Construct Validity and Applicability of a Team-sport-specific Change of Direction Test

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Abstract

BACKGROUND Cuts and fast changes of directions (COD) are frequent movements during games in team sport. As those movements are seen as a key performance parameter in team sport, COD assessments are included in performance diagnostics. However, some tests are criticized as they seem to be confounded by parameters such as linear sprinting performance. Therefore, it is suggested that not only the total COD time should be assessed, but also the athletes' COD movements should be examined in more detail. For example, split times could be analyzed in tests with more than one COD such as the Team-Sport-Specific COD test (TSS-COD) which was developed as a modified version of the Handball Agility-Specific test. We aimed to investigate the construct validity of TSS-COD, focusing on the homogeneity of the different test parts. We also tested how far sprint performance maps onto COD performance.

METHODS Test data were analyzed from 154 elite male and female volleyball and basketball athletes. Explorative principal component analysis (PCA) was calculated including the test interval durations and the athletes' 5, 10, and 20 m sprint performance, to test the validity of TSS-COD.

RESULTS PCA results showed that the COD start interval formed a factor separate from the other COD sub-intervals. In addition, sprint performance was separated from all COD interval measures. The findings were confirmed by split-half validation.

CONCLUSIONS Sprint and COD performance represent independent performance domains. The validity of the TSS-COD test can be increased further by either subtracting the duration of the start interval from the total time or starting assessments after the start interval.

Key Points

This study suggests that using a Change of direction (COD) test with a high number of CODs and without “longer” sprint intervals may reveal an independent performance factor in players that is not related to sprint performance. We therefore suggest TSS-COD to be a valid and applicable tool to measure COD performance in team sports. Because the tests first interval is specific to the TSS-COD test, one recommendation could be to subtract IV1 time from TSS-COD total time to gain even more valid information about specific COD speed in performance diagnostics

Introduction

In many team sport games, on-court performance is characterized by quick changes-of-direction (COD), and intermittent high-speed sprinting [1–6]. In basketball, for example, almost 400 changes-of-direction are performed per game [7]. It is assumed that athletes that are highly skilled in COD have an advantage especially in offensive and defensive 1-on-1 situations, e.g., when fighting for positional advantage [8, 9]. Since this can be decisive for winning in sport games, sprinting and change-of-direction tasks are included in performance diagnostics [5, 10, 11]. Specifically, COD skills are defined as decelerating and re-

accelerating the entire body for a given directional change [12]. In the last decade, there has been lots of research on parameters influencing COD performance [8, 12–17]. From a mechanical perspective, athletes need to quickly accelerate when running up to the COD location first, which is followed by a braking phase, where the athlete has to withstand high eccentric forces. The moment of the final foot contact is defined as plant phase [15]. Current literature suggests, that the penultimate and final foot contact determine COD performance with shorter ground contact time leading to faster CODs [8, 9, 14, 18, 19]. Moreover, Suchomel et al. (2016) reported that, depending on the entry velocity in the plant phase and the severity of COD angle, the rate of force development (RFD) is also critical for COD tasks [20]. When reaching the turning point, the velocity of the center of mass needs to be changed into a new direction [21]. Therefore, athletes have to plant their foot and rotate their body towards the intended movement direction [14, 21]. In this phase, it seems beneficial to keep the body's center of mass close to the ground as this maximizes the ability to apply force and impulse in the intended direction [8, 9, 22, 23]. During the propulsive phase, where athletes need to re-accelerate as fast as possible, primarily concentric forces must be applied [8]. According to Spiteri et al. (2015) the maintenance of a lower body position is also beneficial in the propulsive and braking phase as body displacement needs to be controlled to improve the force transfer into the new direction. Furthermore, triple extension of the lower body can be optimized which allows to rapidly extend the hip to increase propulsion [8]. Summing up, leg muscle qualities like eccentric, concentric, isometric strength, and RFD seem to be parameters determining COD performance [8, 20, 24]. Additionally, running technique (foot-strikes, center-of-mass movement, trunk position, hip orientation, knee flexion) [9, 13, 23, 25] and the athletes' anthropometrics (body weight, size) and age seem to influence COD performance [8, 26–28]. Greater body height, for example, is considered a disadvantage because taller athletes need to overcome greater inertial resistance during deceleration and re-acceleration of the body mass [26].

