Scand J Med Sci Sports 2014: 24: 500–506
doi: 10.1111/sms.12019

Published by John Wiley & Sons Ltd

SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE
IN SPORTS

Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests

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Accepted for publication 14 August 2012

Change of direction speed (CODS) is often considered a main determinant of successful performance in many team sports and is routinely measured using field-based tests. However, controversy regarding test selection still exists based upon the reliability and specificity of the tests. The purpose of this study was to determine and compare the reliability, factorial validity, and interrelationships of five frequently used CODS tests (Illinois, L-Run, Pro-Agility, T-test, and 505). Forty-four physical education students (male $n = 24$; female $n = 20$; age; 16.7 ± 0.6), who compete within team sports, to varying levels of competition, participated in this study. Three trials for each of the five tests were recorded. All tests had high (intraclass correlation coefficient) test–retest reliability ($r = 0.88$–0.95) and low typical percentage error (1.95–2.40%). The principle component factor analysis resulted in the extraction of one significant component which explained 89.52% of the total variance. All selected tests were positively and strongly correlated ($r = 0.84$–0.89). Based upon the results of this study, it was concluded that all tests are highly reliable and valid measures of CODS, with all tests assessing a general athletic ability to change direction. Future research should investigate the factorial validity of the CODS test within homogenous samples.

The significance of agility within sport is well established (Table 1) and has long been regarded as a main determinant of successful performance. However, ambiguity surrounding its classification and definition has led to best protocols of testing being disputed. This debate is founded in the existence of the two fundamental components of agility, perceptual and decision-making factors, and change of direction speed (CODS) (Sheppard & Young, 2006). CODS is considered to be an independent motor skill with a high degree of neuromuscular and biomechanical specificity (Gamble, 2010), and is detached from straight running speed (Young et al., 2001; Little & Williams, 2005), concentric strength, and power (Young et al., 2002; Jullien et al., 2008; Salaj & Markovic, 2011). Consequently, it is inferred that CODS is an independent physical quality that requires specific training and testing protocols (Jeffreys, 2006).

It is acknowledged that the majority of existing agility tests are in fact CODS tests (Ellis et al., 2000), void of the cognitive and reactive component. Therefore, it is accepted that CODS tests do not reflect the open nature of sports performance (Sheppard & Young, 2006). However, CODS tests have previously been shown to distinguish between athletic performance levels (Rotert et al., 1992; Roetert et al., 1995; Sierer et al., 2008) and playing time (Hoffman et al., 1996) across various sports. Considering the high financial cost, time, and potential injury implications surrounding reactive agility movements (Besier et al., 2001), CODS tests are often the preferred method of measuring agility when compared with reactive agility tests.

Coaches rely on field-based measures such as CODS tests to identify talent and routinely monitor the affects of training programs. It is therefore essential that these tests provide reliable and valid data capable of identifying changes in performance. Previously, reliability values for the T-test (Pauole et al., 2000), Pro-Agility (Mayhew et al., 2010), L-Run, and 505 (Gabbett et al., 2008) tests have been presented. However, it is not possible to directly compare these due to the influence of varying subject characteristics within the different studies. A low to moderate association between various CODS tests has also been reported (Pauole et al., 2000; Sporis et al., 2010; Salaj & Markovic, 2011), inferring specificity of movement for each test. Therefore, a direct evaluation and comparison between the different CODS tests, using the same subjects, is required to form a more conclusive analysis. The purpose of this study was to determine the reliability, factorial validity, and interrelationships between five commonly used CODS tests. Such information will aid coaches in selecting CODS tests for future testing batteries.

