Determinants Analysis of Change-of-Direction Ability in Elite Soccer Players

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[1]*Tunisian Research Laboratory "Sport Performance Optimization," National Center of Medicine and Science in Sports, Tunis, Tunisia;* [2]*Fiorentina Football Club, Florence, Italy;* [3]*Department of Health and Physical Education, The Hong Kong Institute of Education, Hong Kong, China;* [4]*Higher Institute of Sport and Physical Education of Ksar-Saïd, University of Manouba, Tunis, Tunisia;* [5]*Football Training and Biomechanics Lab, Technical Department, Italian Football Federation, Florence, Italy; and* [6]*Marche Regional School of Sport, Italian Olympic Committee, Ancona, Italy*

Abstract

Chaouachi, A, Manzi, V, Chaalali, A, Wong, DP, Chamari, K, and Castagna, C. Determinants analysis of change-of-direction ability in elite soccer players. *J Strength Cond Res* 26(10): 2667–2676, 2012—In this study, we examined the components of 2 change-of-direction (COD) ability (CODA) tests in elite-level male soccer players ($n = 23$, age 19 ± 1 years, height 181 ± 5.7 cm, body mass 73.2 ± 4.1 kg, % body fat 11 ± 2.4). As CODA paradigms, the T-test and 5-m shuttle run-sprint (5mSS) test assumed as describing the opposing ends of the COD complexity in soccer (i.e., general and specific tests, respectively) were considered. Results showed that the anthropometric and muscular performance variables were able to account for ~45% ($p < 0.04$) of the common variance of CODA. The T-test performance was explained by 8 variables (adjusted $R^2 = 0.45$, $p = 0.026$), with 5mSS, height, knee extensors isokinetic concentric strength at 60°·per second, and right-to-left knee extensors eccentric strength deficit reaching a level of significance in the provided model ($p \leq 0.02$). The best-fitting equation for 5mSS performance included 10 variables (adjusted $R^2 = 0.48$, $p = 0.036$) of which T-test performance, height, percentage of body fat, and peak power during the countermovement jump resulted significantly affecting the common shared variance ($p \leq 0.03$). This study finding showed that the affecting variables of CODA differ according to the test characteristics. Furthermore, the magnitude of the reported associations suggests that currently CODA should be regarded mainly as a task-specific fitness attribute. Further studies are warranted to detect more relevant performance variables to describe CODA. Meanwhile, soccer coaches and fitness trainers are advised to improve players' CODA using training drills that mimic crucial match actions.

Key Words team sports, fitness training, power, strength, agility, eccentric training

Introduction

Soccer like other team sports is considered as a casually intermittent activity involving sudden variation in directional modes that parallel game-related changes in intensity (45). As a consequence, the ability to perform sudden changes of direction (CODs) is considered as a logically valid criterion for fitness detection in soccer players of different age, competitive level, and gender (38–40,45). The premises that support the logical relevance of COD ability (CODA) in soccer come from the observation of only a limited amount of match time spent by players with ball possession (37,45). Consequently, most of the ~1,300 changes in activity are deemed to be undertaken in off-the-ball conditions (37,45). This reasoning has been recently supported by observational studies that showed frequent variation in directional changes during a competitive match in elite soccer players (8,9).

Despite the perceived and provided evidence of CODA relevance, only few studies have been published with the aim to examine the nature of this fitness component in soccer (12,42). Furthermore, no soccer-specific CODA test has been developed so far based on observational studies; consequently, the tests used to assess this ability possess at best only logical validity or are general in nature (12,38,42,45).

This should be considered an important limitation to soccer physical fitness assessment and development because CODA has been reported to be task specific in observational and training studies (12,13,31,38,42,45,48,52).

In the absence of a gold standard for CODA, soccer players are evaluated with a number of tests aiming to capture a range of neuromuscular abilities that may cover the causal requirements imposed by the match (i.e., tactical strategies, opponent levels, and fatigue development) (13,31,38–40,48).

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As a result, the used CODA tests may possess a different degree of association with game activities and they spread along the test specificity spectrum according to their relevance to soccer (12,45).

The tests aiming to assess CODA may be grouped according to the number and type of the directional changes involved in the trial (12). These features may result in differences in the neuromuscular prerequisites necessary to sustain test performance (12,42). In this regard, Sheppard and Young (42) proposed a universal agility multicomponent model in which CODA was supposed as a systematic module. However, to the best of our knowledge, this model was not tested as per estimation power with relevant variables in soccer (12,42). Information about the components of CODA may discover the important issues in guiding training prescription and intervention studies in soccer.

Therefore, the aim of this study was to examine the general and specific CODA performance (i.e., logical constructs) and to evaluate the neuromuscular determinants (i.e., deterministic constructs) of CODA in elite soccer players. As a work hypothesis, we assumed the logical validity of the deterministic model provided by Sheppard and Young (42,43) for CODA in soccer.