Like COD performance, sprint speed is determined by the athletes' ability to quickly accelerate by applying great force and performing steps with only short ground contact times [20, 29]. RFD is frequently used to measure the ability to increase force as quickly as possible [30]. Among other parameters, RFD is shown to be associated with sprint performance [31–35]. Previous research reports high correlations between maximum lower-body strength and power, and sprinting performance, especially for the first meters [17, 20]. Since sprint and COD performance both consist of propulsive horizontal accelerations and are influenced by force-dependent variables, kinetic parameters, and body composition, the question arises, how accelerating sprint and COD performance relate to each other. Although several studies have already investigated relations between sprint and COD performance, findings on how far these explain independent variance sources have been inconsistent. In 2005, Little and Williams (2005) investigated the specificity of acceleration, maximum speed, and COD speed in soccer players using the Zigzag test (100° angle, three CODs) and a flying 20-m sprint [2]. They report significant correlations between these measures, however, the common variance was only 39%, which led the authors to reject a close connection between sprint and COD performance. Gabbett et al. (2008) investigated athletes via the 505-test, a modified 505-test, and the L-run-test, and reported significant associations to sprint speed [1]. Popowczak et al. (2019) examined two different 30-m COD designs: first, a forward-backward running

task showing high correlations to linear sprinting, and second, a forward-sideward COD task revealing only small correlations [36]. One reason for the differing results might be the design of the COD tasks since they differ in sprint distance, number of turns, or turning angles. Therefore, e.g., the stride pattern, the application of force in different axes, as well as biomechanical and neuromuscular parameters need to be adjusted [15, 37]. In their review, Sugiyama et al. (2021) reported that, up until now, 48 different tests are used to assess COD performance in basketball [38]. Considering the different demands imposed on the athletes by different test designs, it seems to be crucial to first acknowledge the specific demands and movement patterns of the sport being investigated prior to choosing the right COD test [39–41]. In basketball, for example, studies suggest that athletes are exposed to extensive, sometimes high-intensity, intermittent demands, that change every 1-3 s [42]. Except for linear sprints in the midfield, court behavior is characterized by short, fast attacks covering an average maximum distance of 9.48 m [43]. Therefore, the major characteristic seems to be powerful and quick accelerations and decelerations in different directions. In volleyball, 83.7% of rallies last less than 10 s, with male rallies being even shorter than female rallies. As for the distances covered, 45.7% are between 5 and 10 m and 85.3% are less than 15 m [44]. Hence, COD tests such as shuttle runs (e.g., 5 x 10-m distances lasting about 20 s) do not measure the volleyball-specific COD demands [45–47]. In both aforementioned sports, athletes cover mostly short distances with sideward movements often occurring after only a few steps of forward running [6]. Therefore, an adequate COD test should include CODs in different angles and directions and not long-distance linear sprints.

One COD test fulfilling these aforementioned criteria is the so-called Handball Agility-Specific Test (HAST) [10]. It includes forward and backward accelerating and decelerating phases as well as diagonal movements [10]. Five CODs with different angles are executed within a 5 x 5-m square. Because the test uses short durations and distances in addition to different angles and movement directions, it corresponds nicely to the demands of both volleyball and basketball [11, 15]. Until now, the total time of this test has been used to determine COD speed [10, 48]. However, as Nimphius et al. (2016, 2018) stated, using total time as the only performance indicator in COD measurements might, first, be influenced by linear sprinting time in tests that have few CODs and cover longer distances; and, second, it conceals temporal information about the individual COD actions [12, 13]. Therefore, HAST was modified by attaching sensors to the COD cones, representing the time interval boundaries between cone 1 to 2, cone 2 to 3, cone 3 to 4, and so forth. To avoid confusion due to test names, in the following we shall refer to the current version as the “Team-Sport-Specific COD” test (TSS-COD).

