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Title Page

Change of direction and agility tests: Challenging our current measures of performance

Running head: Validity of COD and agility assessment

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Abstract

The ability to change direction is a highly valued athletic quality in sport and has been measured extensively. Despite the importance and magnitude of research on change of direction (COD) and agility, the validity of the performance measures used to assess these abilities have faced limited scrutiny. A critical evaluation of our current measures of COD and agility are presented. Further, a summary of recommendations to enhance the validity of COD and agility assessment is provided in the ultimate effort to improve our understanding of this crucial athletic quality.

Introduction

In many sports, changes of speed or rapid and decisive changes of direction can result in a break, a score or a shift in the momentum of the game. As a result, change of direction (COD) ability has been extensively investigated across various athlete populations using cross-sectional and intervention approaches (84). Traditionally, the majority of research investigating the specific requirements of changing direction or "cutting" was conducted within the context of injury risk and prevention (7, 44, 60, 109). The variables examined in injury research focus on the measures (e.g. ground reaction forces, joint kinetics or joint kinematics) during the "plant phase" of the COD (7, 60). In contrast, sports performance research has more commonly assessed COD ability through measures of total time to complete a variety of COD tests within either planned or reactive (i.e. in response to a stimulus; agility) conditions (12, 29, 30, 38, 54, 61-64, 72, 75, 77, 91, 96, 100, 101, 108). However, more recent studies have begun evaluating COD ability by focusing on a more isolated measure of COD by specifically examining the entry and exit velocity before and after the COD "plant" (35, 77, 89, 90) or measuring the center of mass (COM) motion throughout the entire test (36, 79).

In research and applied practice, the use of total time as a measure of COD performance has been overwhelmingly considered as a "valid" measure of performance. However, recent research has suggested that the use of "total time" from COD and agility tests may be masking actual COD ability (65, 69, 95), primarily because total time is biased to linear sprint ability in most tests (65, 69, 79). In essence, many COD and agility tests may not be valid measures of the performance most practitioners and researchers are intending to measure for reasons that will be discussed. The misidentification or incorrect assessment of a physical quality such as COD ability or agility could subsequently result in a practitioner developing a training program that either fails to improve on an area of need, or potentially focuses on an area that has a limited window for adaptation. Therefore, the purpose of this manuscript is to summarize the different types of COD and agility tests currently used in both applied practice and research, and to provide a critical evaluation by addressing a series of relevant questions with respect to COD and agility performance. This will be followed by recommendations for both the research and coaching community to help improve measurement of true COD ability and ultimately improve applied practice.

Definitions and delimitations

For this paper, COD will refer to the specific event where one uses the *"skills and abilities needed to explosively change movement direction, velocity, or modes"* as defined in the textbook endorsed by the National Strength and Conditioning Association (NSCA) (21). It is acknowledged that in 2006, Sheppard and Young (84) originally defined agility as *"a rapid whole-body movement with change of velocity or direction in response to a stimulus"*. In line with this original definition of agility (89), the current paper will similarly define agility as *"skills and abilities needed to change direction, velocity, or mode in response to a stimulus"* (21). Therefore, the abbreviation 'COD' refers to the specific event of changing direction, which can occur during both planned conditions and during agility conditions. Further, understanding the following definitions are critical to the discussion in this paper:

- Validity *is the degree to which a test or test item measures what it is supposed to measure*.
- Reliability *is the repeatability of the measure*.
- Construct validity *is the ability of a test to represent the underlying construct*.
- Discriminant validity *is the ability of a test to distinguish between two different constructs*.

Current measures of COD performance

Table 1 presents a detailed description of the tests used to assess COD across a variety of populations. Each test varies in length, number of direction changes, angle of direction changes, and modes of travel. Therefore, it can be difficult to compare results from different tests as they can often place distinct demands on various combinations of physical capacities. For example, certain COD tests may be long enough (in time and distance) that anaerobic capacity is a critical factor in performance, making it difficult to know whether changes in performance are due to increases in COD ability or improvements in anaerobic capacity (21, 67). Additionally, different COD tests may require different magnitudes of physical requirements (e.g. eccentric vs. isometric vs. concentric strength) (21, 67, 91), and technical requirements (e.g. curvilinear running patterns for maintaining velocity, termed maneuverability, vs. a COD that requires rapid deceleration) (21). As a result, discussions on developing an array of underpinning physical attributes over various movement patterns classified as COD, maneuverability and agility in an effort to enhance global COD ability have been suggested (21, 67). In essence, the vast array of COD tests in itself indicates that there is little consensus on how to measure COD. The influence of test length has been discussed therefore the following sections of this paper will seek to answer critical questions that can better define the framework for potentially more valid measures of COD performance.