Methods

Experimental Approach to the Problem

In this observational-deterministic research, a group of well-trained elite soccer players were studied for general and specific CODA (i.e., logical constructs) (46). As general CODA test was assumed, players' performance over the T-test reported to be a reliable and valid test in team sports and physical education (7,12,16,24,33,41,42). The T-test involving sudden CODs and directional modes with a duration of ~10 seconds can be considered as mainly involving neuromuscular performance components, thus limiting the influence of metabolic fatigue on the final score (12,16,24,41).

Shuttle running has been extensively reported to be a team sports–relevant directional mode (12,30,35,42). In a study carried out with Norwegian top-level soccer players, shuttle running-sprinting (i.e., 10 m) was reported to be a soccer-specific ability (48). More recently, shuttle running-sprinting showed to be associated with match physical activities performed at high intensity in elite-level professional soccer players (i.e., English Premier League) (35). This provides direct validity (14) for this COD mode in elite-level soccer.

In this study, the specific CODA was represented by the 5-m shuttle run-sprint test (5mSS; 5-m go-and-back = 10 m) involving only 1 COD (i.e., 180° turn) according to the general information provided by Barnes et al. (6). These authors reported that in team sports, players are mostly subjected to sharp COD (i.e., 180° turn) during sprints of ~5 m (6). Consequently, COD tests involving these characteristics would likely be ideal for specific CODA assessment in team sports. Specifically, in competitive soccer, functional shuttle running takes the form of very short sprints supporting the relevance (i.e., logical specificity) of the 5mSS for soccer CODA assessment (8,9,45,48).

These 2 short-duration (i.e., <10 seconds) tests were considered with the preplanned aim to represent the upper and lower end of the complexity spectrum of CODA with respect to the concepts of generality and specificity (i.e., T-test and 5mSS, respectively) for soccer (42).

In an attempt to describe agility, Sheppard and Young (42) proposed a universal multifactorial deterministic model supposing logical validity. In this universal deterministic model of agility, CODA assumed a key role and was considered as the interplay of a number of physical and neuromuscular components (42). However, to the best of our knowledge, no investigation has been carried out so far to examine the supposed association between independent variables (i.e., neuromuscular and anthropometric variables) and the afferent dependent variable (i.e., CODA performance). According to the deterministic model for agility proposed by Sheppard and Young (42), test scores for straight sprinting speed, lower-limb reactive strength, concentric strength and power, and left-right strength balance were included in the systematic module of CODA. In addition to the proposed model, measures of lower-limb eccentric strength were considered in this study (42). This is because in COD, eccentric strength is deemed to be involved to maintain joint congruence and to exert braking actions to allow directional changes (12,23,29,44). As neuromuscular components of the universal model for agility proposed by Sheppard and Young (42), 5-m sprinting, countermovement jumping, and 5-jump test (5JT) were considered for their reported relevance to soccer performance and fitness (3,15,45,48). According to its reported diagnostic importance in soccer, muscular strength (eccentric and concentric) was reported as isokinetic strength (1,2,19).

Subjects

Twenty-three elite-level male soccer players (age 19 ± 1 years, height 181 ± 5.7 cm, body mass 73.2 ± 4.1 kg, % body fat 11 ± 2.4) were randomly chosen among members of a successful first division professional soccer club of the Tunisian National League 1 (Club Africain, Tunis, Tunisia). The club is considered as one of the top 3 ranked teams in Tunisia for the past 15 years. All players involved in this study had competed at national and international level for their respective age-groups. Twelve players were members of the Tunisian national under-21 team, and the remaining 11 belonged to the under-19 team that ranked first during the 2007–08 season (i.e., assessment year). Players possessed at least 6 years of experience in soccer training and competitions at elite level, and took part in national or international championships at the time of the investigation. Players trained 5–6 times a week (~90 minutes per session) with a competitive match taking place during the weekend. Training sessions consisted mainly of technical and tactical skill development (80% of the training time). Physical conditioning was performed twice a week and was aimed toward anaerobic and aerobic performance development (5). Anaerobic training consisted of plyometrics and sprint training drills (5). Aerobic fitness was developed using small-sided games (36) and short-interval or long-interval running (26).

Testing procedures were performed during the last stage of the competitive season (February to March 2007). During the 48 hours preceding testing, players refrained from heavy training and kept their usual daily activities. To avoid dehydration, players were advised to drink "ad libitum" during the testing procedures and to remain in a high-carbohydrate diet the day before and during the time of the investigation.

Written informed consent was obtained from all players after verbal and written explanation of the experimental design and potential risks of the study. The study was conducted according to the Declaration of Helsinki and the protocol fully approved by the Clinical Research Ethics Committee and the Ethic Committee of the National Center of Medicine and Science in Sports of Tunis before the commencement of the assessments. All players were informed that they could withdraw from the study at any time without penalty.

Procedures

All the players were well accustomed to the procedures involved in this study because they were part of their testing follow-up during this study and preceding seasons. To re-arouse testing procedure, players performed a familiarization session during the week preceding testing, with test leaders (first authors) providing a procedural advice when necessary. To limit circadian effect on performance, the testing procedures were performed during the first hours of the afternoon (3–5 PM) when team practice usually took place.