Within this study, we aimed to investigate if TSS-COD is a valid tool to assess COD performance in team sport. Due to the design (five CODs within 25 m distance) and the short test duration, we assumed that COD and sprint times can be separated into different domains.

1. Materials And Methods

To address the abovementioned question, the TSS-COD was included in a sequence of tests carried out as part of longitudinal performance diagnostics with elite basketball and volleyball athletes. Performance

diagnostics were administered three times a year. Each team was measured in its training center. The warm-up and measuring routine were both standardized. The warm-up (15 min) consisted of mobilization, dynamic stretching, movement preparation, neural activation, and individual preparation. Afterward, athletes performed general and sport-specific performance diagnostics that included sprint and COD testing. All tests were performed in a randomized order. Anthropometric tests were also administered to assess weight, height, and armspan. The TSS-COD procedure was explained to the athletes in each diagnostics session. After observing the experimenter executing the test slowly with verbal instructions, participants had one trial to familiarize themselves. There was no external start signal; athletes started whenever they wanted. The starting line was set 1 m behind the light barrier (see Figure 1). After the run-up to the first cone (from the light barrier to the first cone: 5 m), they had to touch the first cone with the left hand and then the second and third cone with the right hand. Interval 4 (IV4) needed to be executed running backward, touching the fourth cone also with the right hand (see Figure 1). The fifth cone touch (i.e., cone number 2) needed to be performed with the left hand. The last interval (IV6) then needed to be performed backward, passing the light barrier marking the finish line. If participants turned around instead of running backward or failed to touch a cone with the appropriate hand, the attempt was stopped and repeated after a break of at least 60 s. Three trials had to be completed correctly in each performance diagnostics.

The study was approved by the local ethics committee of “Westfälische Wilhelms-Universität Münster” (Approval Number: 2015-48-MTF). All participants were informed about the procedure, risks, and purpose of data acquisition. They all gave their written consent. If participants were younger than 18 years, their parents were asked to give written consent. A total of 154 athletes (53 female, 101 male) were tested at least once. Age ranged from 10 to 36 years (mean = 17.29, SD = 5.31). All athletes were playing in a professional volleyball (n = 53) or basketball (n = 101) league or were part of a youth development program in volleyball or basketball. Mean height was 182.6 cm (SD = 11.2); mean weight was 72.6 kg (SD = 15.4). All anthropometric data are displayed in Table 1.

1.1 Measurement Setup

To detect IV times, a Fitlight© System (Visus GmbH, Herrenberg, Germany) was installed on top of the cones (numbers 1, 2, 3, 4). One Fitlight© sensor was used as a light barrier. It was placed facing horizontally on a tripod and programmed so that it started/ended the measurement when the participant passed it (Figure 1). In general, when one light was switched off, the light on the next cone came on automatically. IV times were calculated as the time between touches. Fitlight© System has already been used in previous investigations, showing a high reliability in COD testing (ICC = 0.88- 0.91) [49].

For the sprint tests, magnetic gates (Humotion GmbH) were used to measure 5-m, 10-m, and 20-m sprint time. System reliability has already been proven (ICC = 0.83 - 0.97) [50]. The sensor was attached to the athlete’s lumbar back with a special belt. As in the TSS-COD measurement, athletes were asked to

perform a flying start 1 m behind the first gate. After one familiarization trial, athletes had two more trials to sprint as fast as possible. A 60-s break between trials was mandatory.

Concerning anthropometric data, height was measured using a laser range finder (PLR 25, Bosch, Germany). Weight was determined with a scale. Two investigators used a tape to measure the armspan with the athlete in a lying position.

2.2 Data processing

The TSS-COD trial with the shortest total time was analyzed for each participant. From this trial, the respective IV times were extracted. TSS-COD total time was computed as the sum of IV durations. At the same date, the athletes' shortest sprint value was chosen and included. All supplementary data (age, anthropometrics) were assigned according to the date of the best TSS-COD and sprint trial. Data were then sorted (Microsoft Excel, Version 16.35, Microsoft Corp., Redmond, USA) and analyzed.

