Forster et al., J Athl Enhanc 2021, 10:6

Journal of Athletic Enhancement

Research

A SCITECHNOL JOURNAL

Advancing the Diagnostic Value of the Pro-agility Test

James W Forster, Aaron M Uthoff, Michael C Rumpf and John B Cronin

Sports Performance Research Institute New Zealand (SPRINZ),AUT University, Auckland, New Zealand

***Corresponding author:** James Forster, Sports Performance Research Institute New Zealand (SPRINZ), AUT University, 17 Antares Pl, Auckland, New Zealand 0632, Tel: +64 7 578 3272, +64 22 173 4885; E-mail: jwdfor@gmail.com

Received date: May 19, 2021; **Accepted date:** June 04, 2021; **Published date:** June 11, 2021

Abstract

The pro-agility shuttle is commonly used by practitioners to assess Change of Direction (COD) performance in athletes. The metric of total time is influenced by accelerative and declarative ability and makes “true” COD ability difficult to quantify. The aim of this study was to determine whether an advanced diagnostic protocol, with three timing lights, could be used to reliably measure different components of pro-agility shuttle performance. The traditional set-up was adapted, and additional timing lights were placed 2.28 m from each COD line, enabling different phases of COD performance to be quantified. Ten participants (age: 16.1 ± 0.32 y, height: 1.81 ± 0.11 m, body mass: 76.6 ± 18.04 kg) completed three sessions, consisting of three trials, separated by one week. Absolute and relative consistency was assessed using Coefficients of Variation (CV) and Infraclass Correlation Coefficients (ICC) respectively. A one-way ANOVA was performed to determine whether between-day performance differences existed. Systematic changes were identified between sessions 1-2 for COD1, Moderate Intensity 501, Moderate intensity 105, Stationary 5-0-5 and Flying 5-0-5 (-7.37%, -4.20%, $p<0.05$). However, between session performance stabilized and no significant differences were observed between sessions 2-3 in any of the COD phases. Comparisons between sessions 2-3 resulted in low typical error (CV<4.42%) and excellent relative consistency (ICC>0.90) for all sub-tests. It would seem that the components of the pro-agility test can be measured reliably and therefore can provide valuable diagnostic information to the practitioner to guide COD programming.

Keywords: Change of direction; Speed; Testing; Athlete performance

Introduction

The knowledge of the physical components that contribute to athlete performance has gradually deepened as practitioners seek to assess and develop athletes. Notably, the capability to Change Direction (COD) is imperative for successful performance in many sports [1-3]. The pro-agility shuttle is one such assessment that has been widely adopted in field sports such as Baseball/Softball [4], Soccer [5] and American football [6] as a tool to develop and distinguish between athletes’ performance for team selection purposes [6,7]. The pro-agility shuttle is comprised of two 180° CODs, 4.57 m (5 yard) and 9.14 m (10 yard) linear sprints and has been found to be a reliable assessment of 180° COD ability (ICC=0.90, CV=2.19) athletes [8].

A limitation with the pro-agility shuttle is that total time as a measurement of performance has been shown to be influenced by linear sprint ability [9]. Practically meaning, an athlete can compensate for poor COD performance with good sprinting ability, as identified in other 180°C COD tests, such as the 5-0-5 [10]. This problem can be addressed by assessing linear sprinting and COD as individual performance components [7,9,11]. An example of this is where the 5-0-5 COD test has been updated to include the COD deficit, the average difference between 5-0-5 and 10 m sprint times, providing a practical measure for isolating COD time and better recognizing athlete COD ability. The 5-0-5 test and linear sprint ability have both been found to be “low” to “excellent” measures of reliability [12,13]. While the differentiation between speed and COD performance have been addressed for other 180°C COD tests, only one study [14] has investigated the differentiation of speed and COD performance in the pro-agility, providing insights into different athletic capabilities.