Each subject completed testing over 3 separate sessions with at least 48 hours of recovery in-between. The period between the first and the last tests was within 2 weeks to avoid any change in the physical fitness of the subjects during the testing period. The tests included the 5mSS and T-test for agility, vertical and horizontal jump tests, 30-m sprint, and isokinetic testing (concentric and eccentric contractions) of the knee extensors and flexors. Vertical and horizontal jumps were assessed during the first session, whereas the sprinting ability and CODA were assessed during the second testing session. The third session was dedicated to the isokinetic tests. The week before testing, subjects attended 2 practice sessions, during which they became familiar with the testing equipment and procedures. All anthropometric measurements were obtained during the familiarization sessions.

Anthropometry. Body mass was obtained to the nearest 0.1 kg using an electronic scale (Seca Instruments Ltd., Hamburg, Germany). Height was measured to the nearest 0.1 cm using a stadiometer (Holtain Ltd., Crymych, United Kingdom). Skinfold thickness at 4 sites (biceps, triceps, subscapular, and suprailiac) was measured using a Harpenden calliper (Lange, Cambridge, MA, USA). To increase measurement reliability, the skinfold sites were measured 3 times by the same investigator, with the average value used for data analysis. Percentage of body fat was estimated using the equations described by Durnin and Womersley (21).

Jump Testing. Vertical jump performance was assessed using a portable force platform (Quattro Jump; Kistler, Winterthur, Switzerland). Players performed a countermovement jump (CMJ) according to the protocol described by Bosco et al. (10). Before testing, players performed self-administered submaximal CMJs (2–3 repetitions) as a practice and specific additional warm-up. Subjects were asked to keep their hands on their hips to prevent any influence of arm movements on the vertical jumps and to avoid coordination as a confounding variable in the assessment of the leg extensors neuromuscular performance (16). Each subject performed 3 maximal CMJs, with ~2 minutes recovery in-between. Players were asked to jump as high as possible and the highest jump was used for analysis. Reliability of the CMJ has been shown in previous studies from our laboratory to be very high (16–18).

A quintuple horizontal jump test (5JT) was also performed by each player (15). The 5JT required the subject attempting to cover the greatest horizontal distance possible by performing a series of 5 forward jumps with alternated left and right foot contacts. Immediately before the 5JT, players were instructed to begin and end with their feet parallel. The participants were instructed to move forward using their preferred leg. The 5JT performance was measured, with a measuring tape, as the distance from the front edge of the player's feet at the starting position to the rear edge of the feet at the final landing position. The assessor at landing had to focus on the last stride of the player to determine exactly the last footprint because the players could not always stay on their feet at landing. The starting position was settled on a fixed point. Subjects were allowed 3 trials, with the longest distance used for analysis. The intraclass correlation coefficient (ICC) and *SEM* for the 5JT were reported to be 0.96 and 0.2, respectively (17), in a population similar to that considered in this study.

Sprint and Change of Direction Testing. All sprint and COD times were recorded to the nearest 0.01 second using the same electronic timing system (Brower Timing Systems, Salt Lake City, UT, USA). The running speed of players was evaluated with 30-m sprints (with 5- and 10-m split times also recorded). The subjects performed 3 maximal 30-m sprints on an indoor synthetic track. During the recovery period between 30-m sprints (2–3 minutes), the subjects walked back to the starting line and then waited for their next sprint bout. When ready, the subjects began the sprint from a standing start 0.5 m behind the first timing gate. Stance for the start was consistent for each subject. The run with the shortest 30-m time (and corresponding 5- and 10-m split times) was selected for analysis. Data from our laboratory for 24 soccer players (with similar characteristics to the sample of this study), who performed sprint test on 2 separate occasions, yielded an ICC and SEM of 0.96 and 0.02, respectively.

The T-test was administered using the protocol outlined by Semenick (41). Four cones were arranged in a T-shape, with a cone placed 9.14 m from the starting cone (photocell gates 2 m apart) and 2 further cones placed 4.57 m on either side of the second cone. Subjects were asked to sprint forward 9.14 m from the start line to the first cone and touch the tip with their right hand, shuffle 4.57 m left to the second cone and touch it with their left hand, then shuffle 9.14 m right to the third cone and touch it with their right hand, and shuffle 4.57 m back left to the middle cone and touch it with their left hand before finally back pedaling to the start line. Trials were deemed unsuccessful if participants failed to touch a designated cone, crossed their legs while shuffling, or failed to face forward at all times. Only 1 timing gate placed on the start-finish line was used for timing the T-test. Subjects performed 3 trials and the fastest time from 3 trials was used as the T-test score. Previous research from our laboratory showed T-test to be highly reliable, with an ICC and SEM of 0.96 and 0.1, respectively (17).

For the 5mSS, 2 lines (start line and 5-m line) were marked on the ground, 5 m apart. The subject sprinted from the start line and then turned 180° on the front line 5 m apart, to sprint back crossing the starting line again. One timing gate placed on the start-finish line was used for timing the 5mSS. Only trials that had players stepping on the front line at the 180° turn were considered valid. Players performed 2 valid 5mSS trials, with the fastest retained for calculations (2-minute recovery between trials). Change of direction was performed freely with the preferred foot of the subject. The ICC and SEM for the 5mSS (i.e., test-retest design, $n = 24$) were 0.91 and 0.05, respectively.