****INSERT TABLE 1 About here ****

How does linear sprint speed influence COD performance measures?

One of the major limitations associated with many COD tests is they tend to feature a relatively large amount of linear sprinting, and this has a substantial influence on the total time for the assessment. For example, the pro-agility shuttle, a foundation assessment at most American football combines (32, 33, 65, 87), features a total of 18.28 m of linear sprinting about two, 180° direction changes. Thus, considerably more time is spent in the pro-agility shuttle sprinting linearly than changing direction (65). Even the 505, either the traditional or modified version, which attempts to isolate a single 180° direction change, still inherently requires two linear 5 m sprints (22, 30, 69). Any single performance measure from an entire test that features a large amount of linear sprinting may ultimately mask the actual COD performance of the athlete (i.e. the athlete may be poor at making the COD, but can recover via their superior linear speed). As linear speed training is proposed to not transfer to improving COD ability, they are considered separate physical or athletic qualities (107). Therefore, to provide more practical information for the practitioner, a test should focus more on what happens during the COD, as opposed to the total duration of a test that may predominantly evaluate linear speed capacity.

How do angle and entry velocity influence COD performance?

The specificity of the direction changes and velocities that feature within a COD test should also be considered. The ability to change direction is angle dependent (11, 36, 107) and affected by entry velocity into the COD (98). The technique (kinematics) and loading (kinetics) during execution of a COD at different angles (e.g. a 45° cut executed while sprinting forwards vs. a right-angled 90° cut vs. a 180° up-and-back cut) (7, 8, 92) or at different velocities (98) will vary. Indeed, entry velocity can have a marked effect on COD performance. As an example, performance of a traditional 505 and modified 505 test only differ in the velocity of entry (due to a 10 m run-up leading into the 505 or no run-up). However, this difference in velocity entering the COD affected overall test performance (i.e. total test time) sufficiently enough that performance levels in the traditional 505 only explained 53% of the variance in the modified 505 performance (30).

Further to this, as entry velocity may change an athletes' COD performance, it is also worth noting that increasing linear sprint speed independent of any changes in COD ability may make COD tests more demanding for an athlete. For example, adolescents have been shown to pace their run-up when performing a traditional 505 due to the increased physical demand of a fast entry velocity (66). Some individuals may intentionally modify entry velocity despite if the perceived demands of the COD are great, and this should therefore be monitored if it features as part of the COD assessment.

Should body mass be considered in COD tests for contact sports?

Research has shown that sprint speed may not differentiate sub-elite and elite rugby athletes, but calculation of sprint momentum (i.e. body mass multiplied by sprint velocity) can differentiate the elite from their sub-elite counterparts (3, 4). Therefore, the inclusion of a mass component in any assessment of COD ability in contact sports may be of interest; however, this needs to be evaluated in future research. From an applied perspective, just as momentum could influence the ability to push defenders or drive the ball into the opposition (3), a COD momentum measure may, for example, provide information on likelihood of successful broken tackles. The importance of either sprint or COD momentum must be determined by the needs analysis of the athlete and sport requirements but there is clear scope for further exploration in this area.

Is there more than just 'quantity' to COD performance?

Thus far, this paper has focused on performance based on quantitative aspects of COD performance. However, practitioners should evaluate quantitative measures in COD testing in conjunction with assessing the "quality" of the COD executed by the athlete. Greater qualitative understanding of the performance of the COD, especially within the context of the angle and velocity demands of the task, has the potential to provide highly valuable information for the practitioner. Whilst measures of technique are often quantified by three-dimensional kinematics (e.g. joint angles) in COD research associated with injury (7, 8) and performance (35, 77, 89), practitioners may choose to create a checklist of overarching technical principles relevant to a majority of COD scenarios. These technical principles are beyond the scope of the current manuscript but have been discussed elsewhere (21, 67). Briefly, this qualitative analysis may include, but are not limited to, descriptions on trunk position and control, orientation of the hips relative to the intended direction of travel (77), rear or front foot strike during the stance phase (13), height of COM (86), knee flexion during braking (89, 90), and arm actions and visual focus (21). Qualitatively assessing the technical principles associated with the strategy or technique an athlete uses to change direction can help with the earlier identification of whether reliance on a specific limb, particular movement strategy or asymmetry exists. Such a technical difference in performance of COD may be present despite not being captured by the "total time" measure.

