from in between trials for sprints. Portney (2020) suggests values above 0.75 as being indicative for good reliability. The significance level was set at p < 0.05. The All calculations were performed using the statistical software package SPSS 27.0.1.0 (IBM, Ehningen, Germany).

Results

Eighteen participants did not participate in all tests due to organizational reasons or injury not related to the intervention. These athletes were not included in the correlations. Except athletes' age all data displayed a normal distribution. Performance variables, ICCs, and the 95% confidence intervals (95% CIs) are presented in Table 1. The test-retest reliabilities of strength sprint and jump performances were greater than 0.75, indicating high reliability.

Table 1. Descriptive Statistics and Reliability of Maximum Strength and Sprint and Jump Performances

	Mean±SD	ICC (95% CI)
1 RM	94.3±13.2	0.94 (0.89-0.97)
1 RM/BM	1.3±0.1	
SJ	37.3±4.2	0.87 (0.75-0.93)
CMJ	40.0±4.6	0.94 (0.91-0.96)
LS 5m	1.01±0.04	0.80 (0.68-0.87)
LS 10m	1.73±0.05	0.87 (0.81-0.92)
LS 20m	2.97±0.08	0.94 (0.91-0.96)
LS 30m	4.14±0.12	0.97 (0.95-0.98)

1 RM= One Repetition Maximum back squat (in kg); 1 RM/BM= One Repetition Maximum back squat divided by body mass (in kg*kg-1); SJ= squat jump (in cm); CMJ= countermovement jump (in cm); LS= linear sprint (in s);

Statistically significant differences between the correlations of absolute and relative strength measurements were obtained (Table 2). More precisely, the r values between relative strength measures and jump performances (r= 0.52 to 0.58) were significantly larger than those between absolute strength measurements and jump performances (r= 0.16 to 0.26, z= -1.816 to -1.902, p= 0.029 to 0.035). However, in contrast, the r values between relative strength measures and sprint performances (r= -0.32 to -0.42) were of non-statistical difference to the correlations of absolute strength measurements with sprint performances (r= -0.19 to -0.3, z= 0.349 to 1.17, p= 0.121 to 0.363).

Table 2. Pearson's Correlations (r-Values) and Differences (Z) Between Absolute and Relative Strength With Sprint and Jump Performances

	SJ	CMJ	LS 5m	LS 10m	LS 20m	LS 30m
1RM	0.16	0.26*	-0.19	-0.25*	-0.28*	-0.3*
1RM/BW	0.52*	0.58*	-0.42*	-0.32*	-0.36*	-0.37*
Z	-1.90*	-1.81*	1.17	0.34	0.40	0.36

1 RM = One Repetition Maximum back squat; 1 RM/BM = One Repetition Maximum back squat divided by body mass; SJ = squat jump; CMJ = countermovement jump; LS = linear sprint; *= significant (p<0.05)

Discussion

The study was designed to analyze whether absolute and relative maximum strength measurements of the 1RM parallel squat correlate differently with different jump and sprint performances among a population of trained male youth soccer players. The data showed significant moderate to large correlations for relative strength and sprint and jump performances (r= |0.32| to |0.58|). However, only non-existent to weak correlations (r= |0.16| to |0.30|) were found between absolute strength and sprint and jump performances, respectively. In line with our hypothesis, relative strength measurements demonstrated significantly stronger correlations with jump performances than absolute strength (p= 0.029 to 0.035). However, other than expected the differences between the correlations of absolute and relative strength with sprint performances were of no statistical significance (p= 0.121 to 0.363). Still, it has been well established that the ability to generate largest possible ground reaction forces within a short ground contact time to accelerate one's body mass is a critical contributor to speed-strength performance (Hunter et al., 2005; Morin et al., 2012; Weyand et al., 2010; Weyand et al., 2000). Therefore, considering Newton's second law (force = mass * acceleration), athletes who are able to exert greater amounts of force against their own body mass should be able accelerate faster. With absolute values these relationships between force, mass, and acceleration are not considered,

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which could explain the scattering of results in previous literature.