Table 1. Significance of CODS within various sports

Sport	Movement analysis
Soccer	Players change direction every 2–4 s and make 1200–1400 changes of direction during a game (Bangsbo, 1992; Verheijen, 1997).
Rugby: Union	Utility movements (described as lateral shuffling and backward locomotion) occur on average 59.5 times per match which was equal to 3.6% of relative time (Deutsch et al., 2006).
Basketball	Players change direction every 2 s. Sideward movement equated to 22% of the total distance covered (as much as 1684 m) (McInne et al. 1995; Abdelkrim et al., 2010).
Field hockey	A directional change of movement recorded every 5.5 s (Spencer et al. 2002).
Tennis	Lateral movements account for 70% of movement within competitive tennis. Averages of four changes of direction are made per point and as many as 1000 direction changes per match (Kovacs, 2006; Kovacs, 2009).
Squash	Players on average made 2866 steps during the whole match and 580 steps during a game. The most frequent type of step was the step forward (70.1%) and the step aside (10.6%). Most movements are not performed in a straight line (Vuckovic et al., 2004; Wilkinson et al., 2009).

Materials and methods

Subjects

Forty-four healthy (male $n = 24$; female $n = 20$; age; 16.7 ± 0.6) physical education students, with at least 2 years training and playing experience in team sports (rugby $n = 13$; soccer $n = 11$; Lacrosse $n = 10$; Netball $n = 10$), volunteered to participate in this study. Ethical approval was granted by the Middlesex University Health and Social Sciences School Ethics Committee, and all procedures were conducted in accordance with the Declaration of Helsinki.

Procedures

All subjects completed three timed trials for each of the five CODS tests. To avoid the possible confounding effects of fatigue, the test procedure consisted of two sessions, separated by at least 72 h. The first testing session included the Illinois and Pro-Agility tests and the second session included the T-test, L-Run, and 505. Tests were performed in a non-randomized order.

All testing sessions were performed at the end of the academic year when subjects were not involved in competitive activities. Subjects were asked to refrain from vigorous activity before or during the duration of the experiment and were required to wear the same footwear and similar clothing for both testing sessions. Testing took place on an indoor surface, and to allow for diurnal variation in fitness abilities, all tests were performed at the same time of day ($\pm$ 1 h).

Tests were preceded by a 10-min warm up, which included various pulse-raising activities including linear and multidirectional movements, muscle activation exercises such as body weight lunges and squats, and a mixture of static and dynamic stretches. Each protocol was explained and demonstrated prior to testing, and to minimize the motor learning effect, a practice trial for all tests was administered as not all subjects had previously performed these tests. Three timed trials were administered, with a minimum rest period of 3 min between each trial and approximately 5 min between tests. The time of each trial was recorded to the nearest hundredth of a second by single beam infrared photocells (Brower, Salt Lake City, Utah, USA). For the Illinois, L-Run, T-test, and 505, the timing sensors were set 0.8 m from the ground and positioned 1.3 m apart, facing each other on either side of the start/finish line. The timing sensors for the Pro-Agility test were set perpendicular to the course, at 0.35 m from the ground and positioned 1.3 m apart. They were placed facing each other on either side of the start/finish line. This setup was adopted to allow the subjects to start in a standing neutral stance, with feet on either side of the start line. Although some of the tests used are universally measured in yards, we have converted all measurements to meters for ease of comparison (1 yd = 0.91 m).

Illinois agility test

The Illinois agility test was set up and administered using the protocol outlined by Hoffman (2006; Fig. 1a). The subjects were instructed to lie on their stomachs, with their head just behind the start line and hands by the shoulders. On the “Go” command, the participant got up and sprinted the course as indicated in Fig. 1a. The participants were required to touch the cones opposite the start and finish line and run in and out of (slalom) the cones down the middle of the course.

The L-Run (aka three-cone drill)

The L-Run was set up and administered using the protocol outlined by Reiman and Manske (2009; Fig. 1b). The subjects started in a standing two-point stance, and upon the “Go” command were required to sprint forward 4.55 m (5 yd), touch the cone with either hand, and sprint back to the start line. Next, the subjects reversed direction and sprinted around the first cone, cut right, and circled the second cone, ensuring that the cone was on the left hand side of the body. The test was completed when the participant sprinted through the start/finish line.