An example is shown in Figure 1 where an athlete demonstrates faster than average COD performance on both sides (legs) according to performance measured by total time but attains those times using different techniques to preferentially use the same leg during the COD despite the "side being tested". Performance measures presented include: pacing (10 m run up – maximal 10 m sprint time), total 505 time and COD deficit (505 time – maximal 10 m sprint time). The percentage difference between right and left sides is also presented in a table. For comparison between tests, a standardized score (z-score) is presented, calculated by using the mean and standard deviation from all members of the athlete's team (73). In this example, both 505 time and COD deficit provided a similar assessment outcome for the athlete, however this is not always the case (e.g. Figure 2). The athlete in Figure 1 slightly paces (slow their entry velocity) leading into the 505. The athlete is better than the team mean performance, which may lead a coach to not be overly concerned with assessing technical differences in the COD. However, with this athlete, technical differences provide vast information about *"how"* the athlete attained their quantitative performance measures as shown in Figure 1 (A-F). Therefore, despite the *"what"* or time of the performance, the *"how"* or quality of the COD could provide valuable information to the practitioner for understanding windows of adaptation for an athlete.

**** Insert Figure 1 of right versus left COD *****

What are some recent changes in assessment of COD performance?

During performance of the tests listed in the Table 1, it could be hypothesized the section of the test that should be evaluated is the magnitude and direction of the entry velocity and exit velocity during the COD of interest. This would quantify how the direction change is performed without incorporating confounding factors from outside of the specific COD such as linear speed capabilities. For example, Hader et al. (36) recently evaluated the speed (speed as a scalar measure because the vector components of velocity could not evaluated as with three-dimensional kinematics) of an athletes' COM during a sprint and COD at 45° and 90°. Although the research primarily concerned reliability and provided a descriptive comparison between each of these three conditions, an extended statistical analysis revealed that during both COD tests, the minimum speed reached during the COD was the strongest predictor of performance outcome which was quantified as the total time take to complete the COD test. Adding peak acceleration and peak speed reached at any point of the COD tests to the statistical model further improved the prediction of total performance time during both the 45° and 90° tests (36). It could be argued that this measurement provides more useful information than merely time taken to complete a COD test, with further interest in measures that specifically occur around the COD. Such an analysis could allow for more complex COD tests (e.g. due to modes and number of changes in direction), such as the T-test, to be evaluated at each specific COD allowing for a potentially more valid assessment of COD.

Recent research has also proposed simplifying tests (68) and using a metric termed the COD deficit as a more practical means of removing the confounding factor of large amounts of linear sprinting (65, 69). The COD deficit calculation uses two reliable measures of total time (COD total time and sprint time) to create a metric intended to more directly examine COD ability independent of linear sprint ability. The COD deficit could be calculated with any COD test when you have a linear sprint that is of equal distance to that covered during the COD test. For example, the time taken to run a 10 m linear sprint would be subtracted from the time to complete a 505 test (which covers 10 m) to calculate the COD deficit. Nimphius et al. (69) recently detailed how the COD deficit provides a different measure of COD ability than time alone in the 505 test. This should allow practitioners to understand an athlete's ability to change direction without the confounding factor (large amounts of linear sprinting) associated with the majority of tests presented in Table 1. However, this measure has only recently been assessed and further research is required to evaluate it against other proposed measures of COD ability.

Current measures of agility performance

A summary of many of the current agility tests used in research studies has been extensively outlined in a recent review (71). Agility tests undoubtedly add additional information with respect to the interaction of perceptual-cognitive capacity in conjunction with physical performance. Despite this, all agility tests similarly evaluate total time to complete a task, lending themselves to the same potential shortcomings previously discussed with COD tests. Therefore, these discussions will not be re-stated but readers should consider the aforementioned limitations discussed with respect to COD tests also relevant to agility tests. A potential advantage of most agility tests (Table 2) is they are typically completed within a shorter duration in comparison to a majority of the COD tests (Table 1). This therefore potentially isolates the COD performance and reduces the confounding effects associated with anaerobic capacity requirements. However, as discussed in detail by Paul et al. (71), many of the current agility tests are limited in the range of COD angles used, with a majority only utilizing the "Y-shaped" or 45° agility test (Table 2). Considering the breadth of angles tested in COD tests, this is a clear aspect that could be expanded to enhance the validity of agility tests. However, as the angles increase within an agility test, so too will the joint loading experienced by the athlete. Recently, Sekulic et al. (82) developed an agility test that expanded beyond the "Y-agility" to angles that require the athlete to "reach zero velocity" (or fully decelerate or brake). Unfortunately, the test was only performed in response to a light stimulus, and was also relatively long in duration (~10 s). Further work is therefore required to improve this potentially beneficial development if the intention is to evaluate agility that requires a large braking component for evasion, rather than the maintenance of velocity that is more evident in "Y-shaped" tests.

****INSERT TABLE 2 About here ****

Does the stimulus used during agility tests matter?