For the sprint data, 5-m time was subtracted from 10-m sprint time and 10-m time from 20-m time, resulting in a first phase (0–5-m time), a second phase (5–10 m), and a third phase (10–20 m). The data presented in this study are openly available in Open Science Framework at DOI 10.17605/OSF.IO/T4XUP.

Table 1
Descriptive statistics of the participants. cm = centimeter; kg = kilogram; Min = minimum; Max = maximum; *SD* = standard deviation; TT = total time; IV = Interval time. Interval and sprint times are displayed in seconds (s).

Total Sample				
<i>N</i> = 154	Min	Max	Mean	<i>SD</i>
Age (years)	10	36	17.29	5.31
Height (cm)	150.6	210.3	182.64	11.16
Weight (kg)	40.3	112.8	72.61	15.43
Armspan (cm)	150	220	187.97	13.27
IV1 (s)	0.88	1.37	1.19	0.11
IV2 (s)	0.90	1.57	1.22	0.15
IV3 (s)	0.79	1.46	1.11	0.12
IV4 (s)	1.34	2.21	1.73	0.17
IV5 (s)	0.88	1.46	1.16	0.12
IV6 (s)	0.88	1.42	1.15	0.12
TSS-COD TT (s)	6.33	8.95	7.55	0.61
0–5 m (s)	0.9	1.16	1.02	0.05
5–10 m (s)	0.66	0.9	0.78	0.05
10–20 m (s)	1.19	1.99	1.46	0.17

2. Statistics

Explorative principal components analysis (PCA) was calculated to analyze the relation of sprint and COD performance and uncover the respective performance structure. Because height and weight are parameters that may influence COD performance [13], we tested the robustness of the performance profile for the athletes' individual characteristics such as age, anthropometrics, and gender. To further confirm the results, a split half validation of the results was conducted.

Statistical analyses were calculated using IBM SPSS Statistics 26.0 (IBM Corp., Armonk, NY, USA). First, the correlation between TSS-COD IVs and sprint times was calculated using Pearson's *r*. The Bartlett test of sphericity and the Kaiser–Meyer–Olkin criterion were calculated to test whether the sample qualified for PCA. Afterward, the intercorrelation matrix of the selected variables was factorized using PCA. Eigenvalues (EV) and scree plots were used to define the number of significant principal components in

the matrix extracted by the PCA by retaining EV larger than 0.7 [51]. Varimax rotation was used to improve the interpretability of the PCA [52].

To avoid overestimating the TSS-COD IVs in the analysis, a balanced PCA was calculated including sprint variables and selected TSS-COD IVs. IV 2, 3, and 4 were included because they represented all movement directions of the TSS-COD (further described in the Results section). IV 1 was included because of its significant correlation to a separate factor in the previous analysis. Because it was assumed that TSS-COD and sprint times would be affected by anthropometrics or weight, multiple regression analyses were calculated including sprint times, TSS-COD IVs, and personal data, and t-tests were used post hoc. The significance level was set at $p < 0.05$ for all calculations. To detect whether the data structure (which was found in PCA) was affected by personal data, PCA was then calculated using the residuals of the previous regression analysis. Finally, to confirm the validity of the structure detected in PCA, a split-half validation was administered. The whole sample was divided into two groups, personal data were balanced between both groups (see Table 2), and PCA was then calculated for both groups. For all PCAs, rotated component matrices can be seen in Table 3; scree plots and Eigenvalues are displayed in Figure 2.

Table 2
Descriptive statistics of the participants grouped for split-half validation. cm = centimeter; kg = kilogram; Min = minimum; Max = maximum; *SD* = standard deviation.

Group 1				
<i>N</i> = 77	Min	Max	Mean	SD
Age (years)	10	36	17.32	5.35
Height (cm)	150.6	210	183.22	11.06
Weight (kg)	40.6	112	72.71	15.09
Armspan (cm)	150	219	188.68	13.95
Group 2				
<i>N</i> = 77	Min	Max	Mean	SD
Age (years)	11	35	17.26	5.3
Height (cm)	160.8	210.3	182.06	11.31
Weight (kg)	40.3	112.8	72.51	15.86
Armspan (cm)	165	220	187.27	12.6

Table 3

Principal components analysis, rotated components matrix (varimax with Kaiser normalization). Factor loadings < .3 were excluded. Declared variance after rotation in percent (%). The maximum factor loading for each variable in each PCA was marked. X: variable was not included in PCA.

