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Correlations between maximal strength tests at different squat depths and sprint performance in adolescent soccer players

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Abstract: For track, field and team sports, many authors advise sport-specific strength training with half and quarter squats instead of parallel squats. Due to the sport-specific argument, higher correlations with sprint performance could be expected for half and quarter squats. Hence, correlations between sprint performance (30 m linear sprint) and both One-Repetition-Maximum (1RM) and 1RM in relation to body weight (REL) in young, elite soccer athletes (n=28) were calculated for different squat depths (parallel, half and quarter). Further isometric maximum strength measurements of the trunk muscles were made. Normally distributed data were analysed using Pearson's correlation coefficients. For correlation comparisons, Fisher's z-transformation was computed and the empirical value was compared to the critical value. The data show significant moderate to high correlations for all 3 squat depths (REL) and the performance in linear sprint LS (r = -0.40 to -0.63). No significant differences were found between the correlations of the different squats. However, low to moderate correlations between the maximum trunk strength values and the performance in LS were calculated (r = -0.25 to -0.48). Medium to high correlations between the different squat depths and trunk strength parameters were measured (r = 0.47 to 0.75). Because there is no statistical difference between the correlations of the squat and sprint performances, the researchers' advice is to train and test with the parallel or deep squat because the deeper squat variant requires less weight to generate an adequate stress stimulus for the lower extremities compared with the quarter and half squats.

Keywords: Linear Sprint, Squat, Trunk Strength, 1RM

1. Introduction

Sprints, jumps and throws are complex motor tasks that are influenced by a number of factors, such as coordination. This complexity is also reflected in the muscle groups that are involved in executing movements. In soccer, a very high number of speed-strength actions occur during a game (e.g., linear sprints, sprints with changes of direction, jumps, and throw-ins) and all of these actions can determine whether a game is won or lost.

The acceleration of the centre of mass of a sprinter or soccer player is determined by three external forces: the ground reaction force (GRF), gravitational force, and wind resistance [1,2]. The same external factors exist during the execution of jumps and throws. Of these three forces, the athlete has, by far, the most influence on the development of the GRF (e.g., the force production of limbs). Further, the mechanical energy has to be transfers between body segments while sprinting [1,3]. Every contact with the ground reaches relatively high forces depending on the running speed and stride length [2,4]. Faster running speeds are primarily achieved by the feet exerting greater forces on the ground [5]. In the moment of take-off in the long and high jumps, the GRF can be up to >2 times the body weight and is even higher at depth (jumps and landings) [6-10]. Therefore, high correlations between strength performance and sprints and jumps can be found in the limb muscles

[11-21]. Several different methods have been used to assess strength in the investigation of its relationship to athletic performance. Strong correlations between speed and both absolute and relative strengths have been determined in the use of free-weight squats [11,17,20]. This is true for soccer [18,20,22]. The squat could be performed as a quarter squat, half squat, parallel squat or deep squat (Table 1). The difference between those is the range of motion of each type. The turning point is at a knee angle of 120° in the quarter squat, 90° in the half squat, 60-70° in the parallel squat and 45-60° in the depth squat, depending on thigh and hamstring sizes. Sleivert and Taingahue [23] evaluated strong correlations between the quarter jump squat and performance in a linear sprint. Wisloff et al. [20] demonstrated a strong relationship between the free-weight half squat and jump performance. However, there are also strong correlations between the parallel squat and jump and sprint performance [11,17].

Most of the studies found in the literature review correlated the half squat with athletic performance. There are few studies that evaluated the correlation between the parallel squat and athletic performance, and at least one investigation evaluated the correlation between the quarter squat jump and athletic performance. This is surprising because many track, field and team sports authors recommend sport-specific strength training with half and quarter squats [24-27]. The researchers found no investigation that compared the correlations between different squat depths.