With respect to validity of perceptual-cognitive assessment, it is known that not only do light-based agility tests increase the loading at the joints beyond that of two-dimensional or three-dimensional stimuli (46), but they fail to allow for assessment of sport-relevant perceptual-cognitive ability (70, 106). A light stimulus will not allow for the use of perceptual cues that elite performers actually utilize and therefore both video and human stimuli are more ecologically valid and provide improved stimulus-response compatibility (71). Hence, following a review of protocols, it is recommended to use human stimuli (or video of human stimuli) where possible for agility testing (46, 71). In addition to this, agility tests that do not separate perceptual-cognitive ability (e.g. decision making time) from movement or total time (108) may allow for good COD to mask poor perceptual-cognitive ability or vice versa. Therefore, evaluation of both physical (e.g. movement time or COM velocity) and perceptual-cognitive (e.g. decision making time or perception- response time) aspects will allow for the best evaluation in an effort to target an area that has the largest window for adaptation (i.e. physical capacity or perceptual-cognitive ability) (30).

Is there a use for both COD tests and agility tests to develop athletes?

The definition of agility by Sheppard et al. (84) allowed for an expanded understanding of COD within the context of sport. Individuals could then contextualize the use of COD drills and testing as a method of developing the physical capacities underpinning agility and use other drills (e.g. mirror or small-sided games) to develop the perceptual-cognitive requirements of agility. Using COD tests and subsequent drills as a base for performing agility tests and drills can be paralleled to the understanding used for jump progressions. For example, the increased joint moments at the knees and ankles in a drop jump (DJ) compared with a countermovement jump (CMJ) (10) allows individuals to appropriately progress. Consider the CMJ as a COD movement where a performer has pre-planned knowledge of their movement, versus the DJ as more comparative to an agility task. The DJ involves a sudden impact with the ground, similar to that of an unexpected cut and foot-ground interaction during an agility task. Enhancing eccentric phase muscle activity allows individuals to handle higher eccentric loading as required during the DJ performance (59) and parallels the similar advantages of pre-activity and rate of muscle activity rise associated with agility tasks (93). The temporal uncertainty of agility requires excellent perceptual-cognitive ability to allow for more time, and therefore greater muscle pre-activity in preparation of the subsequent high joint moments (7, 93). With such a concept in mind, it has been proposed that individuals use a combination of COD and agility drills in a manner that allows for progressive loading to develop the physical characteristics required to change direction (21, 67).

Understanding the progressive development of an athlete is often overlooked in research evaluating both COD and agility. For example, much of the research comparing COD and agility tests have concluded that only agility tests provide information that can differentiate elite performers (30, 83, 85). However, it should be noted that such findings are predicated on a difference in mean performance between groups of athletes. There would be individual variations within both elite and sub-elite groups in which both COD and agility tests could provide meaningful information to the practitioner for individual athlete development. As such, previous research has recommended classifying athletes into one of four categories (e.g. fast mover/fast thinker, fast mover/slow thinker, slow mover/slow thinker, slow mover/fast thinker) based upon their physical COD and perceptual-cognitive ability (30). Concluding that

COD tests are of no use is at odds with the concept that COD is a foundation for agility (85), and makes the assumption that the teams used to validate such conclusions are composed of individual athletes with identical levels of COD and agility. Although the purpose of this paper is to highlight the potential issues with all current measures of COD, setting contextual limitations of conclusions drawn from the discussed COD and agility tests as they are currently performed may set a platform for increased understanding of the purpose for both COD and agility testing.

Validity of current COD measures: Different results based on different measures?

Albeit complex to evaluate, validity is a critical aspect of measurement (42). A construct valid measure of COD and agility based on their definitions should be evaluating the relevant change in direction, velocity or mode. However, as previously discussed, research has primarily used "total time" despite large to very large correlations with straight-line running speed (30, 63, 65) therefore failing to demonstrate discrminant validity. Only a few studies have provided measures describing an individuals' COM during a COD (36, 79, 89, 90, 103) which is arguably the most direct, global measure of how well an individual is changing direction. As such, the most common measures of COD (Table 1) and agility (Table 2) when presented simply as total time may not be the most valid assessments to measure the aforementioned capacities.

When considering various measures of COD performance, different conclusions can be drawn depending on what is used as the actual assessment. For example, Nimphius et al. (69) compared the use of a traditional "total time" measure of performance and the COD deficit during the 505 COD test. The results indicated that COD performance as defined by 505 total time and as COD deficit were different (i.e. an athlete who was faster in the 505 was not necessarily a better performer as defined by the COD deficit). Of particular interest to practitioners, was that the metric chosen to evaluate COD changed the perceived COD ability of the athlete in more than 88% of the cases (69). In another example, evaluation of performance outcome differences between stronger and weaker athletes lead to different conclusions when using total time to complete a COD task versus evaluating the exit velocity during the COD (90).