	TSS-COD-Sprint			TSS-COD-Sprint (balanced)			TSS-COD-Sprint (residuals)		
Factor	1	2	3	1	2	3	1	2	3
IV 1			0.926			0.939			0.913
IV 2	0.876			0.924			0.891		
IV 3	0.657		0.488	0.593		0.574	0.565		0.548
IV 4	0.680	0.335	0.348	0.654	0.316	0.443	0.587	.349	0.401
IV 5	0.705		0.345	x			0.649		0.408
IV 6	0.701			x			0.641		
0–5-m sprint	0.319	0.788		0.342	0.758			0.797	
5–10-m sprint	0.515	0.587	0.392	0.502	0.562	0.465	0.380	0.720	0.356
10–20-m sprint		0.879			0.907			0.847	
% variance	74.59			79.66			71.25		

3. Results

On average, athletes took 7.55 s ($SD = 0.61$) to complete the TSS-COD. IV 3 showed the shortest duration (mean = 1.11 s, $SD = 0.12$), whereas backward running (IV 4) took the most time (mean = 1.73 s, $SD = 0.17$). Table 1 presents the descriptive analyses of participants, TSS-COD IV durations, and sprint times. Regarding the correlation analysis, every TSS-COD IV correlated significantly with 5-m and 10-m sprint time. However, only IV 4–IV 6 had a moderate correlation with the 20-m sprint. Within the TSS-COD, IVs correlated with each other except IV 1 and 2. Results are displayed in the correlation matrix (Table 4).

Table 4. Correlation matrix including TSS-COD interval times (1–6), TSS-COD total time (TT) and sprint times. Light gray: $r > 0.30$; darker gray: $r > 0.49$; dark gray: $r > 0.69$; black $r > 0.89$. Pearson = Pearson's r ; TT = total time; $N = 154$ for all cells; $**p < 0.001$.

		IV1	IV2	IV3	IV4	IV5	IV6	TSS-COD TT	0–5 m	5–10 m	10–20 m
IV1	Pearson	1		0.466	0.456	0.430	0.347	0.576	0.336	0.426	0.123
	<i>p</i>		0.303	**	**	**	**	**	**	**	0.128
IV2	Pearson		1	0.467	0.587	0.574	0.498	0.740	0.458	0.476	0.273
	<i>p</i>	0.303		**	**	**	**	**	**	**	0.001
IV3	Pearson	0.466	0.467	1	0.520	0.648	0.511	0.780	0.370	0.624	0.249
	<i>p</i>	**	**		**	**	**	**	**	**	0.002
IV4	Pearson	0.465	0.587	0.520	1	0.641	0.552	0.855	0.522	0.664	0.348
	<i>p</i>	**	**	**		**	**	**	**	**	**
IV5	Pearson	0.430	0.574	0.648	0.641	1	0.504	0.833	0.501	0.602	0.362
	<i>p</i>	**	**	**	**		**	**	**	**	**
IV6	Pearson	0.347	0.498	0.511	0.552	0.504	1	0.742	0.367	0.511	0.311
	<i>p</i>	**	**	**	**	**		**	**	**	**
TSS-COD TT	Pearson	0.576	0.740	0.780	0.855	0.833	0.742	1	0.569	0.730	0.373
	<i>p</i>	**	**	**	**	**	**		**	**	**
0–5 m	Pearson	0.336	0.458	0.370	0.522	0.501	0.367	0.569	1	0.704	0.544
	<i>p</i>	**	**	**	**	**	**	**		**	**
5–10 m	Pearson	0.426	0.476	0.624	0.664	0.602	0.511	0.730	0.704	1	0.469
	<i>p</i>	**	**	**	**	**	**	**	**		**
10–20 m	Pearson	0.123	0.273	0.249	0.348	0.362	0.311	0.373	0.544	0.469	1
	<i>p</i>	0.128	0.001	0.002	**	**	**	**	**	**	

