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Influence of linear-sprint performance, concentric power and maximum strength on change of direction performance in elite youth soccer players

Introduction

Match-play demands in team sports dictate that players perform several high-intensity activities during a game (Bloomfield, Polman, & O'Donoghue, 2007; Duthie, Pyne, & Hooper, 2005). These actions are important for scoring, winning or losing duels and even determining the outcome of the game (Brughelli, Cronin, Levin, & Chaouachi, 2008). Soccer players have to accelerate, decelerate and change directions during a game (Little & Williams, 2005). In particular, change of direction (COD) performance has an essential role in soccer (Brughelli et al., 2008; Faude, Koch, & Meyer, 2012).

Therefore, the testing of COD performance is of great interest for training purposes practice but is controversial. Different authors recommend different COD tests, such as the Illinois agility test (IAT) (Brughelli et al., 2008), the 505 agility test (505) (Draper & Lancaster, 1985; Emmonds, Nicholson, Begg, Jones, & Bissas, 2019), and the agility test of the German Soccer Association (GewT) (Vescovi & McGuigan, 2008). Furthermore, COD tests designed like the triangle test (TriT) are commonly used in team sport assessments (Kadlubowski, Keiner, Hartmann, Wirth, & Frick, 2019).

Isolating the subcomponents involved in a COD (i.e., deceleration, change of

direction, acceleration, excluding decision making processes) assumes that a connection between COD and linear sprint (LS) performance, concentric power and maximum strength exists. In general, correlation analyses show a wide range of explained variance ($r^2 = 0.22$ to 0.56) between linear speed (10 m and 20 m) and COD performance (Draper & Lancaster, 1985; Gabbett, Kelly, & Sheppard, 2008; Lockie, Schultz, Callaghan, Jeffriess, & Berry, 2013; Nimphius, Callaghan, Spiteri, & Lockie, 2016; Young, Miller, & Talpey, 2015). Other research shows heterogeneous results correlating jump performance and different COD tests ($r^2 = 0.06$ to 0.83) (Alemdaroğlu, 2012; Salaj & Markovic, 2011; Schultz et al., 2015). Studies also show heterogeneous relationships between maximum strength and COD performance ($r^2 = 0.03$ to 0.79) (Keiner, Sander, Wirth, & Schmidtbleicher, 2014; Marković, Sekulić, & Marković, 2007; Peterson, Alvar, & Rhea, 2006; Spiteri, Cochrane, Hart, Haff, & Nimphius, 2013).

It is assumed that the different correlations are the result of different test protocols. However, different COD tests possess different durations, lengths, and degrees of change of direction and are therefore influenced by different variables (Kadlubowski et al., 2019; Keiner et al., 2014). A standardized considera-

tion of the tests does not seem possible, but the length and approximate total time of the tests (TriT [10 m, 2.9 to 3.5 s] vs. IAT [approximately 65 m, 14.0 to 18.0 s]) demonstrate the different requirements of the tests (Kadlubowski et al., 2019). To the authors' knowledge, there is no investigation that has (1) analyzed the influence of LS performance, concentric power and maximum strength on change of direction performance without a decision making processes (as indicated by the IAT, 505, GewT, and TriT) in elite youth soccer players and (2) compared the calculated influence on the different COD tests. It was hypothesized that LS performance has the highest influence on COD performance and that the influence of these variables increases as the length of the COD test decreases.

Methods

Experimental approach to the problem

The used tests were carried out on 4 test days within a 2-week period. On test day 1, the LS performance was analyzed first, followed by the SJ. Two days later, on test day 2, the one repetition maximum (1 RM) was determined. One week later, the COD tests were performed on 2 separate testing days. Based on the total distance in ascending order, to avoid

fatiguing effects, the COD tests were performed. On testing day 3, the 505 and IAT were performed, and on testing day 4, the TriT and GewT were performed in the described order. One week before test day 1, the study participants completed a familiarization session on two separate days (day 1: LS, SJ, 1RM; day 2: 505, TriT, GewT, IAT).