A specific example of how the choice of "measure" can influence the perceived COD ability of an athlete is shown in Figure 2 where all the simplified COD tests used were 10 m in length (5 m prior to the COD and 5 m following the COD) therefore COD deficit was calculated using the difference between each COD test total time and the 10 m sprint time. On both the preferred and non-preferred legs for this athlete, the total time and COD deficit provided different results. Therefore, if using total time, one may conclude the athlete is better than average for COD in all directions. However, when using COD deficit one would conclude that they are average or below average in all directions for COD ability and were relying on their better than average acceleration ability (10 m time) to mask their COD performance when assessed using total time.

***** Insert Figure 2 about here****

How can research provide better information on COD and agility?

Many researchers have begun to utilize measures with potential for improved validity by evaluating the movement surrounding the actual COD either during a COD or agility tests. In fact, measures of the COM allow a direct assessment of one's ability to change direction, as defined by the resultant velocity of the COM. In addition to resultant COM velocity, a specific measure of "evasion", which may be represented by the velocity of COM in a horizontal direction to that travelled could be considered in the future. Such a measure was highlighted by Wheeler and Sayers (103), where during an agility condition, the fastest performers had the greatest increase in lateral movement speed prior to the COD, at foot-strike of the COD and exiting the COD. For researchers, assessing COM velocity is often not as great a challenge in comparison to practitioners, hence the recent use of COM velocity in some recent research studies (78, 88, 89, 102). However, the cost (financial and time) associated with measurement of COM velocity from three-dimensional analysis (e.g. using motion capture) could still limit its use for many. As a more practical compromise, COM speed has been measured using the more cost- and time-effective laser distance measurement devices (LDMs; accurately measure distances of an object 100 times per second [sampling rate]) during straight-line, 45° and 90° changes of direction demonstrating acceptable reliability for speed around the COD (36). Therefore, LDMs provided more information around the COD than discrete measures provided by timing gates, while still remaining relatively affordable.

Such research solutions are still not without their limitations. For example, LDMs demonstrated high reliability (36), but can only measure the resultant COM velocity of a single COD with two LDMs synchronized and do not consider the actual angle of the COD performed (16) or specific information on the lateral movement velocity (36). Therefore, future developments with radio frequency identification (RFID) technology may allow for greater spatial accuracy (24) and overcome the large coefficient of variation issues observed when assessing COD ability with existing GPS and inertial measurement units (1, 76, 102). However, for the practitioner, measurement of the COM may be currently limited to using high-speed video available on phones and tablets.

If simple, reliable measures of COM velocity become available with future technological developments, there are additional interesting insights that could provide even better information about COD performance by considering knowledge gained from prior studies associated with acceleration performance in sprinting. In every stance phase in running, external mechanical work is done between the athlete and the environment, which leads to a change in COM velocity. For simple linear acceleration movements, Bezodis et al. (9) therefore proposed using horizontal external mechanical power to appropriately quantify performance based on the amount of external work done (i.e. the change in kinetic energy associated with this change in horizontal COM velocity) with respect to the time taken to achieve it. The same principle appears to offer potential for quantifying COD performance whereby the time spent achieving a change in motion is also fundamental for performance. Although complicated by the inherent change in direction, a scenario with a 180° COD movement can provide simple illustration of this. If a performer approaches the contact phase at a given speed then the combination of their exit speed (in the opposite direction) and the time spent in contact with the ground clearly reflect their COD performance. A greater change in speed, a shorter contact phase, or both, are due to greater external mechanical power and are clearly a tactical advantage which give defenders less chance of adopting an appropriate response (either directly due to less time available or to a faster exiting opponent). Further investigation of the potential efficacy of a COD performance measure based on external mechanical power therefore appears worthwhile, and may provide a single value which can be applied to more appropriately quantify true COD performance.

In summary, a single, ideal measure of COD performance does not currently exist as the ability to change direction is said to be angle (11, 36) and velocity dependent (98). Therefore, future research evaluating more specific measures of COD performance instead of the broad measure of "total time" will be highly relevant to practitioners. Practitioners drawing conclusions from research must first have context for the information they seek (e.g. for evasion or to maintain velocity). Subsequently, practitioners may then seek to interpret research using the following measures of COD: COM velocity entering (entry velocity) and exiting (exit velocity), "evasion" ability assessed by horizontal velocity and external mechanical power during the COD to consider the combination of the change in velocity and the time taken to achieve that COD.