All of these movements and forces of the extremities lead to high forces acting on the trunk and hips. The trunk muscles must control the extremities and transfer the forces so that efficient locomotion is ensured [28,29]. Therefore, athletes are constantly transferring forces between extremities and are in need of support from the musculature of the trunk to keep the kinetic chain of the body intact. Furthermore, researchers have reported abdominal activation during jumping, landing, and running [30,31]. Correlation analyses for different test protocols, trunk strengths and athletic performance measurements [32-40], in addition to longitudinal studies of the effect of trunk muscle strength training on athletic performance [41-45], can be found in the literature. The analyses generally show low to moderate correlations between trunk strength and athletic performance [32-36,38-40] with the exceptions of the investigations of Dendas, Ikeda et al. and Iwai et al. [32,35-37].

Table 1. *Correlations of 1RM for different squat depths and sprint performances*

Investigation	Subjects	Squat variant	Performance	Correlation
McBride et al.[17]	Football players	Parallel-squat	Linear sprint	r=-.45 to r=-.60
Keiner et al.[53]	Soccer players	Parallel-squat	Change of direction sprint	r=-.39 to r=-.70
Baker et al.[11]	Rugby players	Parallel-squat	Loaded jump squat	r=.79 to -.86
Comfort et al.[54]	Professional rugby players	Half-squat	Linear sprint	r=-.96 to r=-.97
Wisloff et al.[20]	Soccer players	Half-squat	Linear sprint, CMJ	r=-.71 to -.94 r=.78
Requena et al.[18]	Soccer players	Half-squat	SJ CMJ	r=.50 r=.50
Chelly et al.[22]	Soccer players	Half-squat	Linear Sprint	r=-.58 to -.66
Ingebrigtsen et al.[55]	Handball players	Half-squat	Linear sprint	r= -.054 to -.33
Sleivert and Taingahue[23]	Male athletes	Quarter jump-squat	Linear sprint	r=-.68

The aim of this study is to analyse correlations between sprint performances, isometric maximum strength measurements of the trunk muscles and 1RM at different squat depths in young elite athletes. Both should provide data that will yield further insight into factors that determine performance in sprints and jumps.

2. Materials and Methods

The objective of this study was to show correlations between maximal isometric trunk strength measures and 1RM in the parallel squat, half squat and quarter squat with a maximal knee angle at the turning point of 60°, 90° and 120° for $1RM_{60}$, $1RM_{90}$, and $1RM_{120}$, respectively, as well as a 30 meter linear sprint (30LS). To accomplish these objectives, 28 elite youth soccer players were evaluated. Each participant was given adequate familiarisation with the tests through a pre-test one week before data acquisition. The testing protocol for the soccer players took place in May 2012, 2-3 weeks after the last match of the season. The last fatiguing training session occurred at least two days before testing. None of the participants reported any injuries at the time of testing. Anthropometric and performance measurements were collected by the same researchers at the same time on testing day, and all participants were asked to wear the same clothing and footwear. All participants were asked to eat and drink a sufficient amount until 1 hour before testing.

2.1. Subjects

The subjects (n = 28) came from three teams (U19 [under 19 years], U17, and U15) from each of the highest German junior divisions (the Junior National League and the Junior Regional League). They came from a training centre for young soccer players run by a professional association of the latter division. The players were 16.4 ± 0.9 years old. The soccer players were 71.2 ± 8.6 kg and 177.1 ± 6.8 cm in size. The investigators informed all the subjects of the objectives of the investigation and all aspects of the research. Informed consent was obtained from the participants' parents, and when the participants were aged 18 years and older, from the participants themselves. The researchers followed the principles outlined in the Declaration of Helsinki.

2.2. Testing

Each participant was given adequate familiarisation with the tests through a pre-test one week before data acquisition. The test protocol was divided into 4 testing days to eliminate possible common motivation problems that occur when a test session lasts too long. Test day 1 was completed one week before test day 2 and so on. The strength tests were evaluated through a maximum of 5 trials. All participants completed the following series of tests, in the displayed order, after completing a standardised warm-up routine. There was an additional warm-up prior to the 1RM testing which consisted of 3 sets of squats with 6 to 8 repetitions with a submaximal weight. The resting time between attempts was at least 5 minutes. The investigators supervised the range of motion of all of the groups during each squat test.