Isokinetic Testing. Isokinetic concentric and eccentric knee extensor (quadriceps) and flexor (hamstrings) strength of both limbs was assessed at an angular velocity of 60°·per second using an isokinetic Cybex II Norm dynamometer (Cybex NORM; Henley Healthcare, Cybex International, Inc., Medway, MA, USA), according to Chamari et al. (15). The concentric strength of the quadriceps and hamstrings was assessed during continuous (bidirectional) knee extension-flexion movements. A pause of 1 second was allowed between extension-flexion movements to avoid a contribution to hamstring torque from the previous quadriceps action. Eccentric muscle strength was measured during dual concentric-eccentric actions of the same muscle group. The order of tests was concentric extensor, concentric flexor, eccentric extensor, and eccentric flexor. Testing was preceded by a standardized warm-up procedure including cycling and hamstring and quadriceps dynamic stretching exercises. As part of the warm-up, the subjects sat on the Cybex Norm dynamometer and were secured to both the dynamometer and the corresponding chair according to the manufacturer's specifications to minimize extraneous movements and to maintain a constant hip joint angle (90°). After height, limb mass, gravity correction, and individual-specific full range of knee motion were recorded, subjects performed a set of 4–5 submaximal leg extension and flexion contractions on the isokinetic dynamometer at 180°·per second as a specific warm-up. After a 3-minute rest, the participants were asked to perform 5 maximal concentric and eccentric repetitions with a rest period of 3 minutes between sets, and the highest peak torque values of the flexors and extensors of each leg were used for the analysis. Five repetitions were chosen because it is acknowledged in the literature that no more than 5 repetitions are necessary when assessing strength (11). The limb tested first was randomly chosen for each participant. After testing, the participants completed a 5-minute cool-down period on a cycle ergometer. Bilateral muscle strength imbalance was calculated using the formulae (right leg − left leg/right leg × 100).

Statistical Analyses

Data are presented as mean ± *SD* and confidence intervals at 95% level (95% CIs). Before any parametric statistic was performed, the assumption of normality was tested with the Shapiro-Wilk test on each variable. Association between variables was assessed using Pearson's correlation coefficient. Magnitude of correlation was qualitatively ranked according to Hopkins (25) as follows: trivial $r<0.1$, small $0.1 < r < 0.3$, moderate $0.3 < r < 0.5$, large $0.5 < r < 0.7$, very large $0.7 < r < 0.9$, nearly perfect $r > 0.9$, and perfect $r = 1$. The Sheppard and Young (42) deterministic model for CODA was tested using a linear model (i.e., forward stepwise multiple regression). The model assumed as constructs of CODA the 5mSS or T-test (i.e., dependent variables). According to Sheppard and Young (42), the following variables were considered as components of the universal agility model proposed: (a) body mass, percentage of body fat (% body fat), height, leg length, and body mass index as representatives of anthropometry; (b) 5-m sprint performance as straight sprinting speed factor; (c) CMJ peak power (CMJ-PP) as power factor; (d) 5JT performance as a reactive strength measure (15); (e) quadriceps and hamstring concentric (QuadConc and HamConc, respectively) and eccentric (QuadEcc and HamEcc, respectively) isokinetic strength at 60° per second (mean of the right and left limbs) as dynamic strength factors (19,28); and (f) percentage of difference of right versus left concentric and eccentric isokinetic strength (60° per second) of quadriceps (QuadCImb% and QuadEImb%, respectively) and hamstrings (HamCImb% and HamEImb%, respectively) muscles as representative of left-right muscle imbalance.

Median-split technique was used to assess the likelihood of difference between players scoring high or low with respect to CODA performance (i.e., T-test and 5mSS test).

Table 1. Multiple correlation summary of the deterministic model assuming T-test as a dependent variable.*

T-test	Beta (*SE*)	*B* (*SE*)	*p*	R^2	Step
5mSS	0.64 (0.20)	1.32 (0.41)	0.006	0.15	1
Height	0.93 (0.27)	0.05 (0.01)	0.003	0.29	2
QuadConc	−0.88 (0.30)	−0.01 (0.01)	0.011	0.37	3
QuadEImb%	−0.44 (0.18)	−0.01 (0.01)	0.029	0.43	4
QuadEcc	−0.55 (0.28)	−0.04 (0.01)	0.066	0.50	5
5-m sprint	0.29 (0.18)	0.96 (0.62)	0.145	0.55	6
CMJ-PP	0.38 (0.22)	0.02 (0.01)	0.104	0.59	7
% Body fat	0.40 (0.26)	0.05 (0.03)	0.139	0.65	8

*Step = forward stepwise regression variable inclusion step; 5mSS = 5-m shuttle run-sprint; QuadConc = quadriceps concentric isokinetic strength at 60° per second; QuadEImb% = percentage of difference of right vs. left eccentric isokinetic strength of quadriceps muscles; QuadEcc = quadriceps eccentric isokinetic strength at 60° per second; CMJ-PP = countermovement jump peak power.