Subjects

A total of 67 male youth soccer players (height: 1.78 ± 0.06 m; weight: 70.1 ± 7.95 kg; age: 17.54 ± 2.1 years old) were recruited from the under 17-years-old (U17), under 19-years-old (U19) and amateur (U23) teams of two youth elite training centers. The youth soccer teams played in the highest German junior divisions (the U17 Bundesliga and the U19 Bundesliga). The U23 players played in the 5th highest German league. The soccer players performed 4 to 5 soccer sessions per week (1.5–2 training sessions/day) and competed on the weekend. All participants had played soccer since their early childhood and therefore were very highly trained relative to others their age. The soccer players were used to the 1RM, LS and SJ tests because they were part of their semi-annual performance diagnostics routine. The participants did not participate in fatiguing training sessions for a minimum of 3 days before testing. None of the participants reported any injuries at the time of testing.

Each participant and his parents (if the participant was not 18 years old) were informed about the experimental risks involved with the research. All participants and their parents (if the participant was not 18 years old) provided written informed consent to participate in the present study. Furthermore, approval for this study was obtained from the institutional review board (German University of Health and Sport, No. 01/2019.92002800). The study was performed with the use of human participants in accordance with the Helsinki declaration.

Testing protocol

For maximum strength, a 1RM squat measurement was used. The warm-up (two sets of 6–8 reps) was performed with a submaximal, nonfatiguing amount of weight or squats. Then, the 1RM was determined during a maximum of five attempts. The depth of the squat was standardized to be approximately when the top of the thigh was parallel to the floor.

The warm-up for testing days 1, 3 and 4 consisted of nonspecific running with low-to-medium intensity for approximately 5 min. Then, coordination exercises, such as running with lifted knees, heeling, and side stepping, were performed for approximately 5 min. Afterwards, the athletes completed a 5-min dynamic stretching program (standing scales, hand walks, lunge steps with twisting and lateral lunges with rotation). Subsequently, three acceleration runs over approximately 30 m were performed with short intervening walking breaks. Overall, the total warm-up time on each test day was 20 min.

The subjects performed three attempts per COD test, which were separated by a 3-min break. The TriT were performed three times right and three times left around. The best trial was used for the statistical analysis. The description of the test setups can be found in the literature as follows: 505 (Nimphius, Callaghan, Bezodis, & Lockie, 2018), IAT (Guarav, Singh, Singh, & Rathi, 2011), GewT (Desch & Lottermann, 2003) and TriT (Keiner et al., 2014). If the pylons or hurdle bars were knocked down or touched during COD testing, a follow-up attempt was completed. The tests were separated by a break of 15 min. LS performance was measured for a distance of 10 m. Each athlete also had three attempts. Between each completed sprint, the athletes received a 3-min break (Thomas & Nelson, 2001). The time was measured for all tests with a double-timing gate system (Browser TC Timing System, Biederitz, Germany). The starting point was marked with a small cap 0.75 meters away from the starting gate to avoid early triggering, e.g., by a hand movement or a bent body position. The subjects inde-

pently chose when the measurement began according to the activation of the barriers. Thus, the reaction time was excluded from the measurement.

Jumping performance were measured using a contact mat (Refitronic, Schmitten, Germany) that operates as a switch. This system sent information to the computer regarding whether the mat was loaded. From this information, the flight time and the jump height were determined for all jumps. The jump height was calculated from the flight time ($gt^2/8$; g = the gravitational acceleration [$9.81 \text{ m} \cdot \text{s}^{-2}$] and t = flight time). The squat jump was initiated at a knee angle of 90° without counter movement. The participants had five trials in which to achieve their best result. Between every jump, the athletes received a 1-min break.

Statistical analyses

The data were analyzed using SPSS 26.0 (IBM, Ehningen, Germany). The significance level for all statistical tests was set at <0.05 . Descriptive statistics for all measures in each age group are presented as the mean $\pm$ standard deviation (SD). For the soccer players ($n = 67$), the Kolmogorov-Smirnoff test for normal distribution confirmed the normality of the group's data.

Reliability analyses were performed using the intraclass correlation coefficient (ICC) and a 95% confidence limit. The magnitudes of the ICCs analysis were classified according to the following thresholds: $0 < \text{ICC} < 0.1$ = very weak correlation, $0.1 \leq \text{ICC} < 0.3$ = weak correlation, $0.3 \leq \text{ICC} < 0.5$ = moderate correlation, $0.5 \leq \text{ICC} < 0.7$ = strong correlation, $0.7 \leq \text{ICC} < 0.9$ = very strong correlation, $0.9 \leq \text{ICC} < 1.0$ = nearly perfect correlation and $1 =$ perfect correlation (Shrout & Fleiss, 1979).