2.2.1. Day 1

The linear sprint time was determined using four double light barriers (System produced by the University of Frankfurt/Main). The time was started after the subject passed the first light barrier from a starting point set 0.75 meters in front of it. Time was measured in the linear sprint after 5, 10, 20 and 30 meters. The test-retest correlations for the linear sprint parameters were 0.94 – 0.98 ($p<0.05$). Three measurements were taken for each subject and the attempt with the shortest time after 30 meters was used for the linear sprint analysis.

2.2.2. Day 2

Parallel squat ($1RM_{60}$): The turning point in the parallel squat is at a knee angle of 60-70°. The test-retest correlation was r=0.99 (p=0.001) for the parallel squat. Determination of the 1RM was completed within a maximum of 5 trials.

Isometric trunk strength measurements were obtained with the lumbar/thoracic extension (EXT) of the David 130 (David, Neu-Ulm, Germany) and with the lumbar/thoracic flexion (FLEX) of the David 110 (David, Neu-Ulm, Germany). This measurement system has been validated, and its reliability has been confirmed (r = 0.96 to 0.99) [46]. The strength of each subject was measured in a sitting position. In both measurements, the knee angle was 80°. The hip angle was 80° for the FLEX measurement and 60° for the EXT measurement. Strength measurements were obtained to determine the maximum isometric strength (N). Each subject had three measurements for each classification attempt, before two habituation trials.

2.2.3. Day 3

Half-Squat ($1RM_{90}$): the subjects carried out half back squats to 90° of knee extension. To achieve the required movement range in the knee joint, a goniometer was used on the subjects' right knees. Increases in weight loads to determine the 1RM in half squats were cancelled when the subjects were not able to stabilise the bar with their backs. The test-retest correlation was r=0.96 (p=0.001). Determination of the 1RM was completed within a maximum of 5 trials.

2.2.4. Day 4

The Quarter-Squat ($1RM_{120}$): the subjects carried out half back squats to 120° of knee extension. To achieve the required movement range in the knee joint, a goniometer was used on the subjects' right knees. Increases in weight loads to determine the 1RM in quarter squats were cancelled when the subjects were not able to stabilise the bar with their backs. The test-retest correlation was r=0.91 (p=0.001). Determination of the 1RM was fulfilled within a maximum of 5 trials.

2.3. Statistical Analysis

The trunk strength ratio (FLEX / EXT) and total trunk strength (TRUNK = FLEX + EXT) were calculated. Performances in squat depths were relativised to bodyweight (REL) by dividing the 1RM by the body mass. The data were analysed using the statistical software package SPSS 17.0. Descriptive statistics were calculated for all data. The data were analysed using the Kolmogorov-Smirnov test for normal distribution. Relationships between the test variables were calculated for the normally distributed data using bivariate Pearson correlations. If the data were not normally distributed, relationships between the test variables were calculated using Spearman correlation coefficients. The significance level was set at $p <0.05$. The relationships were classified as follows: 0 = no correlation, $0 < | r | <0.2$ = very weak correlation, $0.2 \leqslant | r | <0.4$ = weak correlation, $0.4 \leqslant | r | <0.6$ = moderate correlation, $0.6 \leqslant | r | <0.8$ = strong correlation, $0.8 \leqslant | r | <1.0$ = very strong correlation, 1 = perfect correlation. For correlation comparisons $z' = 1/2*\ln((1+r)/(1-r))$ was calculated. The results from the z′ value's empirical value (zemp) were computed and compared to the critical value (zcrit). If zemp > zcrit (zcrit=1.645), the correlation differed statistically ($p<0.05$).

3. Results

All data displayed a normal distribution. The players reached LS5 m in 1.045 ± 0.041 seconds (s), LS10 m in 1.767 ± 0.144 s, LS20 m in 3.084 ± 0.090 s and LS30 m in 4.307 ± 0.145. The soccer players lifted 75.4 ± 20.8 kg in $1RM_{60}$ (REL_{60} = 1.1 ± 0.2), 109.2 ± 27.0 kg in $1RM_{90}$ (REL_{90} 1.5 ± 2.3) and 155.4 ± 28.6 kg in $1RM_{120}$ (REL_{120} 2.1 ± 0.3). The correlations of the squat depths and sprint performances are shown in Table 1. The comparisons of the correlations of the different squat depths ($REL_{60,90,120}$) and performances in LS showed no significant differences between the calculated correlations (zemp < zcrit).