Multivariate analysis of variance with a between-group design was used assuming as dependent variables T-test and 5mSS performances split into 2 groups according to the median score (i.e., best and worst performers groups). Preliminary assumption testing was conducted to check for normality, linearity, univariate and multivariate outliers, homogeneity of variance-covariance matrices, and multicollinearity. The same test scores as dependent variables were used as per the multiple regression analysis. The independent variables were group difference in T-test and 5mSS scores.

Practical significance was assessed by calculating the Cohen's *d* effect size (0.1 = trivial, 0.2 = small, 0.5 = medium, 0.8 = large) and eta square (η^2; small = 0.01, medium = 0.06, large = 0.14). The reliability of the tests used in this study was assessed with ICCs before the commencement of the study in a population of soccer players and ranged from 0.91 to 0.96 (47).

Results

Using T-test as a dependent variable (15 model independent variables), the forward stepwise multiple regression showed best fit after 8 steps ($R = 0.81$, $R^2 = 0.65$, adjusted $R^2 = 0.45$, $F_{8,14} = 3.25$, $p = 0.026$). The best fit for the 5mSS performance was achieved with a 10-step model ($R = 0.85$, $R^2 = 0.72$, adjusted $R^2 = 0.48$, $F_{10,12} = 3.03$, $p = 0.036$). Details of the forward stepwise multiple regressions are reported in Tables 1 and 2.

Significant effects ($p < 0.05$) were obtained for 5mSS, height, QuadConc, and QuadEImb% for the T-test model, and for T-test, height, % body fat, and CMJ-PP for the 5mSS model. Using the "median-split" technique, the soccer players were divided into 2 groups (best and worst) according to the median T-test (T-test$_{best}$ and T-test$_{worst}$) and the 5mSS (5mSS$_{best}$ and 5mSS$_{worst}$) scores. The player with the median time value was excluded to obtain 2 subgroups with the same number of participants ($n = 11$).

There was a statistically significant difference between T-test$_{best}$ and T-test$_{worst}$ on the combined dependent variables ($F_{4,17} = 4.65$, $p = 0.01$, $\eta^2 = 0.52$). When the results for the dependent variables were considered separately, statistically significant differences were observed in sprint time over 5 m ($F_{1,20} = 7.52$, $p = 0.0013$, $\eta^2 = 0.273$), CMJ-PP ($F_{1,20} = 5.20$, $p = 0.034$, $\eta^2 = 0.206$), 5mSS ($F_{1,20} = 4.99$, $p = 0.037$, $\eta^2 = 0.200$), and hamstring peak eccentric torque ($F_{1,20} = 5.49$, $p = 0.030$, $\eta^2 = 0.215$) (Table 3). No significant

Table 2. Multiple correlation summary of the deterministic model assuming 5mSS test as a dependent variable.*

5mSS	Beta (*SE*)	*B* (*SE*)	*p*	R^2	Step
T-test	0.59 (0.18)	0.29 (0.09)	0.008	0.15	1
QuadCImb%	0.15 (0.21)	0.01 (0.01)	0.489	0.29	2
Height	−1.43 (0.40)	−0.04 (0.01)	0.004	0.35	3
% Body fat	−0.62 (0.23)	−0.04 (0.01)	0.020	0.44	4
CMJ-PP	−0.48 (0.19)	−0.01 (0.01)	0.027	0.50	5
Leg length	0.75 (0.43)	0.03 (0.02)	0.109	0.58	6
QuadEImb%	0.41 (0.21)	0.01 (0.01)	0.074	0.63	7
QuadConc	0.66 (0.35)	0.01 (0.01)	0.081	0.66	8
QuadEcc	0.42 (0.30)	0.01 (0.01)	0.182	0.69	9
5JT	−0.26 (0.25)	−0.05 (0.05)	0.331	0.72	10

*Step = forward stepwise regression variable inclusion step; QuadCImb% = percentage of difference of right vs. left concentric isokinetic strength of quadriceps muscles; CMJ-PP = countermovement jump peak power; QuadEImb% = percentage of difference of right vs. left eccentric isokinetic strength of quadriceps muscles; QuadConc = quadriceps concentric isokinetic strength at 60° per second; QuadEcc = quadriceps eccentric isokinetic strength at 60° per second; 5JT = 5-jump test.

Table 3. Summary of the multivariate analysis of variance statistics (significant differences, $p \leq 0.01$) using the median-split technique for T-test score.*

	T-test_{best} (mean ± *SD*)	T-test_{worst} (mean ± *SD*)	Mean difference	95% Confidence interval	Magnitude of the difference	
					Effect size	Interpretation
CMJ-PP (W)	34.38 ± 5.73	30.02 ± 2.76	4.36	0.26 to 8.47	0.206	Large effect
5-m sprint (s)	1.07 ± 0.07	1.16 ± 0.08	−0.93	−0.16 to −0.02	0.284	Large effect
Time 180° (s)	2.82 ± 0.09	2.95 ± 0.13	−0.13	−0.24 to −0.03	0.200	Large effect
HamEcc 60° ($N\cdot s^{-1}$)	−174 ± 22	−148 ± 28	−25.36	−47.95 to −2.78	0.215	Large effect

*CMJ-PP = countermovement jump peak power; HamEcc = hamstring eccentric isokinetic strength at 60° per second.

difference between the variables of interest was found when the groups were formed according to the 5mSS score.