The manifest variables of the correlation matrix were factorized using PCA. The Bartlett test showed a chi-squared of 703.4 ($df = 36$, $p < 0.001$) and KMO was 0.833. This indicated a substantial level of shared variance among the variables and therefore supported the application of PCA methods. Three factors were extracted that explained 74.6% of the variance. IV2–IV6 times correlated significantly with Factor 1, sprint times with Factor 2, and IV1 with Factor 3 (see Table 3). Because IV1 seemed to describe an isolated factor, it was entered into the balanced PCA in which a smaller number of items for the TSS-COD was included (Table 3). Again, durations of IV2 and IV4 correlated with the first factor extracted, sprint times with the second factor, and IV1 with the third factor ($KMO = .743$, $p < 0.001$). The model explained 79.7% of the variance.

Within the regression analysis, the dependent variables were TSS-COD IVs and sprint times; the independent variables were height, weight, armspan, age, and gender. As expected, TSS-COD IVs and sprint times were influenced by weight, age, and gender (Table 5). The calculated model explained 7.2–28.2% of the variance ($R^2_{\text{corr}} = 0.072\text{--}0.282$) in the TSS-COD and 12.2–38.1% of the variance ($R^2_{\text{corr}} = 0.122\text{--}0.381$) in sprint times.

Table 5

Regression analysis. Dependent variables: TSS-COD intervals and sprint times. Independent variables: weight, age, and gender. Height and armspan are not displayed because they revealed no significant effects in the post-hoc analyses.

		TSS-COD						Sprint		
		IV1	IV2	IV3	IV4	IV5	IV6	0–5 m	5–10 m	10–20 m
Main effect	$F(5, 148)$	3.37	13.02	11.66	8.8	8.81	4.06	8.96	19.81	5.25
	p	0.006	< 0.001	< 0.001	< 0.001	< 0.001	0.002	< 0.001	< 0.001	< 0.001
	R^2_{corr}	0.072	0.282	0.258	0.203	0.124	0.091	0.206	0.381	0.122
Post hoc										
Weight	$t(148)$		-2.93				-2.4			
	p		0.004				0.018			
Age	$t(148)$		-2.1			-2.14		-3.96		-4.11
	p		0.038			0.031		< 0.001		< 0.001
Gender	$t(148)$	3.07		5.73	2.59	3.97			5.79	
	p	0.003		< 0.001	0.011	< 0.001			< 0.001	

To detect whether the PCA structure was influenced by athletes' characteristics, another PCA was calculated including regression residuals (Bartlett test, $p < 0.001$, KMO = .808) in which 71.3% of the variance could be explained via extracting three factors. The standardized residuals loaded on the same factors as the variables (TSS-COD IVs, sprint time) did before (see Table 3).

In terms of split-half validation, the first half showed a chi-squared of 358.19 ($df = 36$) in the Bartlett test ($p < 0.001$, KMO = 0.703), the second half also displayed a significant test outcome (Bartlett, $p < 0.001$, KMO = 0.871). In the first half, extracting three factors could explain 74.5% of the variance (Table 6). As displayed in Table 6, IV1 loaded on a different factor than IV2–IV6; sprint times also loaded on a separate factor. In the second half, three factors explained 76.1% of the variance. IV1 also loaded on a factor of its own; IV2–IV6 and sprint on different factors. Compared with the first half, 10-m sprint time had a slightly higher load on Factor 1 than on Factor 3. However, because the difference was only .002, we could still interpret the structure as remaining the same, whereas sprint times differed from TSS-COD IVs, and TSS-COD IV1 turned out to be unique.

Table 6

Split-half validation: principal components analysis, rotated components matrix (varimax with Kaiser normalization). Declared variance after rotation in percent (%). Factor loadings < .3 were excluded. Maximum factor loading was marked for each variable in each PCA.