The EXT was 255 ± 68 N and FLEX was 166 ± 34 N. The trunk strength ratio (FLEX/EXT) was 0.68 ± 0.15 and the

TRUNK was 421 ± 94 N. The correlations between trunk strength values and sprint performances of the soccer players are shown in Table 2, and the correlations of trunk strengths and $1RM_{60,90,120}$ are shown in Table 3. Correlation of trunk strength values and squat performances of the soccer players are shown in Table 4.

4. Discussion

This study examined the relationships between 3 different squat depths, the maximum isometric strength of trunk muscles and performance in a linear sprint. The data show significant moderate correlations for all 3 squat depths ($REL_{60,90,120}$) and performance in LS. However, weak to moderate correlations were found between the maximum trunk strength values and performance in LS. Weak to medium correlations between trunk strength and performance in LS were found. Further, medium to high correlations between the different squat depths und trunk strength parameters were measured.

The literature review did not find any investigations comparing the correlations in quarter, half and parallel squats. Table 1 describes some investigations that analysed correlations between different squat depths and sprint and jump performances. The correlations found in this investigation are only partially consistent with the correlations in Table 1. Most of the investigations listed in Table 1 show moderate to strong correlations between performances in the 1RM and sprint tests irrespective of the squat variant. Thus, the literature review indicates that the parallel squat predicts sprinting performance in the same way half and quarter squats do. However, some authors state that there must be an assumed difference in the correlations between performances in parallel, half and quarter squats and sprint and jump performances because angles at the turning point of the motion (1RM) match with the joint angles where the highest force production demands occur in different sports (e.g., sprints and jumps) [24-27]. The data in this investigation also show that this argument (angle specificity of athletic performance resulting in the advice to train with the quarter squat) seems to not be true. According to the authors, a strong correlation does not imply cause and effect; however, a longitudinal investigation that compared a periodised 10-week parallel and quarter squat training program only found significant improvements in jump performance for the subjects with deep squat training [47]. Additionally, Bloomquist et al. found that deep squats elicited favourable adaptations to knee extensor muscle size and function compared to training with shallow squats in a 10-week training intervention [48]. However, it is likely that increases in back squat strength may result in an improvement in sprint performance, although it is still essential to ensure that athletes have optimal techniques in terms of both sprint and jump mechanics and exercise techniques, especially in young athletes. The authors note that when compared to half and quarter squats, the deep squat variant causes less shear and compressive stress at the knee-joints and vertebral column because lower weight loads can be lifted compared to half and quarter squats [49].

Table 2. *Correlation of squat variant strength values and sprint perfomances*

	LS 5 m	LS 10 m	LS 20 m	LS 30 m
$1RM_{60}$	-0.39	-0.23	-0.46*	-0.48*
REL_{60}	-0.48*	-0.44*	-0.52*	-0.46*
$1RM_{90}$	-0.29	-0.27	-0.40	-0.45*
REL_{90}	-0.44*	-0.63*	-0.48*	-0.47*
$1RM_{120}$	-0.40	-0,26	-0.46*	-0.47*
REL_{120}	-0.48*	-0.55*	-0.41	-0.29

LS=linear sprint; m=Meter; $1RM_{60,90,120}$=One Repetition Maximum with maximum knee angle of 60°, 90° or 120°; *=significant ($p<0.05$)

Table 3. *Correlation of trunk strength values and sprint performances*

	LS 5 m	LS 10 m	LS 20 m	LS 30 m
Flex	-0.10	-0.11	-0.45*	-0.48*
EXT	0.02	0.02	-0.35	-0.40
FLEX/EXT	0.25	0.22	0.25	0.20
TRUNK	-0.17	-.0.07	-0.45*	-0.48*

EXT= isometric Lumbar/Thoracic Extension; FLEX= isometric Lumbar/Thoracic Flexion; LS=linear sprint; m=Meter; *=significant ($p<0.05$)

