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**Change of Direction Ability**

# Construct Validity and Applicability of a Team-Sport-Specific Change of Direction Test

*by*
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*Cuts and changes of direction (COD) are frequent movements during games in team sports. Since those movements are seen as a key performance variable, COD assessments are included in performance diagnostics. However, some tests are criticized as they seem to be confounded by variables such as linear sprinting. Therefore, it is suggested that not only total COD time should be assessed, but also the athletes' COD movements should be examined more closely. For example, split times could be analyzed in tests with more than one COD like the Team-Sport-Specific COD (TSS-COD) test. We aimed to investigate the construct validity of the TSS-COD test, focusing on the homogeneity of the different test parts. We also tested how far sprint performance mapped onto COD performance. Test data were analyzed from 154 elite male and female volleyball and basketball athletes. A Fitlight© System was used to assess duration of the TSS-COD test. For the sprint tests, magnetic gates (Humotion GmbH) were used to measure sprint time. Explorative principal component analysis (PCA) was conducted including the test interval duration and the athletes' 5, 10, and 20 m sprint performance, to test the validity of the TSS-COD test. PCA results showed that the 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 of the PCA were confirmed by split-half validation. Since sprint and COD performance represent independent performance domains within this analysis, we suggest the TSS-COD test to be a valid test to assess COD performance.*

***Key words***: *performance, principal component analysis, testing.*

## Introduction

In many team sport games, on-court performance is characterized by quick changes of direction (COD) and intermittent high-speed sprinting (Gabbett et al., 2008; Little and Williams, 2005; Salaj and Markovic, 2011; Young et al., 2002). In basketball, for example, almost 400 CODs are performed per game (Fox et al., 2020), which vary in their movement characteristics by virtue of in-game situations differing depending on the opponent, the score and so forth.

CODs are characterized by a change in the direction of movement, where an initial acceleration is followed by a deceleration in the same direction and acceleration in a (given) new direction (Nimphius et al., 2016). In this context, a short ground contact time of the penultimate, as well as the final foot contact, seems to lead to a fast COD time (Dos'Santos et al., 2017; Spiteri et al., 2015). Other factors that influence the change of direction time include the run-up speed, the angle of the change of direction, and the rate of force development (RFD) of the athlete (Suchomel et al., 2016). On top of that, body orientation seems to influence COD time (Spiteri et al., 2015), which means the general direction the lower body and the hip are facing while moving. Especially in striking and team sports, this direction is often given based on the position of the opponent or the net, for example in badminton, when one has to hit the shuttle on one side of the pitch and then

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return to the middle while still facing the opponent. Spiteri et al. (2015) and Suchomel et al. (2016) further emphasize the relevance of leg muscle qualities (eccentric, concentric, isometric strength, and the RFD) for a fast COD. In addition, the athletes' anthropometrics (body weight, size), age, and the body's center of gravity seem to influence COD performance (Dos'Santos et al., 2017; Spiteri et al., 2015). With a differing COD test design, also the stride pattern, the application of force in different axes, and biomechanical and neuromuscular variables need to be adjusted (Dos'Santos et al., 2018; Suarez-Arrones et al., 2020). COD performance as well as sprint speed are determined by the athletes' ability to quickly accelerate by applying force and performing steps with short ground contact times (Suchomel et al., 2016). Unlike sprinting, however, in game sports these CODs occur in different directions, with different angles, evolving from forward, sideward or backward movements. In addition, body orientation may or may not change during CODs, e.g., facing the same direction after the COD or facing a new direction. Based on the specific sport and position, some COD patterns occur more often than others, such as in volleyball, where facing the net is constantly required with no changes in body orientation during forward-backward CODs of attackers and sideward-sideward CODs of middle blockers.