Discussion

This is the first study that has examined the components of CODA in elite-level soccer players using the Sheppard and Young (42) universal model components for agility. The main finding of this study was the existence of explanatory models that were moderately successful in describing the determining variables of the CODA tests considered here in elite soccer players.

Change-of-direction ability is considered as a relevant fitness variable in team sports (12,42). However, despite the supposed importance of CODA, no universal gold standard is currently available for its assessment (12,16,42). Furthermore, there are several constructs that have been proposed in the international literature to define CODA (6,12,42).

Recently, Sheppard and Young (42) proposed CODA as a systematic component of agility considered as a physical performance attribute possessing a strong cognitive component. The CODA was defined by Brughelli et al. (12) as the ability to change direction while sprinting over a preplanned course. Despite the logical validity of this definition, no universal test is currently available in team sports and the attempts to develop specific tests provided protocols that at best possess logical validity (12,16,42,43). The CODA tests may be successfully classified according to the number of CODs considered in the test protocol and complexity of variation in movements (12).

In this study to assess the CODA in elite-level soccer players, 2 tests were used that differed for CODs number and exercise modes involved (i.e., 5mSS and T-test). The T-test initially developed for CODA assessment in basketball progressively acquired team sports interest for its feasibility, validity, and reliability (7,12,16,33,41). Indeed, the T-test, involving lateral and backward running switching from short sprinting, mimics the movement pattern considered as relevant in most of the team sports (12).

Shuttle run-sprinting performance is considered as a pertinent activity in elite soccer and descriptive studies suggested to consider it as a "per se" ability (22,27,31,35,45,48). In this study, we used the T-test and the 5mSS test, as logical representative of general and specific CODA test paradigms in soccer, respectively. The independence of the 2 tests used as agents of the ideal CODA spectrum ends (i.e., universality vs. specificity) was supported by the moderate and non-significant correlation between 5mSS and T-test ($n = 23$, $r^2 = 0.14$, 95% CI −0.03 to 0.69, $p = 0.07$).

The CODA is commonly considered as a multifactorial fitness attribute of team sport players. Sheppard and Young (42) proposed a universal multicomponent model to describe the supposed determinant of CODA. However, they did not provide information about the specific nature of the components proposed. In this study, the logically valid framework of the universal multicomponent model was challenged using a number of performance variables that were considered relevant to soccer physical performance and assumed as representative of the component constructs (19,40,45,48). Differently from what originally proposed by Sheppard and Young (42), the deterministic model was fed with variables describing lower limb eccentric strength as well (28). This was undertaken because CODA involves fast acceleration that converts into sudden decelerations requiring high–eccentric strength gradients (12,42).

Multiple correlation analyses showed that 8 and 10 variables determined the best-fitting model for the T-test and 5mSS test, respectively (Tables 1 and 2). Interestingly, in both models, CODA performance, anthropometry, strength, and muscular imbalance provided significant effect in the predicting equations. However, the adjusted R^2 resulting from best fitting ranged from 0.45 to 0.48, showing that the explanatory strength of the models was moderate.

These findings are similar to those recently reported by Jones et al. (28) who studied the physical determinants of COD speed in a population ($n = 38$) of university students who were involved in recreational sport activities. These authors reported that the explanatory terms (i.e., short-term linear sprinting and isokinetic eccentric strength) used were able to explain ~67% (using R^2) of the common variance of COD (i.e., 505 test) performance (42). Unfortunately, Jones et al. (28) did not report the adjusted R^2 to characterize the population goodness of fit, and consequently, the generalization of their findings is doubtful.

In this study, the considered line-sprint component (i.e., 5-m sprinting) showed only a marginal effect on the predictive model differently from what was reported by Jones et al. (28). Indeed, in the Jones et al. (28) study, the flying 5-m sprint accounted for ~58% of the COD variance.

The difference found between the studies may be because of the populations assessed and may suggest specific training adaptations in soccer players (45). Interestingly, the effect of linear sprinting was detected by the proposed model only for the general CODA test in this study (i.e., T-test) and in recreational athletes in the Jones et al. (28) study. This finding challenges the consideration of straight sprinting speed (i.e., 5 m) as a factor in the soccer-specific component model of CODA. It could be argued that the sprint distance considered in this study may have had an impact on the explanatory strength of the straight sprinting speed component in the model. In this study, player's sprint performance was also assessed for the 10 and 30 m according to what was suggested by Cometti et al. (19). Results showed that the 5-m sprint time was almost perfectly and very largely correlated with the 10 m ($r = 0.97$, $p < 0.0001$, 95% CI 0.94–0.99, $n = 23$) and 30 m ($r = 0.74$, $p < 0.0001$, 95% CI 0.46–0.88, $n = 23$) sprint scores, respectively. Furthermore, the 10-m sprint performance was very largely associated with the 30-m scores ($r = 0.85$, $p < 0.0001$, 95% CI 0.67–0.93, $n = 23$). The resulting high collinearity and the evidence-based soccer sprinting pattern suggested the introduction of the 5-m test as representative of linear sprinting performance in the predicting model considered (19,45,48).