Pro-Agility test (aka 5-10-5)

The Pro-Agility test was set up and administered using the protocol outlined by Harman et al. (2000; Fig. 1c). The subjects started in a neutral stance, straddling the start line. On the “Go” command, the subjects were instructed to turn and sprint to the right 4.55 m (5 yd), touching the cone with their right hand. They then turned to the left and ran 9.10 m (10 yd) to the far cone. The subjects touched this cone with their left hand and then sprinted 4.55 m (5 yd) to the finish.

T-test

The T-test was set up and administered using the protocol outlined by Semenick (1984; Fig. 1d). Upon the “Go” command, the subjects were instructed to sprint forward 9.10 m (10 yd), touch the cone with their right hand and without crossing their feet, side shuffle 4.55 m (5 yd) to the left, and touch the cone with their left hand. The subject then shuffles to the right 9.10 m (10 yd), touches the cone with their right hand, and returns to the center cone by side shuffling 4.55 m (5 yd). The subject then touches the center cone with their left hand and back pedals 9.10 m (10 yd) through the finish line, ensuring that balance is maintained.

505 agility test

The 505 agility test was set up and administered using the protocol outlined by Draper and Lancaster (1985; Fig. 1e). On the “Go” command, the subjects were instructed to sprint for 15 m (through the timing gates at 10 m), turn on their preferred foot, and sprint back through the timing gates.