It is assumed that COD-skilled athletes have an advantage in offensive and defensive situations (Spiteri et al., 2015), and since this can be decisive for winning in sport games, sprinting and COD tasks are included in performance diagnostics (Fernandez-Fernandez et al., 2022; Iacono et al., 2015; Wen et al., 2018). There is a wide variety of COD tests (Nimphius et al., 2018), however, there has been criticism concerning the relation of COD and sprint performance in some of the used tests (Nimphius et al., 2018). Although several studies have already investigated these relations, findings have still been inconsistent. In 2005, Little and Williams investigated the specificity of acceleration, maximum speed, and COD speed in soccer players using the Zigzag test (100° angle directional changes while running around cones) and a flying 20-m sprint (Little and Williams, 2005). They reported significant correlations between these measures, with common variance of about 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, as well as the L-run-test, and reported significant associations to sprint speed. 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. Since the tests being investigated differ in sprint distance, the number of turns, turning angles, and body orientation, the COD test regimen might influence the relation to sprint performance (Nimphius et al., 2018). Of particular interest is the body orientation compared to the running direction before and after the COD, which in most tests mentioned above is identical, although it is often not the case in a team sport situation. This becomes clear in the widely used 505-test, where a 180° turn is made with an equivalent turn in the body direction, thus the athlete always runs forward. Still, even the rotational direction influences COD time (Nimphius et al., 2018), therefore it is to be expected that CODs are affected even more by different body orientations.

Considering these different demands imposed on athletes by different test designs, it seems to be crucial to first acknowledge the specific requirements and movement patterns of the sport being investigated before choosing the right COD test (Brughelli et al., 2008). In basketball, for example, studies suggest that athletes are exposed to extensive, sometimes high-intensity, intermittent demands, that change every 1–3 s (Stojanović et al., 2018). Except for linear sprints in the midfield, court behavior is characterized by short, fast attacks covering an average maximum distance of 9.48 m (Scanlan et al., 2011). Therefore, the major characteristic seems to be powerful and quick accelerations and decelerations in different directions. Furthermore, these bursts happen mostly close to the net, meaning that the athlete faces his or her goal or the opponent. Because of that, these accelerations or decelerations are performed with a body orientation differing from the locomotion direction, which leads to different movement patterns than linear sprinting. In volleyball, 83.7% of rallies last less than 10 s, with male rallies being even shorter than female ones. As for the distances covered, 45.7% are between 5 and 10 m and 85.3% are less than 15 m (Hank et al., 2016). 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 (Melrose et al., 2007). In both aforementioned sports, athletes cover mostly short distances with sideway movements often occurring after only a few steps of forward running (Young et al., 2004). Therefore, an adequate COD test should include multiple CODs involving different angles and body orientations depending on the athletes being measured, and not long-distance linear sprints.

One COD test fulfilling these aforementioned criteria is the so-called Handball Agility-Specific Test (HAST), which includes forward and backward accelerating and decelerating phases, as well as diagonal movements (Iacono et al., 2015). Therefore, the body orientation is different from the perspective of the COD for each change. Five CODs with at most a 90° angle are executed within a 5 x 5-m square, where the athlete has to touch cones at COD points. Therefore, every COD is a clear cut with an acceleration and a deceleration phase. Furthermore, because the test is of short duration and distances in addition to the different angles and movement directions, it corresponds nicely to the demands of both volleyball and basketball (Dos'Santos et al., 2017; Wen et al., 2018). Until now, the total time of this test has been used to determine COD speed (Iacono et al., 2015). 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 require covering longer distances; and, second, it conceals temporal information about the individual COD actions, which could be used in examining specific CODs with different body orientation. Therefore, the 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 test).

Even though the test has already been evaluated concerning its test-retest reliability (ICC = 0.92, typical error of measurement = 2.3%) (Iacono et al., 2015), it has not yet been investigated regarding its construct validity. Since a major criticism of the currently used COD tests is the dependence on sprint performance, we aimed to test whether the TSS-COD test could distinguish between these domains and therefore validly represent COD performance.