The correlations of the squat depths and the sprint times are mostly moderate. In considering the correlations, it is striking that the correlation coefficients for 1RM and sprint performances at 5 and 10 m are only low to moderate ($p<0.05$), but $REL_{60,90,120}$ values of the squat depths yielded mostly moderate to strong correlations ($p>0.05$). This is not surprising because in acceleration the body weight must be accelerated. In a similar finding, other investigations showed that after calculating REL there was a strong correlation between maximum strength values and speed strength performance [15,50]. Therefore, it can be assumed that the $REL_{60,90,120}$ values in squats are better predictors of sprint performance for the first 10 m than the 1RM.

Table 4. *Correlation of trunk strength values and squat performances*

	1RM 60	1RM 90	1RM120
Flex	0.47*	0.58*	0.67*
EXT	0.69*	0.75*	0.72*
FLEX/EXT	-0.40	-0.37	-0.19
TRUNK	0.67*	0.75*	0.75*

EXT= isometric Lumbar/Thoracic Extension; FLEX= isometric Lumbar/Thoracic Flexion; TRUNK= FLEX + EXT; $1RM_{60,90,120}$=One Repetition Maximum (knee angle of 60°, 90° or 120°); *=significant ($p<0.05$)

Striking, but not surprising, is that moderate to strong correlations between trunk strength values and performances in the squat variations were found. Strong correlations were observed in $1RM_{60,90,120}$ with FLEX, EXT and TRUNK. This is consistent with the observations of the researchers that in the determination of 1RM, the limiting factor seemed to be primarily trunk strength. Particularly in the $1RM_{120}$, the attempts usually failed because the subjects were not able to stabilise the barbell load with their trunk.

A literature review on the relationship between trunk strength and athletic performance shows results similar to this investigation [24-28,30-32], but no isometric maximal strength test (FLEX, EXT) for the trunk muscles or calculated correlations to athletic performance could be found. However, the data in this study (low to moderate correlations between trunk strength and sprints) show no uniform direction, which is also consistent with the literature. The trunk strength ratio (FLEX/EXT) does not appear to limit athletic performance. Due to the heterogeneous performance of the tested participants, it must be assumed that, in this study, statistically higher correlations could be calculated. It is possible, therefore, that moderate correlations for FLEX, TRUNK and sprint performance (LS20 and LS30) could be calculated in this study. This may result from weak trunk muscles (FLEX, EXT). It could be that these muscle were not able to transfer the forces so they became performance limiting directly.

The limitation of the measured trunk strength is that the performance parameters were measured with a dynamic test, whereas the trunk strength was determined by an isometric strength measurement. In sporting performance, no isometric action of trunk muscles can be assumed, just nearly isometric actions. This (isometric vs. eccentric-concentric measurement) could have led to lower correlations between the parameters [51]. Further, an isometric measurement is always an angle-specific measurement and the position of the athlete while measuring trunk strength is very different from the position of the body while sprinting. This is a problem that actually affects most trunk strength measurements. Nonetheless, a correct test design (maximum strength test for the trunk) was used in this investigation, referring to the high forces which have to be transferred by the trunk muscles while sprinting.

In summary, the researchers' recommendation is to train and test the parallel or deep squat for soccer players because the data show that this squat variant represents sprint performance like the half and quarter-squats do. This advice is based on the additional information that the deeper squat variant requires less weight to generate an adequate stress stimulus for the lower extremities compared with the quarter and half squats [47,48,52]. When compared to half and quarter squats, the deep squat involves lower shear and compressive stresses on the knee joint and vertebral column [49]. Provided that the technique is learned accurately under expert supervision and with progressive training loads, the 1RM in a parallel squat displays a strong correlation with sprint performance. The observation that $1RM_{60,90,120}$ and trunk strength is a performance limiting factor must permit the conclusion that, at least in subjects without strength training experience, as in this investigation, the assessment of leg strength must be handled with caution. This is especially important when training or testing young athletes. Further, the researchers' advise that strength performance in relation to body weight (REL) should be evaluated instead of primarily relying on absolute strength values.

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