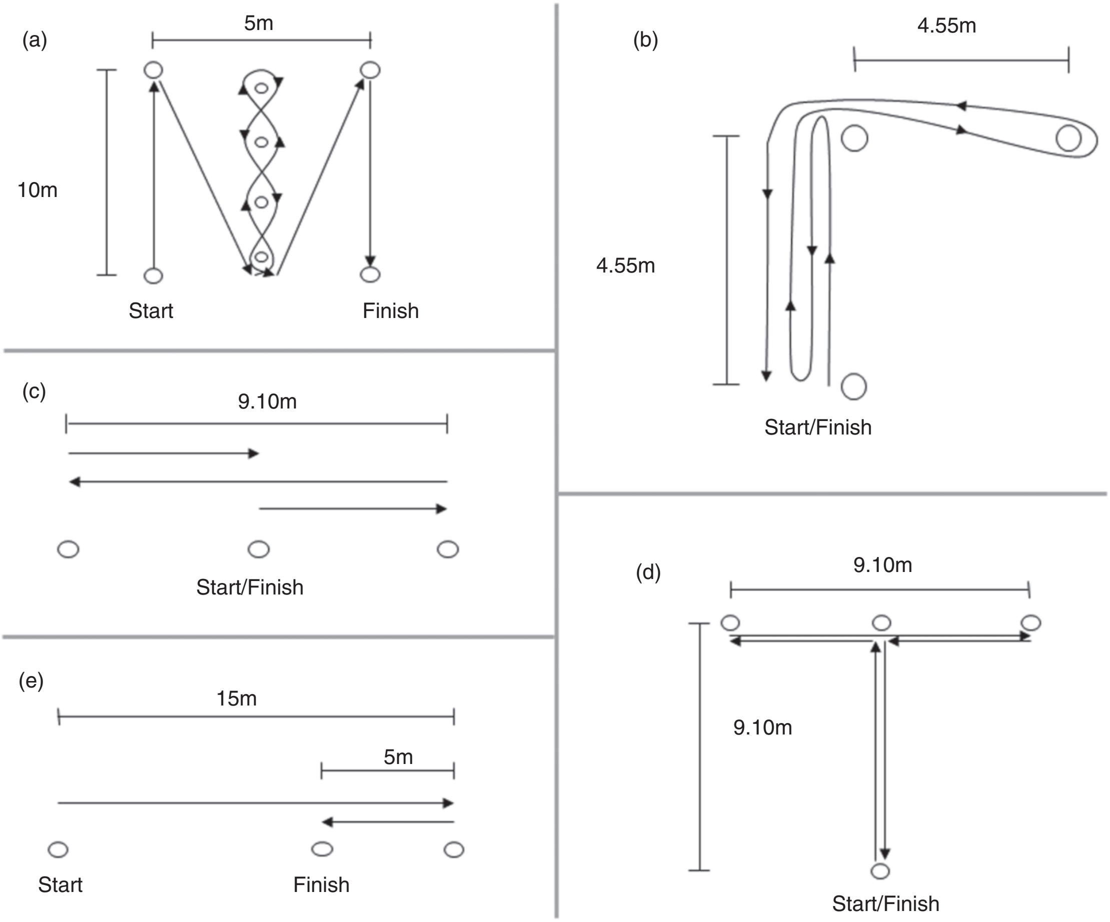

Fig. 1. A schematic of the five CODS tests used within this study. These are the Illinois (a), L-Run (b), Pro-Agility (c), *t*-test (d), and 505 (e).

Statistical analyses

The mean and standard deviation (SD) were calculated for each trial. Data sets were assessed for normality by converting the skewnesss and kurtosis values to *Z*-scores as described by Fields (2009). A one-way repeated measures analysis of variance (ANOVA) was used to test for differences between all trials of all five CODS tests. Absolute and relative within-day reliability was assessed for each test. A two-way random effects intraclass correlation coefficient (ICC) with absolute agreement was used to determine relative within-day reliability. ICC values of 0.75 and above were considered to indicate good reliability (Portney & Watkins, 1993). Absolute within-day reliability was reported as the standard error of measurement (SEM), as described by Weir (2005; square root of the mean square error from the repeated measures ANOVA), and by the coefficient of variation (CV), as described by Atkinson and Nevill (1998). The SEM was performed to provide an absolute error of each test (SEM) for future uses, while the CV was performed to allow for comparison of error between the tests (CV), given the different duration of each test. The level of association between tests was assessed using Pearson's correlation coefficient with the strength of the relationship being reported in accordance with Cohen (1988) as: small 0.2–0.4; moderate 0.5–0.7; large > 0.7. A principle component analysis (PCA) was used to report the amount of underlying set of test types, determined by the Kaiser-Guttman criterion as an indicator of factorial validity. Statistical significance was set at $P < 0.05$. All data analyses were performed using SPSS (V18.0; SPSS, Inc., Chicago, Illinois, USA).

Results

The descriptive data (mean and SD) for all three trials and the average of each individual's best time across all trials of each test are presented in Table 2. A one-way repeated measures ANOVA revealed significant ($P < 0.05$) differences between the time for trials 1 and 2 and 1 and 3 for both the L-Run and Pro-Agility, and trials 1, 2, and 3 for the T-test. This revealed that the first trial is significantly slower than trials 2 and 3 for the L-Run and Pro-Agility and there was a significant decrease in time across all trials of the T-test, i.e., performance improved with trials.

The ICC values are displayed in Table 3. All tests were found to have very high reliability across all trials ($r = 0.88$–0.95), with the L-Run and T-test reporting the highest values ($r = 0.94$ and $r = 0.95$, respectively). All tests had a good within-subject variation, with CV values ranging from 1.95 to 2.40%.