## Methods

### *Participants*

The study was approved by the local ethics committees of two universities as testing has been extended over a longer time. The study was approved by the local ethics committee of Westfälische Wilhelms-Universität Münster (Germany, approval number 2015-48-MTF) as well as of Goethe University Frankfurt (Germany, approval number 2021-30). 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 provide 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). At the time of the study, 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. Athletes joining these youth development programs performed sport-specific training at least five times a week. All senior athletes played in the first national division volleyball or basketball league.

Mean height of participants was 182.6 cm (SD = 11.2), and mean body mass was 72.6 kg (SD = 15.4). All anthropometric data are displayed in Table 1.

### *Measures*

To detect IV times, a Fitlight© System (Visus GmbH, Herrenberg, Germany) was installed on the 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. The Fitlight© System has already been used in previous investigations, showing high reliability in COD testing (ICC = 0.88–0.91) (Čoh et al., 2018).

The TSS-COD test trial with the shortest total time was analyzed for each participant. From this trial, the respective IV times were extracted. TSS-COD test total time was computed as the sum of IV times' duration. On 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 test and the sprint trial.

Data were then sorted (Microsoft Excel, Version 16.35, Microsoft Corp., Redmond, USA) and analyzed.

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 = 0.93–0.97) (Machulik et al., 2020). The sensor was attached to the athlete's lumbar back with a special belt. As in the TSS-COD test 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 rest interval between trials was mandatory.

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 the Open Science Framework at DOI 10.17605/OSF.IO/T4XUP.

Concerning anthropometric data, body height was measured using a laser range finder (PLR 25, Bosch, Germany). Body mass was determined with a scale (Bomann®, Type PW1409FA, Germany). Two investigators used a tape to measure the arm span with the athlete in a lying position.

### *Design and Procedures*

To address the abovementioned question, the TSS-COD test was included in a sequence of tests carried out as part of longitudinal performance diagnostics with elite basketball and volleyball players. Performance diagnostics were administered three times a year. Each team was measured in its training center. The warm-up and the 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 randomized order. Anthropometric tests were also administered to assess body mass, height, and the arm span. The TSS-COD testing procedure was explained to athletes in each diagnostics session. After observing the experimenter executing the test slowly with verbal instructions, participants had one trial to familiarize themselves with the test. There was no external start signal; athletes started whenever they were ready. The starting line was set 1 m behind the light barrier (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 (Figure 1). The fifth cone touch (i.e., cone number 2) needed to be performed with the left hand. The last interval (IV6) was then performed backward, passing the light barrier marking the finish line. The height of all cones was set to 28 cm. 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 rest interval of at least 60 s. Three trials had to be completed correctly in each of the performance diagnostics.

### *Statistical Analysis*

Explorative principal components analysis (PCA) was calculated to analyze the relationship between sprint and COD performance and uncover the respective performance structure. Since body height and mass are variables that may influence COD performance (Nimphius et al., 2018), we tested the robustness of the performance profile for the athletes' individual characteristics such as age, anthropometrics, and gender. To further confirm the results of the PCA, a split-half validation of the results was conducted.

Statistical analyses were performed 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 PCA by retaining an EV larger than 0.7 (Jolliffe, 2002). Varimax rotation was used to improve the interpretability of the PCA (Dien, 2010).

To avoid overestimating the TSS-COD IVs in the analysis, a balanced PCA was performed 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 due to its significant correlation to a separate factor in the previous analysis. Since it was assumed that the TSS-COD test and sprint times would be affected by anthropometrics or body mass, multiple regression analyses were performed including sprint times, TSS-COD IVs, and personal data, and *t*-tests were used post hoc. The level of significance 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 conducted using the residuals of the previous regression analysis. Finally, to confirm the validity of the structure identified in PCA and to test the robustness of the results, a split-half validation was performed. The whole sample was divided into two groups, personal data were balanced between both groups, and PCA was then performed for both groups. For all PCAs, rotated component matrices can be seen in Table 2, while scree plots and Eigenvalues are displayed in Figure 2.