Furthermore, a bivariate Pearson correlation analysis was used to assess the relationship between the different COD tests and the linear-sprint, concentric power and maximum strength. The best time for each test was used for the statistical analysis.

Benjamini and Hochberg's method, which was used to control the study-wise false discovery rate, was 0.05.

Results

The calculation by the Kolmogorov-Smirnov showed that all parameters were normally distributed. The COD performance on all the different tests, the ICC and the 95% confidence intervals (95% CIs) for the performance tests are provided in **Table 1**. The ICCs of the tests were greater than 0.70, so the values indicate a very strong to nearly perfect correlation and therefore a good reliability according to Shrout & Fleiss (1979).

The Pearson product-moment correlation coefficients between the different COD tests and the LS performances, concentric power and maximum strength performances are shown in **Table 2**. The highest significant correlation was calculated between the TriT-L and the 10 m LS performance ($r^2 = 0.39$) and between the 505 and the 10 m LS performance ($r^2 = 0.36$), while the least significant coefficients were found between the TriT-L and the 1 RM ($r^2 = -0.09$) and between the 505 and the 1 RM ($r^2 = -0.07$). There was no significant correlation between the GewT and the SJ ($r^2 = -0.02$) and the 1 RM ($r^2 = -0.01$) or between the IAT and the 1 RM ($r^2 = -0.04$). After adjusting for the study-wise false discovery rate, the largest p value that was significant was $p = 0.0169$.

Discussion

The study was designed (1) to evaluate the influence of LS performance, concentric power and maximum strength on change of direction (COD) performance in elite youth soccer players and (2) to compare the calculated influence on the different COD tests. The results showed that the performance parameters had a different (heterogeneous) influence on COD performance. In general, the LS performance had the greatest impact on COD performance ($r^2 = 0.18$ to 0.39). However, SJ performance had a weak to strong influence on COD performance ($r^2 = -0.19$ to -0.29), which is in line with research from other studies (Alem-

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Influence of linear-sprint performance, concentric power and maximum strength on change of direction performance in elite youth soccer players

Abstract

Change of direction (COD) performance has an essential role in soccer. In the literature, there is a wide range of explained variance in correlation analyses between linear-sprint performance, concentric power and maximum strength and COD performance. Therefore this study has (1) analyzed the influence of linear-sprint performance, concentric power and maximum strength on COD performance in elite youth soccer players and (2) compared the calculated influence on the different COD tests. To answer the research questions, 67 elite youth soccer players were tested. The linear-sprint (10 m, [LS]) performance, concentric power (squat jump [SJ]) and maximum strength (1 repetition maximum [1 RM]) and COD (measured via the Illinois agility test [IAT], the 505 agility test [505], the agility test of the German Soccer Association [GewT], and the triangle test [TriT]) were assessed. The Pearson correlation analysis was used to assess the relationship. Benjamini and Hochberg's method, which was used to control the study-wise false discovery rate, was 0.05. The LS performance had the greatest impact on COD

performance with a wide range of explained variance between the different COD tests ($r^2 = 0.18$ to 0.39). However, SJ compared to LS performance had lower influence, but also a wide range of explained variance ($r^2 = -0.02$ to -0.29). Correlations for 1 RM and COD test were calculated with $r^2 = -0.01$ to -0.09 . Thus, (1) the greater the similarity between the performance tests (i.e., LS, SJ, 1 RM) and the COD tests, the higher the explained variance between the variables in question. Furthermore, (2) as the different COD tests are affected to different degrees by linear-sprint, concentric power and maximum strength performance, it might be concluded that the tests have a different physiological requirement profile. Therefore, coaches and sport scientists must review and select different tests with logical validity, based on the requirement profiles of soccer.

Keywords

Athletic performance · 505 agility test · Illinois agility test · 1 repetition maximum · Squat jump

daroglu, 2012; Salaj & Markovic, 2011; Schultz et al., 2015). Only the GewT did not significantly correlate with SJ performance. The maximum strength only significantly correlated with 505 and TriT performance ($r^2 = -0.07$ to -0.09), which is supported by results from Marković et al. (2007).