All CODS were positively and strongly associated to one another (Table 4). The correlation coefficient values (r) were of a similar strength, with the highest correlation existing between Illinois and Pro-Agility, T-test and 505 ($r = 0.89$). The principle component factor analysis

Table 2. Descriptive data: Mean and SD for all trials and the average of each individual's best time across all trials of each test ($n = 44$)

	Pooled ($n = 44$)		Male ($n = 24$)		Female ($n = 20$)	
	Mean	SD	Mean	SD	Mean	SD
1. Illinois	16.90	1.30	16.21	1.26	17.73	0.76
2. Illinois	16.71	1.13	16.07	0.97	17.47~	0.76
3. Illinois	16.71	1.15	15.97	0.86	17.60	0.75
Illinois Best	16.46	1.12	15.74	0.84	17.33	0.73
1. L-Run	8.91	0.65	8.50	0.46	9.39	0.50
2. L	8.75~	0.65	8.31~	0.43	9.28	0.49
3. L	8.69~	0.65	8.24~	0.52	9.23~	0.44
L-Run Best	8.63	0.67	8.19	0.46	9.16	0.47
1. Pro-Agility	5.09	0.36	4.88	0.26	5.35	0.28
2. Pro-Agility	4.99~	0.37	4.73~	0.19	5.30	0.25
3. Pro-Agility	4.99~	0.39	4.71~	0.23	5.32	0.26
Pro-Agility Best	4.93	0.36	4.67	0.21	5.23	0.25
1. T-test	11.30	0.99	10.59	0.61	12.14	0.62
2. T-test	11.17~	0.99	10.48	0.58	11.99~	0.71
3. T-test	10.99~^	0.94	10.35~^	0.57	11.76~^	0.67
T-test Best	10.94	0.93	10.31	0.46	11.70	0.67
1. 505	2.58	0.19	2.47	0.15	2.71	0.14
2. 505	2.55	0.20	2.43	0.16	2.69	0.12
3. 505	2.56	0.19	2.44	0.16	2.70	0.13
505 Best	2.51	0.20	2.38	0.15	2.66	0.13

~, faster than trial 1 ($P < 0.05$); ^, faster than trial 2 ($P < 0.05$).

Table 3. Intraclass correlation (ICC; ± 95% confidence interval; CI), standard error of the measurement (SEM), and coefficient of variation (CV) for male (M), female (F), and pooled (P) data sets for all CODS tests

	ICC			95% CI			SEM			CV (%)		
	M	F	P	M	F	P	M	F	P	M	F	P
Illinois	0.80	0.83	0.89	0.66–0.90	0.67–0.92	0.83–0.94	0.55	0.30	0.39	2.21	1.64	1.95
L-Run	0.80	0.88	0.94	0.55–0.91	0.75–0.95	0.90–0.96	0.18	0.16	0.17	2.23	1.63	1.96
Pro-Agility	0.67	0.82	0.90	0.34–0.84	0.67–0.92	0.84–0.94	0.13	0.11	0.12	2.51	1.81	2.19
T-test	0.86	0.83	0.95	0.70–0.94	0.57–0.93	0.92–0.97	0.23	0.23	0.21	1.69	2.29	1.96
505	0.77	0.81	0.88	0.61–0.88	0.65–0.91	0.81–0.93	0.07	0.05	0.06	2.80	1.92	2.40

from all five tests resulted in the extraction of one significant component which explained 89.5% of the total variance of all tests.

Male subjects were significantly faster than female subjects in all tests ($P < 0.05$). When the sample was split by gender, a similar effect of trial number was found as with the pooled data, with the L-Run and T-test times becoming quicker with trial number ($P < 0.05$; Table 2). However, the improved time of the pooled data within the Pro-Agility test appears to be due to the male subjects showing a significant improvement ($P < 0.05$), as females reported no change in Pro-Agility time (Table 2).

The reliability (ICC, SEM, and CV; Table 3) of the CODS tests was slightly greater for the female group, with an exception of the T-test. The ICC (Table 3) and Pearson's correlations (Table 4) of the gender-split data were lower than that of the pooled data (potentially due to the more homogenous data set; see discussion).