Practical Applications

Existing literature has supported the use of quantifying COD ability relative to one's straight-line sprint ability either as a percentage decrement (15), as an absolute score (65), or further converted to a z-score for comparison to any performance test (69); or to examine COD ability over a shorter distance (79). Therefore, to increase the validity of testing when equipment cost and time is limited, as is the case for many practitioners, the following recommendations can be considered:

1. Consider the "why" of testing by understanding the characteristics of the test and the directional changes required for the athlete. For example, intending to assess the ability to maintain velocity as required in the L-run, termed "maneuverability" (21, 67), versus tests such as the 505 (180°) or a 90° cut that requires a large degree of deceleration in conjunction with the directional change.
2. Shorten the distance over which the COD is evaluated, during both COD and agility tests, but consider increasing the velocity (by increasing run-up

distance) to alter the demands of COD where applicable. Additionally, evaluate COD momentum (COM velocity × body mass) where applicable.

3. Consider the use of the COD deficit measure (68, 69) by evaluating linear speed over the same distance required of the total distance covered during the chosen COD test as an absolute score or z-score.
4. When no timing gates are available, or in addition to quantitative measures, perform a technical evaluation of the COD to describe movement quality.
5. Use of lights for agility testing or training may be practically more convenient, but consider the use of human stimuli for a more ecologically valid stimulus that can still have moderate reliability and high validity (71).

Conclusion

Just as there is no single COD requirement across all athletes and for all situations, it is likely there is not a single comprehensively valid test of COD or agility. However, understanding the actual measure that is the best indicator of the performance one is seeking to measure could vastly improve our knowledge on COD and agility (i.e. *"why"* are you testing?). Practitioners and researchers should consider that angle of the COD, the entry velocity into the COD, in conjunction with the intention of the COD (e.g. to evade or complete in minimal time or with maximal velocity) influences the outcome measure that best represents performance success, and the type of test that may best evaluate these sub-qualities associated with COD performance. It should be acknowledged that current standards of only collecting total time over longer distances is likely suboptimal for isolating the performance quality (i.e. COD or agility) intended to be assessed. Finally, from a coaching perspective, there is not one way to change direction, and therefore a combined consideration of outcome and process (e.g. *"what"* was the performance result and *"how"* was it obtained) will ultimately provide the most comprehensive, applied assessment of COD performance.

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Figure Legends

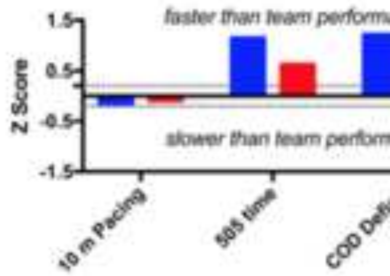
Figure 1. Comparison of a 180° COD during a traditional 505 on the right and left sides. The one-second (1.4 meters entering and exiting) around the COD is shown in figures A – F. As the athlete enters the right COD they are more upright (B & C), preferentially loading the inside left leg for deceleration (shown by the closer foot position) during the COD step (C) and subsequently have poorer body position and right leg acceleration mechanics when exiting the COD (D & E). In comparison, they can effectively decelerate using the outside left leg (C) on the left side and subsequently effectively re-accelerate (D) out of the COD when turning on the “left” side. The combination of these technical differences helps explain the variation in time taken to exit the COD (F) and provide reason to use constraints or drills that require equal development of both legs.

Figure 2. Comparison of simplified COD tests for an athlete using total time and COD deficit. The standardized scores presented were calculated using the team mean and standard deviation for each test. The z scores were reversed so the values above the line are better or faster performance.

Figure 1

Click

	Left	Right (*ACL)	Absolute Difference (L - R)	% Difference (L - R)
10 m sprint (s)	1.82		N/A	N/A
10 m pacing* (s)	0.18	0.17	0.01	5.7%
505 time (s)	2.23	2.36	-0.13	-5.7%
COD Deficit (s)	0.41	0.54	-0.13	-27.4%