In general, the overall results that LS performance showed higher correlations than SJ and 1 RM performance with COD performance do not seem surprising. When considering changes of direction, linear acceleration, deceleration and COD components can be derived. The acceleration component is directly reflected in one of the recorded variables, the LS performance. In principle, a high rate of explanation of COD performance was thus expected. This finding is in line with other results ($r^2 = 0.22$ to 0.56) (Draper & Lancaster, 1985; Gabbett et al., 2008; Lockie et al., 2013; Nimphius

et al., 2016; Young et al., 2015). Interestingly, shorter distance (≤ 10 m with 1–2 turns) COD tests (i.e., the TriT and 505) correlate more strongly ($r^2 = 0.36$ to 0.39) to LS performance (10 m) than the longer distance tests (20 m to 65 m with 6 to 11 turns; $r^2 = 0.18$ to 0.26 , respectively). The highest correlations between two variables are assumed to have the highest possible agreement in terms of neuronal, metabolic and/or morphological demands. Due to the similarity in the lengths and speeds of the shorter CODs and those of the LS performance, the higher correlation can be deduced logically (Vescovi & McGuigan, 2008). However, this observation could be also an accidental finding because the TriT-R had a lower correlation with $r^2 = 0.26$. However, the higher correlations of LS performance with IAT compared to GewT might be possibly due to one or

Table 1 Reliability of the performance variables		
Fitness test	Mean $\pm$ SD	ICC (95% CI)
TriT-R	3.21 $\pm$ 0.14 s	0.94 (0.91–0.96)
TriT-L	3.19 $\pm$ 0.16 s	0.89 (0.84–0.93)
505	2.21 $\pm$ 0.1 s	0.85 (0.77–0.9)
GewT	7.65 $\pm$ 0.33 s	0.78 (0.67–0.86)
IAT	14.36 $\pm$ 0.6 s	0.97 (0.96–0.98)
10-m LS	1.74 $\pm$ 0.07 s	0.89 (0.84–0.93)
SJ	37.1 $\pm$ 4.44 s	0.97 (0.96–0.98)
1 RM	91.90 $\pm$ 17.96 kg	0.99 (0.98–1.00)

Mean test scores $\pm$ standard deviations and reliability data for all players
 ICC intraclass correlation coefficient, CI confidence intervals, 505 505 agility test, IAT Illinois agility test, GewT Gewandtheitslauf, TriT-L triangle test left around, TriT-R triangle test right around, SJ squat jump, 1 RM one repetition maximum, 10-m LS 10-meter linear sprint, s seconds, kg kilogram

Table 2 Correlation and determination coefficients for the change of direction tests and linear sprint performance, concentric power and maximum strength				
Fitness test		10-m LS	SJ	1 RM
TriT-L	r	0.623*,**	–0.432*,**	–0.299*,**
	r ²	0.39	–0.19	–0.09
TriT-R	r	0.512*,**	–0.529*,**	–0.303*,**
	r ²	0.26	–0.28	–0.09
505	r	0.601*,**	–0.54*,**	–0.260*,**
	r ²	0.36	–0.29	–0.07
GewT	r	0.428*,**	–0.153	–0.091
	r ²	0.18	–0.02	–0.01
IAT	r	0.506*,**	–0.437*,**	–0.205
	r ²	0.26	–0.19	–0.04

505 505 agility test, IAT Illinois agility test, GewT Gewandtheitslauf, TriT-L triangle test left around, TriT-R triangle test right around, SJ squat jump, 1 RM one repetition maximum, 10-m LS 10-meter linear sprint
 *Level of significance ($p < 0.05$), ** $p < \text{false discovery rate of } 0.05 \text{ for this study}$

more of the four 10 m linear sections in the IAT.

The correlation coefficient of SJ and COD was lower than LS and COD performance, which is in line with the hypothesis. The SJ is a measure of concentric force development, and various studies show high correlations between the SJ and acceleration (Schultz et al., 2015), but not as complex as the COD tasks. The more complex COD task is, the lower the chance of transfer of concentric power, which can probably be argued reflecting the task specificity of the central nervous system (Carroll, Riek, & Carson, 2001). Various studies have shown that there are specific adaptations to the joint angles, movement speeds and contractions selected during training (Carroll et al., 2001; Rutherford & Jones, 1986). In a logical manner, the corre-

lations between CODs with shorter distances (≤ 10 m with 1 to 2 turns; $r^2 = -0.19$ to -0.29) are at least higher than those for the GewT (20 m with 6 turns; $r^2 = -0.02$). However, this fact is not true for the IAT (about 65 m with 11 turns; $r^2 = -0.19$), which is possibly again due to one of the four 10 m linear sections in the IAT.