The findings of this study are in line with other research reports that suggested CODA as not being influenced by forward sprinting ability in soccer (12,45,48). It is of interest to note that the CODA tests employed in this study showed a mutual influence on the relative explanatory models despite absence of collinearity. This suggests that simple CODA, as represented by 5mSS performance, may play a role in the more articulated CODA test (i.e., T-test) performance when associated with ideal anthropometric and muscular conditions and vice versa.

Muscle power and strength variables only marginally explained the CODA performances. Despite the supposed effect in either deterministic model, the quadriceps and hamstring eccentric strength played a marginal role. Specifically, eccentric strength yielded a significant support to CODA determinism only in T-test model when assumed as eccentric strength imbalance between the right and left legs. However, the models' best fitting showed to be optimized by the introduction of eccentric strength variables (Tables 1 and 2).

It could be speculated that probably the considered expression of eccentric strength (i.e., isokinetic strength at 60°) was the cause of the resulting marginal effect of this type of contraction regimen on CODA. Consequently, future studies using more functional eccentric strength variables (i.e., assessed at higher angular velocities) are warranted.

These results are different from those reported by Jones et al. (28) who showed a significant effect of hamstring isokinetic eccentric strength at 60° on a CODA test similar to 5mSS. These differences may be partly explained by difference in training background (recreational athletes vs. elite soccer players) and the nature of the explanatory variables used.

Reactive strength is considered as a measure of the ability to change rapidly from an eccentric to a concentric action (42). In CODA and agility studies, measures of reactive strength have been performed using a depth jump (DJ) from various drop heights (6,12,20,28,51). Despite the supposed effect of reactive strength, the studies that examined the association between CODA and DJ performance only reported moderate associations (i.e., correlation coefficient) (6,12,20,28,51). Indeed, in the reported studies, the shared variance (i.e., r^2) between CODA and DJ performance ranged from 0.13 to 0.22, an effect that was dramatically lower than the critical 0.50 threshold that should be exceeded to justify generality (46). According to these findings, the use of DJ as a measure of reactive strength in CODA studies is questioned.

In this study, the 5JT was considered as testimonial of reactive strength (15). Recent studies showed that 5JT was a valid and reliable test in elite-level soccer players (15). Furthermore, 5JT performance showed large association (i.e., $r = -0.61$, $p = 0.02$) with T-test in elite-level male basketball players (16). The rationale that informed the introduction of the 5JT in the predictive models was its greater functional relevance to CODA performance compared with classic variables of reactive strength such as DJ performance (12,15,16,42,49). Despite the supposed relevance to COD performance, results showed only a marginal effect of 5JT in 5mSS performance.

This finding and those of others do not provide evidence to justify the inclusion of reactive strength in the specific model of CODA in soccer (6,12,20,28,51). However, it could be speculated that at the moment, a functional measure of reactive strength has yet to be found in soccer (45). In this regard, training and descriptive studies using several measures of reactive strength are warranted.

Muscle power has been suggested to be an explanatory variable of CODA (42). According to Young et al. (50), CMJ-PP was considered as a variable representing muscle power in this study. Peak power during CMJ showed to be significantly ($p = 0.027$) associated with 5mSS performance (Table 3) only. This finding was different from what was previously reported in other studies that showed trivial and nonsignificant relationship between CMJ power or height and CODA test performance (12,42). The selective association of CMJ-PP and CODA (i.e., 5mSS vs. T-test) may be explained with CODA test complexity (42). Sheppard and Young (42) suggested that probably CODA test complexity (i.e., distance covered and number of change in directions) was related to variability in acceleration and deceleration before changing in direction and in technique, which may have affected the magnitude in association between CMJ performance and CODA test results. Indeed, in the only study reporting significant association between CMJ and CODA performance, the considered test involved only 1 COD like in this study (32).

In this study, the effect of muscle imbalance on CODA was examined considering the right-to-left difference in concentric and eccentric strength of knee extensors and flexors. Although measures of muscle imbalance were entered in both the T-test and 5mSS explanatory models, the association resulted significant only for the former test. Specifically, the higher the player right-to-left imbalance (QuadEImb%), the better the T-test performance. This is quite an unexpected finding that suggests that eccentric asymmetry of knee extensors should be considered as an advantage in multi-direction agility tasks (i.e., forward, sideward, and backward running). It could be speculated that players during T-test performance used as pivoting leg their right lower limb. The studies that examined muscular imbalance effect on CODA performance reported no supporting evidence; consequently, this study finding was quite unexpected. With the descriptive nature of this study, it was not possible to explain the reason underpinning this finding and this warrants further studies. Future research should focus on more functional strength imbalance measures to evaluate its relationship with COD technique (42).