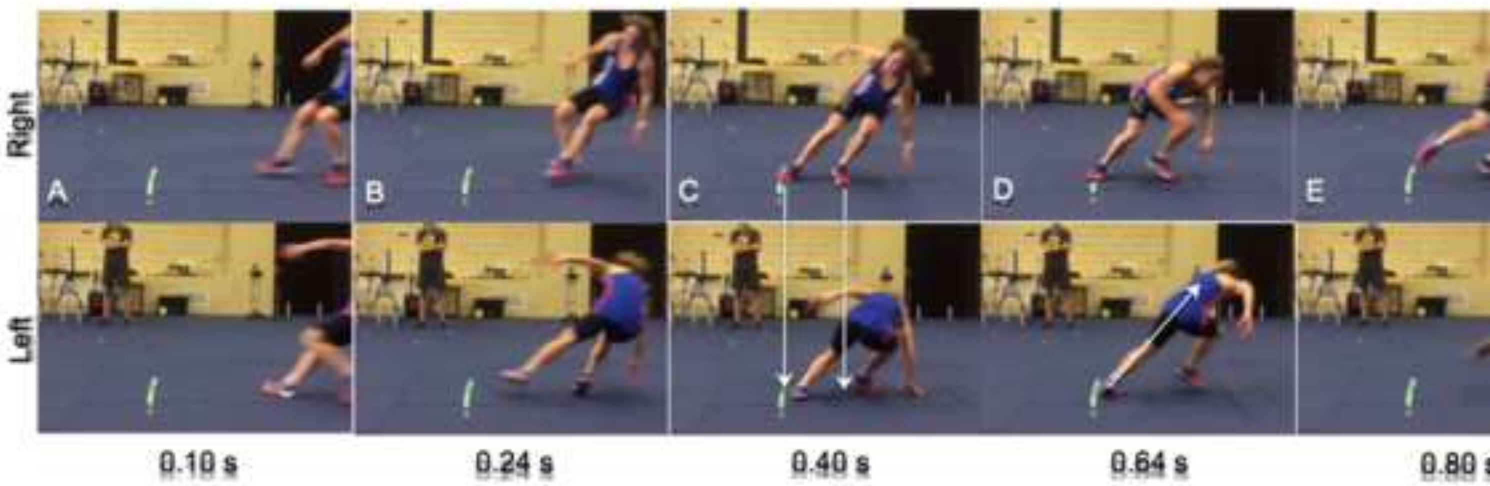
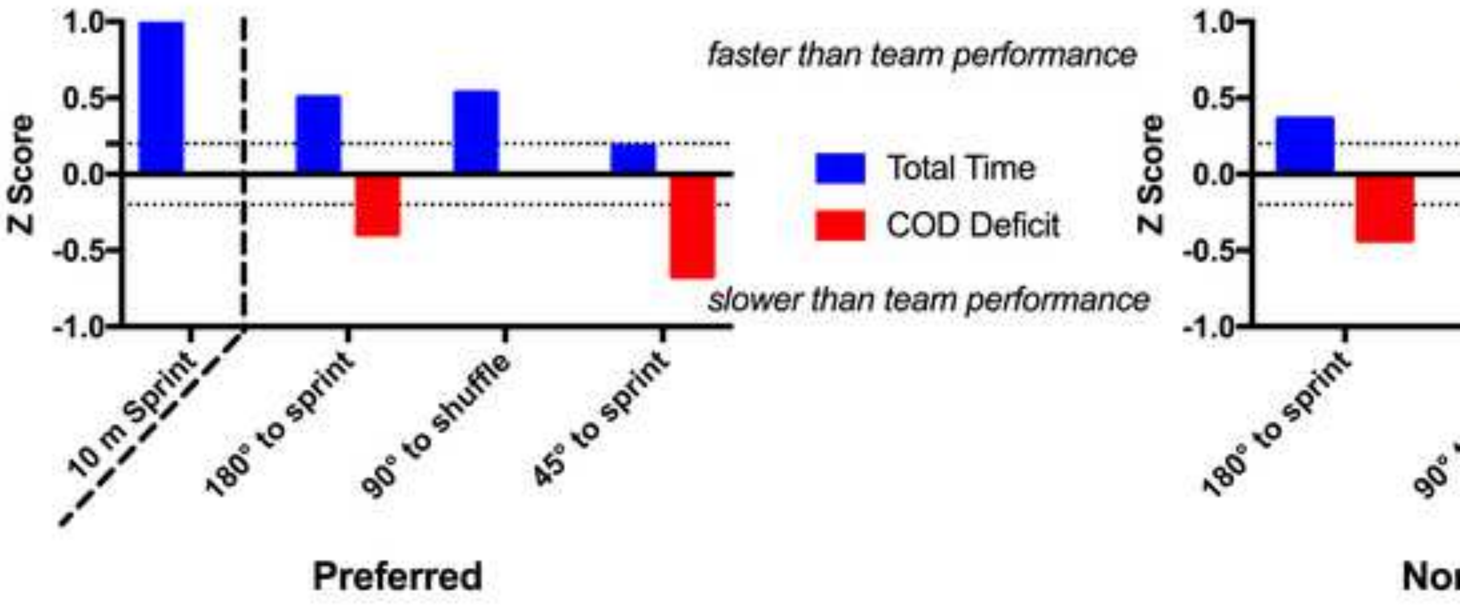


Figure 2

Cl



1.0
0.5
0.0
-0.5
-1.0
Z Score
faster than team performance
slower than team performance
Total Time
COD Deficit
10 m Sprint
180° to sprint
90° to shuffle
45° to sprint
Preferred

Table 1

Table 1: Tests that are typically used to measure change of direction (COD) performance.