What also must be considered is, that with increased complexity of the performance task (jump vs. short sprint performance vs. long sprint performance) smaller correlations with strength measurements are generally observed. Therefore, the data might not be sensible enough to illustrate the influence of body weight on more complex speed strength performances like sprinting, as other influences like technical fluency affect performance to a certain extent.

However, recently, Loturco et al. (2021) found large correlations (r= |0.54| to |0.60|) between squat and countermovement jump height, 30-m sprint performance and maximum strength expressed relative to body mass, but non-significant correlations in absolute terms (r= |0.26| to |0.34|). These results are of particular significance as all r values of relative strength measures with jump and sprint performances were, considering Fisher's Z, significantly larger than those of absolute strength measures (p= 0.02 to 0.03). These results, in conjunction with the findings of the current study, suggest that superior speed strength performances are a product of the athlete's ability to exert greater amounts of force against their own body weight. Consequently, it seems reasonable to consider strength expressed relatively to body mass to be a superior indicator for speed strength performance, especially for short sprint and jump performances. Moreover, this conclusion is in accordance with previous literature showing largest possible ground reaction forces of 2 to 5 times body weight during jumps and sprint starts to be mandatory for superior speed strength performance (Bass et al., 2007; Hunter et al., 2005; Lafortune et al., 2000; Weyand et al., 2000).

The study has limitations. Initially, 63 athletes were part of this study but due to organizational reasons or injury, not related to the intervention, 18 missed some of the measurements. This should have had small effect on the results considering the total sample size. On the contrary, with 45 participants the study provides a substantial sample size considering the performance level of the participants. It is also noteworthy that this study actually controlled for significant differences between the correlations of absolute and relative strength measures with jump and sprint performances. This has not been done in previous literature (Boraczynski et al., 2020; Comfort et al., 2014). Investigating the data of this study, it is conspicuous that the strength levels and jumping heights, especially in the squat jump, are considerably lower compared to similar studies with well-trained youth soccer players (Comfort et al., 2014). However, these studies also reported sprinting performances similar to those examined in this investigation. Technical disparities in measuring squats and squat jumps as maximum strength and speed strength tests could be a possible explanation for differences between the present study and previous studies. When determining a 1RM of the squat, a key limiting factor in many cases, especially in younger, less experienced athletes, seems to be trunk strength (Keiner et al., 2014). As such, only accepting trials with proper technique, with the athlete stabilizing the barbell load with his trunk without spinal flexion, the one-repetition maximum squat might not be an adequate assessment of pure maximum lower body strength. However, this might explain why this investigation reached lower strength values and showed weaker correlations compared to previous research. Still, even though all participants were already accustomed with the testing procedures as they had performed similar exercises during their regular athletic training, this study utilized an extensive familiarization protocol to ensure reliable performance measurements. In terms of evaluating the squat jump, similar difficulties could explain the lower correlations between the measurement and the observed values. Initiating a jump out of 90° knee flexion after a two second hold without momentum and pure concentric movement usually does not belong to the typical movement repertoire of a team sports athlete. Therefore, it is reasonable to assume lower technical efficiency, resulting in limited force production and jumping height, especially when emphasizing on correct form without the utilization of momentum. Further evidence is found in a lower ICC in the squat jump. Despite these limitations, the applied study protocol and the included sample allow a solid evaluation of the relationships between the analyzed variables.

Conclusion

The primary findings of this study were significant differences between the correlations of absolute and relative strength measurements with jump performances. The data supports findings in previous literature of enhanced acceleration and speed strength performances by higher levels of absolute and relative strength in various athletic populations, with faster and more powerful athletes being able to generate larger forces against their own body weight. However, taking into account the results by Loturco et al. (2021), strength expressed relative to body mass might be considered a superior indicator of speed strength performance in general. Therefore, assessing relative strength performances within soccer-specific performance diagnostic protocols might provide more relevant information than absolute strength values about the athlete's speed strength abilities.

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Conflicts of Interest

The authors declare no conflict of interest.

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