Anthropometry was proposed to have potential in affecting COD speed (12,16,42). Body composition (i.e., body mass and percentage of body fat) has been reported to affect T-test performance in elite male professional basketball players (16). Indeed, Chaouachi et al. (16) found very large (i.e., $r = 0.80$, $p < 0.001$) and large (i.e., $r = 0.58$, $p < 0.05$) associations between T-test performance and percentage of body fat in elite male basketball players. In this study, percentage of body fat significantly contributed to the 5mSS prediction model suggesting that in 180° CODA tests, the amount of body fat may result detrimental.

Other anthropometric factors that may potentially be related to CODA are players' height, lower limb length, and center of gravity height (42). In this study, players' height accounted significantly to the explained variance of T-test and 5mSS models. Leg length only marginally contributed to the 5mSS variance (Table 2).

These findings suggest that shorter height and or a lower center of mass may be an advantage in soccer players when attempting sharp COD and more complex COD tasks. A possible explanation of this result may be that players with lower center of mass could be conceivably able to apply horizontal forces more effectively than taller players, with shorter time required to lower the center of gravity to perform a quick lateral COD (12,42).

The within-group cross-sectional designs enable tracking of independent variables that are associated with the partitioning construct (i.e., dependent variable) (17). This analysis method constitutes an explorative strategy useful to gain information to guide training interventions through descriptive (i.e., time independent) studies (i.e., static screening) (46). In this study, with the aim to simulate training effects, players were grouped according to their CODA performance (i.e., discriminative construct, T-test, and 5mSS test) using the median-split technique (17). Players possessing greater-than-median T-test performance reported better performance also in some of the supposed attributes of the multicomponent model (42). Specifically, soccer players scoring high in the T-test showed superior performance also in CMJ-PP, 5-m sprinting, and 5mSS performance. Furthermore, they showed higher eccentric strength of hamstrings. Interestingly, the same statistical procedure (i.e., median-split technique) was not successful in discriminating model component variables when grouping players according to their 5mSS performance. These findings may be considered as evidence of the supposed different nature of the CODA tests used. The more complex protocol of T-test, involving superior demand on balanced movement skill, may partly explain the reported differences.

The 5mSS performance paralleled difference in T-test performance suggesting that short-term shuttle running ability can favorably affect more complex COD tasks as those involved in the T-test. This provides support to the results obtained by the forward stepwise regression analysis when challenging the T-test universal CODA model. However, this was not a biunivocal occurrence because T-test was not able to discriminate between best and worst performance groups when 5mSS was considered as a dependent variable.

Unfortunately, with this research design (i.e., descriptive correlational design), it was not possible to disclose the reasons underpinning this difference. However, it could be speculated that movement or protocol complexity played a role in the discriminative ability of the performance components considered here.

Interestingly, eccentric strength level of hamstrings showed to discriminate between T-test performance groups. These results are in line with those reported by Jones et al. (28) that showed association between CODA performance and hamstring isokinetic eccentric strength in recreational athletes. Findings of descriptive studies in association with enhancement of short-sprint performance in soccer players as a consequence of eccentric strength hamstring improvement suggest the importance of eccentric hamstring strength in complex CODA tasks (4,28). It could be speculated that this was the result of hamstrings acting as mediators of the breaking forces occurring during sudden change of movement and directions (12).

In light of the findings of this study, the CODA universal proposed model failed to fully explain the performance in the 5mSS test and T-test. Indeed, a number of the variables used to represent the supposed explanatory model constructsdid not affect the estimation of the CODA tests. Acceleration ability, muscular strength, and body makeup showed to be predictors of CODA in this population of elite-level soccer players. Further studies using more relevant CODA tests to soccer performance and functional representative of model constructs are warranted. In this context, lower limb internal and external rotational peak torque and abductors/adductors power may be considered in further studies. Even though not currently and widely assessed, these 2 functional performances are involved in most, if not all, CODA tasks. We therefore hypothesize that including such functional performances could empower the COD explanatory model.

Practical Applications

When acceleration abilities are required such as in team sports, the body composition of players should be considered. Elite soccer players should get rid of excess of body fat to optimize their ability to perform sudden COD with large angles (from 90 to 180°). This can be favorably achieved as soccer is not a collision sport and players different from football and team handball do not require fat to dampen opponent impacts during crucial part of the game (34). Eccentric strength training should be considered for improving maximal dynamic strength of knee extensor and flexor muscles.

The information provided by this study results support the already reported notion of training prescription specificity for CODA (12,42). With the current gained evidence, soccer strength and conditioning coaches should elaborate CODA drills that replicate the most frequent and challenging action of the match (45). In this regard, sport scientists interested in soccer should carry out descriptive studies (i.e., match and time-motion analyses) to better detect movement pattern during soccer competitions. Studies aiming to develop soccer-specific CODA tests are warranted.

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