## Results

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

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 (Table 2). Since 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 test was included (Table 2). Again, duration 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 body height, mass, the arm span, age, and gender. As expected, TSS-COD IVs and sprint times were influenced by body mass, age, and gender (Table 4). The calculated model explained 7.2–28.2% of the variance ($R^2_{\text{corr}}$ = 0.072–0.282) in the TSS-COD test and 12.2–38.1% of the variance ($R^2_{\text{corr}}$ = 0.122–0.381) in sprint times.

To detect whether the PCA structure was influenced by athletes' characteristics, another PCA was performed including regression residuals (Bartlett test, $p < 0.001$, KMO = 0.808) 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) before (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. As before 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 0.002, 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.

## Discussion

Considering that COD is viewed as a major performance variable in team sports, it often gets assessed in performance diagnostics. There is an ongoing discussion concerning the validity of COD assessments primarily because of the potential correlation of COD and sprint performance (Nimphius et al., 2011). The TSS-COD test seems to be highly applicable in team sports such as volleyball and basketball (Melrose et al., 2007; Scanlan et al., 2011), however, construct validity has not yet been proven. In the context of performance tests, a test can be valid if the measurement has validity with respect to the issue being measured (Colliver, 2012). Construct validity aims to test theoretical assumptions about correlation structures of theoretical concepts (constructs such as, e.g., COD and sprint performance) based on empirical data (Colliver, 2012). Therefore, structure-seeking procedures such as PCA can be used (Salaj and Markovic, 2011). In the context of test development in sport, the extent to which a performance test captures the desired variable or can be separated from other variables is calculated.

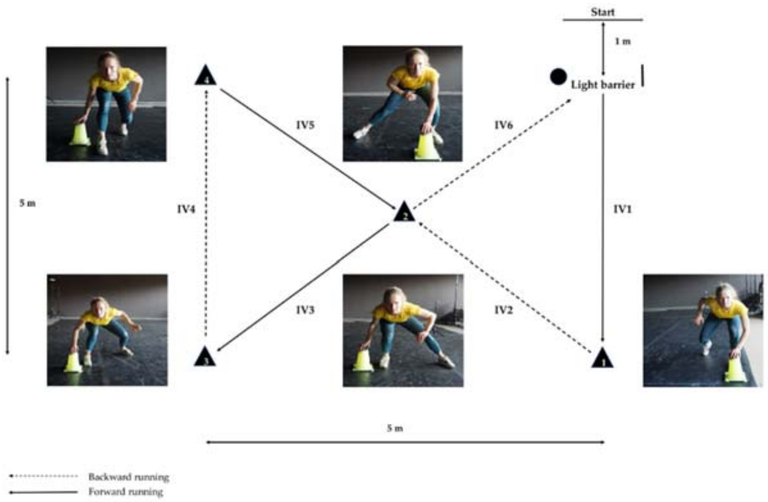
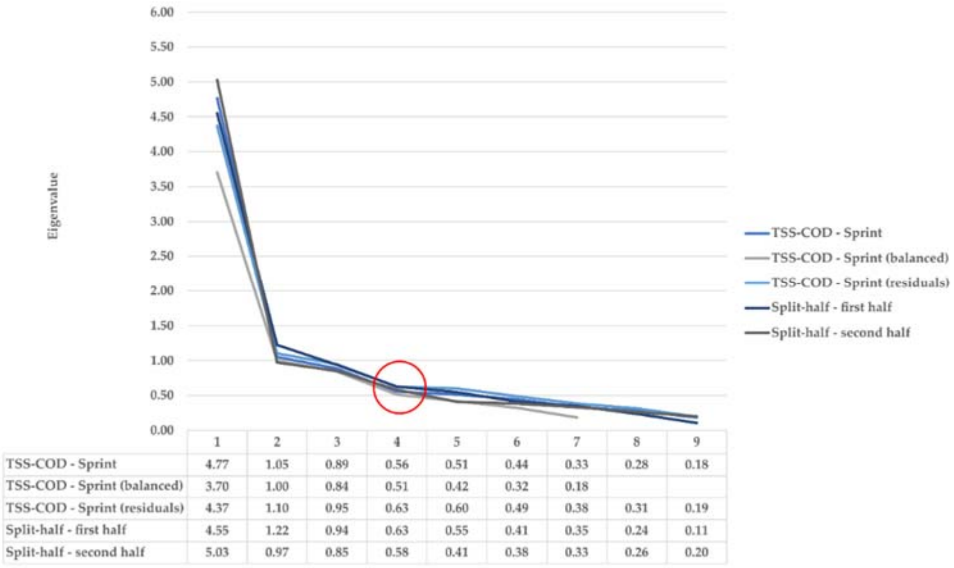