Table 4. Pearson correlation coefficient (r) between all CODS tests for males, females, and pooled data sets

	Illinois	L-Run	Pro-Agility	*T*-test	505
Male					
Illinois	1.00				
L-Run	0.73*	1.00			
Pro-Agility	0.65*	0.53*	1.00		
T-test	0.70*	0.65*	0.48†	1.00	
505	0.78*	0.73*	0.80*	0.60*	1.00
Female					
Illinois	1.00				
L-Run	0.78*	1.00			
Pro-Agility	0.88*	0.77*	1.00		
T-test	0.85*	0.73*	0.87*	1.00	
505	0.77*	0.90*	0.66*	0.72*	1.00
Pooled					
Illinois	1.00				
L-Run	0.88*	1.00			
Pro-Agility	0.89*	0.85*	1.00		
T-test	0.89*	0.86*	0.86*	1.00	
505	0.89*	0.88*	0.86*	0.84*	1.00

*Correlation is significant at the 0.01 level (two-tailed).
†Correlation is significant at the 0.05 level (two-tailed).

Discussion

The purpose of this study was to investigate a range of commonly used CODS tests to evaluate reliability, validity, and interrelationships, and determine whether specificity of movement exists within the selected tests. Overall, our results show that the Illinois, L-Run, Pro-Agility, T-test, and 505 CODS tests are all highly reliable measures, and that within a heterogeneous sample, they all test for the same physical attribute. When the sample was split into male and female subgroups (i.e., a more homogenous group), the relative reliability (ICC) was reduced compared to the more heterogeneous pooled data, although absolute measures of reliability (CV and SEM) showed similar findings.

The findings from the present study show a significant difference between the mean time for trial 1 and 2 and 1 and 3 for both the L-Run and Pro-Agility and between all trials of the T-test. For all tests, the differences were expressed as a reduction in time, i.e., an improved performance. Previously, Pauole et al. (2000) concluded that performing one trial of the T-test was sufficient, based upon the ICC ($r = 0.98$, across three trials). Despite showing comparable ICC values between this study and that of Pauole et al.'s (2000), the repeated measures ANOVA indicates a lack of agreement between consecutive trials. It should be noted that reliability in the form of ICC is influenced by the sample used (see later). Although the Illinois and 505 tests did not display the same magnitude of variation, there was still an insignificant reduction in time across trials (1.18% ± 0.02 and 1.13% ± 0.02, respectively). These findings indicate that a motor learning effect was present, despite this study including a complete warm-up and a submaximal practice trial before each test. This study is in agreement with Markovic et al. (2004) and Sporis et al. (2010), who suggested that maximal trials should precede testing to reduce this motor learning effect. It appears that a minimum of one maximal trial is required for the L-Run and Pro-Agility tests, with more required for the T-test.

All CODS tests were found to have very high intraday reliability, with the highest values reported for the T-test ($r = 0.95$) and L-Run ($r = 0.94$). The ICC values found for the T-test, L-Run, and 505 within this study are consistent with the intraday reliability reported by Pauole et al. (2000; T-test: $r = 0.94$–0.98) and the interday reliability of Gabbett et al. (2008; L-Run: $r = 0.95$; 505: $r = 9.0$). It should be noted that the L-Run performed in this study and that used by Gabbett et al. (2008) was slightly different. This study reported higher reliability values for the Pro-Agility test ($r = 0.90$) in comparison with Mayhew et al. ($r = 0.80$; 2010). However, this discrepancy may reflect the difference in timing method, with Mayhew et al. (2010) opting for hand timers. Although retest correlation is a good measure of reliability, Hopkins (2000) states that within-subject error, reported in this study as SEM and CV, is a better measure. This margin of error is of great importance within sports science, as the smaller the within-subject variation, the easier it is to measure and monitor changes in performance. The greatest SEM (Table 2) was reported within the Illinois and the lowest within the 505 test. This is due to the varying time taken to complete each test. However, the CV was acceptable for all measures with all tests reporting similar results. The lowest CV reported was within the L-Run agility test (1.96%) and T-test (1.96%), and despite expressing the lowest SEM, the 505 test reported the highest CV (2.40%). The CV presented for the T-test by Sporis et al. (2010) was higher (3.3%) than that reported in this study (1.96%).