Also in line with the hypothesis 1 RM showed lower explained variances to the COD tests than LS performance and SJ. However, there are many studies that show moderate to strong correlations ($r^2 = -0.29$ to 0.34) between the 1 RM and the LS performance and SJ (Carlock et al., 2004; McBride et al., 2009). Following the logic of this argument, the influence of the 1 RM on COD performance can also be accepted. It is also assumed that a high maximum strength level is related to deceleration, possibly because of the

effect of the high eccentric load of this movement. In the literature, there are high correlations ($r^2 = 0.31$) between eccentric and dynamic maximum strengths (Wirth, 2011). Therefore, the present study showed a significant but small correlation ($r^2 = -0.07$ to -0.09) between the 505 and the TriT and maximum strength. However, these correlations are smaller than those calculated in other research ($r^2 = -0.53$ to -0.72 ; Nimphius, McGuigan, & Newton, 2010). The difference in the calculated correlation coefficients between that study and this study may have been due to the more heterogeneous performance level of the participants in the study of Nimphius et al. (2010), which levelled out the potential overestimation of the real correlation coefficients for elite athletes.

Overall, the data from this investigation assumed that the COD tests correlated moderately with speed performance. Other authors recommend to optimize leg strength to improve COD performance (Jones, Bampouras, & Marrin, 2009; Lehanç, Binet, Bury, & Croisier, 2009). Therefore, it must be considered that maximum acceleration in short distances plays a crucial role in soccer performance (Barnes, Archer, Hogg, Bush, & Bradley, 2014). Additionally, some longitudinal studies showed that strength performance has a significant influence on speed, jumping and COD performance (Keiner et al., 2014; Sander, Keiner, Wirth, & Schmidtbleicher, 2013). Because of this, maximum strength training represents an adequate training intervention to improve COD performance in soccer. Additionally, in line with this argument, the correlations between the 1 RM and the performance of the longer distance CODs (i.e., the IAT 65 m; Lockie et al., (2013) and GewT 36.6 m; Desch & Lottermann (2003)) did not achieve level of significance and had lower coefficients ($r^2 = -0.01$ to -0.04). This again highlights the different influences of LS performance, concentric power and maximum strength on different COD tests.

It is important to point out that the ICC of the GewT was lower than that of the other tests, and therefore, the calculations from the GewT should be consid-

ered with caution. However, the level reliability (ICC = 0.78 [CI 95%: 0.67–0.86]) can still be classified as acceptable (Shrout & Fleiss, 1979).

Conclusions

Data from this investigation, in general, show that change of direction (COD) performances are influenced by linear-sprint (LS) performance, concentric power and maximum strength. Therefore, in general, maximum strength and plyometric strength training is recommended to increase COD performance. The results show that LS performance showed higher correlations than squat jump (SJ) and one repetition maximum (1 RM) performance with COD performance. Furthermore, the data show the greater influence of LS performance, concentric power and maximum strength variables on shorter COD tests. Alternatively, the performance of longer distance CODs with more turns is influenced more by other variables, such as metabolic capacity or task-specific variables (e.g., degree of turning, speed of turning). As the different COD tests are affected to different degrees by LS, concentric power and maximum strength performance it might be concluded that the tests have a different physiological requirement profile. Therefore, the tests analyzed in this study do not seem to measure a 'general' ability to change direction, but task-specific performance. Therefore, coaches and sport scientists must review and select different tests with logical validity, based on the requirement profiles of soccer.

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Compliance with ethical guidelines

Conflict of interest. B. Kadlubowski, M. Keiner, T. Stefer, A. Kapsecker, H. Hartmann and K. Wirth declare that they have no competing interests.

All procedures performed in studies involving human participants or on human tissue were in accordance with the ethical standards of the institutional and/or national research committee and with the 1975 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

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