**Figure 1.** *Design of the Team-Sport-Specific COD (TSS-COD) test based on Iacono et al. (2015). Arrows show running direction. FL: Fitlight© used as a light barrier to start/end the measurement; 2: Fitlight© of the middle cone needed to be touched twice, first with the right, then with the left hand.*



| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|
| TSS-COD - Sprint | 4.77 | 1.05 | 0.89 | 0.56 | 0.51 | 0.44 | 0.33 | 0.28 | 0.18 |
| TSS-COD - Sprint (balanced) | 3.70 | 1.00 | 0.84 | 0.51 | 0.42 | 0.32 | 0.18 | | |
| TSS-COD - Sprint (residuals) | 4.37 | 1.10 | 0.95 | 0.63 | 0.60 | 0.49 | 0.38 | 0.31 | 0.19 |
| Split-half - first half | 4.55 | 1.22 | 0.94 | 0.63 | 0.55 | 0.41 | 0.35 | 0.24 | 0.11 |
| Split-half - second half | 5.03 | 0.97 | 0.85 | 0.58 | 0.41 | 0.38 | 0.33 | 0.26 | 0.20 |

**Figure 2.** *Scree plots of PCAs with eigenvalues (EV) of the factor. Factors were retained if EV > 0.7. Points of inflection are marked in the graphs as a red circle.*

**Table 1.** *Descriptive statistics of 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 | | | | |
|---|---|---|---|---|
| *N* = 154 | Min | Max | Mean | *SD* |
| Age (years) | 10 | 36 | 17.29 | 5.31 |
| Height (cm) | 150.6 | 210.3 | 182.64 | 11.16 |
| Body mass (kg) | 40.3 | 112.8 | 72.61 | 15.43 |
| Arm span (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 |

**Table 2.** *Principal components analysis, rotated components matrix (varimax with Kaiser normalization). Factor loadings < 0.3 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 | | | **0.93** | | | **0.94** | | | **0.91** |
| IV 2 | **0.88** | | | **0.92** | | | **0.89** | | |
| IV 3 | **0.66** | | 0.50 | **0.59** | | 0.57 | **0.57** | | 0.55 |
| IV 4 | **0.68** | 0.34 | 0.35 | **0.65** | 0.32 | 0.44 | **0.59** | 0.35 | 0.40 |
| IV 5 | **0.71** | | 0.35 | X | | | **0.65** | | 0.41 |
| IV 6 | **0.70** | | | X | | | **0.64** | | |
| 0–5-m sprint | 0.32 | **0.79** | | 0.34 | **0.76** | | | **0.80** | |
| 5–10-m sprint | 0.52 | **0.59** | 0.39 | 0.50 | **0.56** | 0.47 | 0.38 | **0.72** | 0.37 |
| 10–20-m sprint | | **0.88** | | | **0.91** | | | **0.85** | |
| % variance | 74.59 | | | 79.66 | | | 71.25 | | |