	TSS-COD-Sprint			TSS-COD-Sprint		
	First half			Second half		
Factor	1	2	3	1	2	3
IV1			0.934			0.934
IV2	0.903			0.869		
IV3	0.627		0.507	0.609	0.567	
IV4	0.672	0.319	0.428	0.619	0.417	0.321
IV5	0.712		0.320	0.662	0.503	
IV6	0.486		0.533	0.797		
0–5-m sprint		0.841		0.430		0.661
5–10-m sprint	0.484	0.629	0.405	0.500	0.485	0.498
10–20-m sprint		0.856				0.910
% variance	74.46			76.07		

4. Discussion

Because COD is viewed as a major performance parameter in team sports, it often gets assessed in performance diagnostics. In most cases, COD tests consist of linear sprints that include at least one COD. There are multiple test designs, all differing in COD count, COD angle, and different durations and distances to be covered [5, 13, 38]. Therefore, it is important for analyzing sport-specific movements to choose the test which fits the demands best. Because TSS-COD includes several CODs with different angles and only short distances, it seems appropriate to use this test in team sports such as volleyball or basketball [47, 53]. However, there is an ongoing discussion concerning the validity of COD assessments primarily because of the potential correlation of COD and sprint performance [1, 29, 41, 54, 55]. Therefore, TSS-COD IVs and sprint speed were analyzed in more detail. As assumed, intervals of TSS-COD did correlate with linear sprint speed. To reduce the number of manifest variables to fewer independent factors, PCA was used [4]. Even though there were medium to strong correlations between most variables, three factors could be extracted with PCA. The first factor included durations of TSS-COD IV times 2–6. The second factor summarized all sprint variables. We, therefore, assume that TSS-COD IV times represent a different domain than sprint times. This result is consistent with an investigation by Salaj and Markovic (2011) who also calculated a PCA [4]. These authors extracted four factors representing COD ability, sprint ability, concentric and slow jumps, and reactive jumping ability. However, they discussed

whether these results could be gender or age-specific. Therefore, in the current study, regression analysis was calculated including sprint, COD, and anthropometric data. The main parameters influencing TSS-COD IVs and sprint speed were gender, age, and weight. Importantly, when calculating PCA with the residuals of regression analysis, the results were unchanged. The fact that age, gender, height, weight, or armspan did not affect the determined performance clusters confirms our assumption that TSS-COD IV times differ from sprint performance. The validity of the factors extracted by PCA could also be shown in the split-half calculation. Once again, in the evaluated performance cluster, IV1 surprisingly seemed to represent a specific factor related to neither COD nor sprint ability. Looking at movement patterns appearing in this first IV, high acceleration followed immediately by high deceleration within the braking phase and a small angle (45 degrees) COD were specific to this IV (see Figure 1). In comparison, IV2, for example, had a smaller entrance speed based on a shorter distance between the cones and therefore less propulsion. Due to the decreased movement velocity, ground reaction forces can be assumed to be lower in IV2 [15, 56]. Additionally, in IV2 (as well as in IV3, IV5, and IV6) COD angle is less sharp (90 degrees) than in IV1 (and IV4), which allows to maintain high average movement velocity [15], which also predicts superior COD performance [57]. Especially in the braking phase of a COD, high eccentric strength is required to shift the momentum towards the required direction [8, 14, 24]. Spiteri et al. (2014) reported that eccentric and isometric strength provide the highest overall contribution to COD performance (about 50%) followed by maximal dynamic and concentric strength [24]. Eccentric strength, however, was detected as sole predictor of COD test performance, which shows the importance of braking capacity to improve re-acceleration [9, 24]. The authors state, that with higher severity and number of the directional changes in a COD test, the emphasis on braking capacity increases [24]. This might be one reason why fast accelerations in linear sprint tests do not predict short COD times but, instead, slower run-ups can lead to shorter times within a COD test [58]. The approach strategy, e.g., the degree to which a high initial speed within a change of direction is useful and the extent to which this value depends on the eccentric muscle strength of the athletes both still need to be investigated further. Within this investigation, participants might have adjusted rather than maximized their acceleration in IV1 to reduce entrance velocity for a smoother transition to IV2.