Test	Number of Direction Changes	Approximate Time to Complete Test (s)	Total Test Distance (m)	Estimated Angle o Direction Change
5-0-5	1	1.5-3	10*	180°
Modified 5-0-5	1	2-3	10	180°
COD speed test	1	1.5-2	8	45°
Y-shaped planned agility	1	2-3	10	45°
Softball; Home to 2nd base	1	5.5-7	35.8#	90°
10 yd shuttle	2	2.5-3.5	9.14	180°
10 m shuttle	2	2-4	10	180°
20 yd shuttle	2	4.5-5.5	18.29	180°
48 ft sideways shuffle	2	5-9	14.63	180°
Cricket; run-a-three	2	8.5-11	53.04	180°
Pro-agility shuttle	2	4-5.5	18.28	180°
Zig-zag	3	5-6	20#	100°

NB: yd = yards; ft = feet; s = seconds. m = meters. *A rolling, moving or fly in start was utilized to com bending around cones (termed manoeuvrability) therefore the distance provided is based on linear measure athlete path or trajectory, actual distance travelled will vary.

Table 1: Tests that are typically used to measure change of direction (COD) performance. *continued*.

Test	Number of Direction Changes	Approximate Time to Complete Test (s)	Total Test Distance (m)	Estimated Angle Direction Change
4 x 5 m sprint	3	4.5-6	20	90°, 180°
T-test	4	7.5-13	36.56	90°
Modified T-test	4	3-7	11-20	90°
COD and acceleration test	4	5.5-6.5	24#	45°, 90°
Sprint 9-3-6-3-9 m with 180° turns	4	6-8	33	180°
L-run/3 cone drill	5	4.5-7	20-27#	90°,180°
Australian Football League agility test	5	8-9.5	15#	90°,180°
30 m sprint with 5 CODs	2-5	4-10.5	30#	45°, 90°,120°
Sprint with 90° Turns	6	6-8	21	90°
4 x 5.8 m shuttle	8	5-9	23.2	180°

NB: yd = yards; ft = feet; s = seconds. m = meters. *A rolling, moving or fly in start was utilized to com bending around cones (termed manoeuvrability) therefore the distance provided is based on linear measure athlete path or trajectory, actual distance travelled will vary.

Table 1: Tests that are typically used to measure change of direction (COD) performance. *continued*.

Test	Number of Direction Changes	Approximate Time to Complete Test (s)	Total Test Distance (m)	Estimated An Direction Ch
The field planned visual stimuli agility test	8	14-16	51	90°
Box test	10	15-17.5	57.9	45°, 90°
Illinois agility run	11	13-19	60#	90°, 180°
Squash specific COD speed test	11	9.5-13	16.1#*	45°, 90°, 180
Slalom run	11	7-14	22#	90°, 180°
6 x 5 m shuttle	12	10-12	30	180°
Stop 'n' go change of direction speed	15	8-10	32*	45°, 90°, 180
Hexagonal test	18	8-16	10	60°
10 x 5 m shuttle	20	18-22	50	180°

NB: yd = yards; ft = feet; s = seconds. m = meters. *A rolling, moving or fly in start was utilized to com bending around cones (termed manoeuvrability) therefore the distance provided is based on linear measure athlete path or trajectory, actual distance travelled will vary.

Table 2

Table 2: Tests that are typically used to measure agility performance.

Test	Number of Direction Changes	Approximate Time to Complete Test (s)	Total Test Distance (m)	Estimated Ang Direction Cha
Reactive agility test	1	1.5-3	8	45°
Reactive agility speed test	1	2-2.5	10	45°
Video reactive agility test	1	2-2.5	11	45°
Light reactive agility test	1	2-2.5	11	45°
The rugby league reactive agility test	1	1.5-2.5	10	45°
Y-shaped reactive agility	1	1.5-2	10	45°
Basketball specific reactive agility test	2	4-5.5	13.5	45°
Australian Football reactive agility test	2	1.5-2	12	45°
Tennis specific shuttle	3	6-9	28.85	180°
Netball reactive agility test	3	3-4	11.1	45°, 90°, 180°
The field reactive visual stimuli agility test	8	16-20	51	90°
Stop 'n' go reactive agility test	15	10-12	32*	45°, 90°, 180°

NB: yd = yards; ft = feet; s = seconds. m = meters. *A rolling, moving or fly in start was utilized to commenc

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