**Table 3.** *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 < 0.01.*

| | | IV 1 | IV 2 | IV 3 | IV 4 | IV 5 | IV 6 | TSS-COD TT | 0–5 m | 5–10 m | 10–20 m |
|---|---|---|---|---|---|---|---|---|---|---|---|
| IV 1 | Pearson | 1 | | 0.47 | 0.46 | 0.43 | 0.35 | 0.58 | 0.34 | 0.43 | 0.12 |
| | *p* | | 0.3 | ** | ** | ** | ** | ** | ** | ** | 0.13 |
| IV 2 | Pearson | | 1 | 0.47 | 0.59 | 0.57 | 0.5 | 0.74 | 0.46 | 0.48 | 0.27 |
| | *p* | 0.3 | | ** | ** | ** | ** | ** | ** | ** | < 0.01 |
| IV 3 | Pearson | 0.47 | 0.47 | 1 | 0.52 | 0.65 | 0.51 | 0.78 | 0.37 | 0.62 | 0.25 |
| | *p* | | ** | | ** | ** | ** | ** | ** | ** | < 0.01 |
| IV 4 | Pearson | 0.47 | 0.59 | 0.52 | 1 | 0.64 | 0.55 | 0.86 | 0.52 | 0.66 | 0.35 |
| | *p* | ** | ** | ** | | ** | ** | ** | ** | ** | ** |
| IV 5 | Pearson | 0.43 | 0.57 | 0.65 | 0.64 | 1 | 0.5 | 0.83 | 0.5 | 0.6 | 0.36 |
| | *p* | ** | ** | ** | ** | | ** | ** | ** | ** | ** |
| IV 6 | Pearson | 0.35 | 0.5 | 0.51 | 0.55 | 0.5 | 1 | 0.74 | 0.37 | 0.51 | 0.31 |
| | *p* | ** | ** | ** | ** | ** | | ** | ** | ** | ** |
| TSS-COD TT | Pearson | 0.58 | 0.74 | 0.78 | 0.86 | 0.83 | 0.74 | 1 | 0.57 | 0.73 | 0.37 |
| | *p* | ** | ** | ** | ** | ** | ** | | ** | ** | ** |
| 0–5 m | Pearson | 0.34 | 0.46 | 0.37 | 0.52 | 0.5 | 0.37 | 0.57 | 1 | 0.7 | 0.54 |
| | *p* | ** | ** | ** | ** | ** | ** | ** | | ** | ** |
| 5–10 m | Pearson | 0.43 | 0.48 | 0.62 | 0.66 | 0.6 | 0.51 | 0.73 | 0.7 | 1 | 0.47 |
| | *p* | ** | ** | ** | ** | ** | ** | ** | ** | | ** |
| 10–20 m | Pearson | 0.12 | 0.27 | 0.25 | 0.35 | 0.36 | 0.31 | 0.37 | 0.54 | 0.47 | 1 |
| | *p* | 0.13 | < 0.01 | < 0.01 | ** | ** | ** | ** | ** | ** | |

**Table 4.** *Regression analysis. Dependent variables: TSS-COD intervals and sprint times. Independent variables: body mass, age, and gender. Height and arm span 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* | <0.01 | < 0.01 | < 0.01 | < 0.01 | < 0.01 | <0.01 | <0.01 | < 0.01 | < 0.01 |
| | $R^2_{corr}$ | 0.07 | 0.28 | 0.26 | 0.20 | 0.12 | 0.09 | 0.21 | 0.38 | 0.12 |
| Post hoc | | | | | | | | | | |
| Body mass | *t*(148) | | -2.93 | | | | -2.40 | | | |
| | *p* | | <0.01 | | | | 0.02 | | | |
| Age | *t*(148) | | -2.10 | | | -2.14 | | -3.96 | | -4.11 |
| | *p* | | 0.04 | | | 0.03 | | < 0.01 | | < 0.01 |
| Gender | *t*(148) | 3.07 | | 5.73 | 2.59 | 3.97 | | | 5.79 | |