One factor, which was not analyzed within this investigation but is recently discussed refers to body side differences or side dominance in athletes [6, 59–62]. Dos Santos et al. (2019) showed that 49% of athletes investigated had side differences larger than 10% in the 505 test [61]. Hart et al. (2014) stated that side asymmetries lead to performance decreases of 5–10% [63]. Bishop et al. (2019) investigated bilateral deficits, showing effects on COD tasks, but not on linear sprinting [59]. Interestingly, side differences in muscle strength do not seem to affect COD performance [60]. However, this was investigated using only the 505 test and therefore needs further analysis. Because side differences seem to be an important factor, especially in team sport athletes, future diagnostics will need to execute TSS-COD in both directions. Additionally, video analysis should be conducted to allow qualitative COD analysis. This could be used, for example, to analyze the technique of a COD, which could be advantageous as this seems to be a trainable parameter affecting COD performance [64, 65].

In summary, TSS-COD is a valid tool to test COD performance. In PCA, TSS-COD IVs load on different factors than sprint times. Therefore, we assume that there is a sprint-independent COD ability represented by TSS-COD duration. IV1 stands out from the other variables. This might be due to a specific approach strategy used for the first COD in TSS-COD. Further qualitative investigations, e.g., by adding motion capturing, could help the athlete to develop a beneficial technique [13]. TSS-COD is an easily applicable assessment tool that should be performed in both directions to gain knowledge about side differences relevant to sport-game performance.

5. Conclusions

TSS-COD consists of several different angle CODs with only short distances between forward, sideward, and backward movements, and therefore reflects movement patterns of team sports such as volleyball, handball, or basketball. Calculating a PCA, we investigated the construct validity of the TSS-COD by integrating TSS-COD IV durations and sprint durations. Parameters were clustered in “COD performance”, “sprint performance” and “TSS-COD IV1”. Because TSS-COD IVs 2–6 were all grouped in the “COD performance” cluster, we propose that TSS-COD is a valid tool to assess COD performance, which is also valid in terms of anthropometrics, gender, or age.. Because IV1 is specific to the TSS-COD test, one recommendation could be to subtract IV1 time from TSS-COD total time to gain even more valid information about specific COD speed in performance diagnostics. This study suggests that using a COD test with a high number of CODs and without “longer” sprint intervals may reveal an independent performance factor in players that is not related to sprint performance. We therefore suggest TSS-COD to be a valid and applicable tool to measure COD performance in team sports.

Declarations

Ethics approval and consent to participate.

The study was approved by the local ethics committee of “Westfälische Wilhelms-Universität Münster” (Approval Number: 2015-48-MTF). All participants were informed about the procedure, risks, and purpose of data acquisition. They all gave their written consent. If participants were younger than 18 years, their parents were asked to give written consent.

Consent for publication.

Not applicable

Ability of data and materials.

The data generated and analysed during the current study are available in the Open Science Framework (OSF) at <https://osf.io>, reference number DOI 10.17605/OSF.IO/T4XUP

Competing interests.

Christina Willberg, Axel Kohler and Karen Zentgraf certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

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Authors' contributions.

Conceptualization, W.C., K.A and Z.K.; methodology, W.C., K.A. and Z.K.; formal analysis, W.C., K.A and Z.K.; investigation, W.C. and Z.K.; resources, W.C. and Z.K.; data curation, W.C. and Z.K.; writing—original draft preparation, W.C.; writing—review and editing, K.A and Z.K.; visualization, W.C.; supervision, Z.K.; project administration, W.C. and Z.K.; funding acquisition, Z.K. All authors have read and agreed to the published version of the manuscript.

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Figures

Figure 1

Design of the Team-Sport-Specific COD test (TSS-COD) based on Iacono et al. (2015). Arrows show running direction. FL: Fitlight® used as a light barrier to start/end the measurement; 2: Fitlight® of the middle cone needed to be touched twice, first with the right, then with the left hand.

Figure 2

Scree plots of PCAs with eigenvalues (EV) of the factor. Factors were retained if $EV > .7$. Points of inflection are marked in the graphs as a red circle.