Despite Gabbett et al. (2008) reporting a high correlation ($r = 0.73$) between the 505 and L-Run among elite rugby league players, other studies have reported low to moderate values. Specifically, Sporis et al. (2010) reported low correlations for elite male junior soccer players ($r = -0.20$–0.55), while Pauole et al. (2000) showed similarly low correlations for college-aged participants (male and female) of varying athletic ability ($r = 0.48$). The authors suggest that the limited relationships between tests were determined by the specificity of movement and infer that each test is a measure of specific movement patterns and not an indication of an athlete's ability to change direction effectively (Pauole et al., 2000; Sporis et al., 2010). The results from this study are in disagreement to those of Pauole et al. (2000) and Sporis et al. (2010). It is evident (Table 4) that all selected CODS tests were positively and highly correlated to one another ($r = 0.84$–0.89) with all measures displaying similarly high values. The other method of assessing commonality across tests was the PCA which resulted in the extraction of one significant principle component that explained 89.95% of the variance of all five CODS tests. All measures have high correlation coefficients with the principal component ($r = 0.94$–0.96), supporting the commonality of the tests. Since the correlation between the tests and extracted factor represents the tests factorial validity, it can be stated that all tests measure the same component. These findings contrast that of Metikos et al. (2003) who reported seven statistically significant principal components from 32 agility tests.

When splitting up the data by gender (male $n = 24$; female $n = 20$), we were able to produce more homogeneous data sets. The reduced relative reliability (i.e., ICC) reported for these gender-split data sets supports the suggestion that the high ICC scores for the pooled data is partly due to the large variability between subjects. However, a good reliability is still suggested within these more homogeneous data sets through good CV (male 1.69–2.80%; female 1.63–2.29%; Table 3) and SEM scores (male 0.07–0.55 s; female 0.05–0.30 s; Table 3). In addition to the reduced relative reliability, a lower, although still significant, interrelationship was reported between all CODS tests for both males and females.

It is noted that favorable correlation and PCA values between tests may have been a result of the nonhomogenous nature of the sample. The subjects were not highly trained in one particular sport, and, therefore, mastery of specific movement patterns is likely to be limited. Whereas, previous studies have compared CODS tests using trained athletes from specific sports and as such, the specificity of movement may differentiate ability between different tests. Additionally, the variability between subjects was large compared to the variability within subjects, allowing for a high ICC to be reported (even though the ICC with absolute agreement was used; McGraw & Wong, 1996), but due to the consistent change in scores, the repeated measures ANOVA was still reporting differences across trials. Therefore, it is suggested that further research is needed to determine the association values of the same tests on highly trained homogenous groups to fully understand the implications of the individuals' training history, i.e., trained vs untrained subjects.

We conclude that all CODS tests used within this study were found to have high retest reliability and acceptable typical percentage error (CV) with only marginal differences between all tests. With high correlation values and the extraction of only one principle component, it is suggested that all tests demonstrate a high proportion of commonality, with all tests measuring the same factor. This indicates high validity and infers that CODS testing is not a measure of specific movement patterns but of a general athletic ability to change direction effectively.

Perspective

Findings from this study have the following implications: (a) when administrating CODS tests, maximum effort trial/s should precede testing in an attempt to reduce the motor learning effect; (b) all tests within this study were shown to have high intraday reliability; and (c) all five tests assess the same physical component and, therefore, any of the tests within this study can be used to effectively assess CODS. Furthermore, only one test is required to evaluate an athlete's ability to change direction at speed. Although it has been shown that all tests assess the same attribute, it may still be beneficial to employ one that replicates the movement patterns found within the sport.

Key words: change of direction, field tests.

Acknowledgements

The author would like to thank the staff and students of the Physical Education Department of St Georges VA and The Cavendish School.

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