To verify whether it is appropriate to perform PCA with the data collected, correlations between TSS-COD test and sprint IVs were calculated. As assumed, intervals of the TSS-COD test did correlate with linear sprint speed. Even though there were medium to strong correlations between most variables, three factors could be extracted with PCA. The first factor included duration of TSS-COD IV times 2–6. The second factor summarized all sprint variables. We therefore assumed that TSS-COD IV times would represent a different domain than sprint times. This result is consistent with an investigation by Salaj and Markovic (2011). Also using PCA, those authors extracted four factors representing COD ability, sprint ability, concentric and slow jumps, and reactive jumping ability. 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 variables influencing TSS-COD IVs and sprint speed were gender, age, and body mass. Importantly, when calculating PCA with the residuals of regression analysis, the results were unchanged. Age, gender, body height, mass, or the arm span did not affect the determined performance clusters. The construct validity could further be confirmed by a split-half analysis where the same three factors were extracted. Surprisingly, IV1 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 was specific to this IV (Figure 1). In comparison, IV2 and the later had 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 those (Dos'Santos et al., 2018). Additionally, in IV2 (and IV5) the COD angle is less sharp (90 degrees) than in IV1, which allows to maintain high average movement velocity (Dos'Santos et al., 2018), predicting superior COD performance (Hader, 2015). Especially in the braking phase of a COD, high eccentric strength is required to shift the momentum towards the required direction (Dos'Santos et al., 2017; Spiteri et al., 2014, 2015). Spiteri et al. (2014) reported that eccentric and isometric strength provided the highest overall contribution to COD performance (about 50%) followed by maximal dynamic and concentric strength. Eccentric strength, however, was detected as a sole predictor of COD test performance, which shows the importance of braking capacity to improve re-acceleration (Spiteri et al., 2013, 2014). Those authors state that with higher severity and the number of directional changes in a COD test, the emphasis on braking capacity increases (Spiteri et al., 2014). This might be one reason why fast accelerations in linear sprint tests do not predict short COD times, instead, slower run-ups can lead to shorter times within a COD test (Hewit et al., 2013). 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 athletes still needs to be investigated. 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 during this investigation, but was recently discussed refers to body-side differences or side dominance in athletes (Bishop et al., 2019; Delaney et al., 2015; Dos'Santos et al., 2019; Young et al., 2002). Dos Santos et al. (2019) showed that 49% of athletes investigated had side differences larger than 10% in the 505 tests. Hart et al. (2014) stated that side asymmetries led to performance decreases of 5–10%. Bishop et al. (2019) investigated bilateral deficits, showing effects on COD tasks, but not on linear sprinting. Interestingly, side differences in muscle strength did not seem to affect COD performance (Delaney et al., 2015). However, this was investigated using only the 505 test and therefore requires further analysis. Since side differences seem to be an important factor, especially in team sport athletes, future diagnostics will need to execute the TSS-COD test 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 variable affecting COD performance (Lupo et al., 2019).

In summary, the TSS-COD test is a valid tool to assess COD performance in junior and senior elite athletes. 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 test duration. IV1 stands out from the other variables. This might be due to a specific approach strategy used for the first COD in the TSS-COD test. Further qualitative investigations, e.g., by adding motion capturing, could help the athlete develop a beneficial technique (Nimphius et al., 2018). The TSS-COD test is an easily applicable assessment tool that should be performed in both directions to gain knowledge about side differences relevant to sport-game performance.

### Conclusion

The TSS-COD test 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, and basketball. Performing PCA, we investigated the construct validity of the TSS-COD test by integrating TSS-COD IV duration and sprint IV duration. Variables 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 the TSS-COD test is a valid tool to assess COD performance in junior and senior elite athletes, which is also valid in terms of anthropometrics, gender, and age. Since IV1 is specific to the TSS-COD test, one recommendation could be to subtract IV1 time from TSS-COD test 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 the TSS-COD test to be a valid and applicable tool to measure COD performance in team sports.

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