The ability to distinguish between measures of accelerative (*i.e.*, acceleration and re-acceleration) and COD may improve our understanding of an athlete’s concentric and eccentric capabilities [9,10]. For example, early acceleration requires concentric action of the muscle, where propulsive forces are a product of powerful concentric action of the muscle [15,16]. Alternatively, deceleration is dependent on eccentric strength as the eccentric nature of deceleration requires athletes to tolerate high braking forces [17,18]. Additionally, possessing high levels of isometric strength will allow athletes to withstand high forces that occur during the plant phase benefitting COD technique, allowing the athlete to maintain optimal body positioning [17,19,20]. Therefore, in order to perform a COD successfully, it is imperative that athletes possess sufficient concentric strength, eccentric strength, and isometric strength [15,21]. The use of advanced diagnostic protocols may enable a more in-depth analysis of pro-agility shuttle performance by decompartmentalising components of the test. For example, a single study by Forster et al. [14] used additional timing lights, placed 1 m before the COD line, to identify the different phases of the pro-agility shuttle. Additionally, Clarke et al. [22] used a beam-based ground contact system (Opt Jump, Micro gate, Italy) and timing lights (Witty, Micro gate, Italy) to investigate different phases of the 5-0-5, and found phases of initial approach time, entry time, full approach time, time to plant, exit time, and 505 COD time to be reliable (CV=2.3–6.3%, ICC=0.73–0.94). The findings of Forster et al. [14] and Clarke et al. support investigation of individual phases within 180°C COD tests. However, the entry distance used by Clarke et al. was consistent; therefore it is unknown how performance may vary between entries of different starting distances.

Movement velocity before and after COD in the pro-agility shuttle may be dependent on entry distance, eliciting different loading requirements. An example of this is that greater eccentric loading is required during deceleration into the second COD in the pro-agility, compared to that required for the first COD, due to a longer entry distance allowing for higher velocities to be reached before deceleration occurs [20,23]. Similarly, higher and lower reactive acceleration ability out of a COD may also be present in the pro-agility shuttle, as determined by the eccentric-concentric force capability from 5 m and 10 m entries [20,23]. Early acceleration from a stationary position, such as that performed in the stationary 5-0-5 [24], relies more on concentric muscle action to propel athletes over the first 5 meters, where relatively slow COD entry velocity will require relatively low eccentric loading [17,20]. Alternatively, during reacceleration from relatively faster COD entry velocities, due to accelerating from a flying start as those seen in the flying 5-0-5, will be more indicative of higher eccentric strength and elastic capabilities of the athlete [17,25].

Finally, although phases of the pro-agility shuttle were initially measured by Forster et al. [14], they acknowledged that reliability of measures may improve when timing gates are placed at equal distances between the COD and start/finish lines. In doing this, modified versions of the aforementioned tests may be built into the pro-agility shuttle as sub-tests (*i.e*., 4.57 m and 9.14 m sprints, stationary 5-0-5 and flying 5-0-5 into the first and second 180° COD). Therefore, the pro-agility may provide more diagnostic information than a singular test time, while minimizing athlete fatigue caused by evaluation of multiple speed and COD assessments [14,26,27]. While advanced protocols have enabled the differentiation between linear and COD speed for the 5-0-5 test, it is currently unknown whether an advanced diagnostic protocol can be used to reliably determine performance between different phases and sub-tests of the pro-agility shuttle.

Given that COD performance is comprised of multiple speed and COD components, it is of interest to investigate whether the individual qualities which constitute the pro-agility shuttle can be measured accurately and consistently. Therefore, the aim of this study is to investigate the reliability of different phases and sub-test measures (*i.e.*, linear acceleration, reacceleration, and COD phases), in field sport athletes, by advancing the diagnostics provided by the pro-agility shuttle. We hypothesized that after appropriate subject familiarization with the pro-agility shuttle; all sub-test measures would be reliable. Additionally, we hypothesized that given the complexity of COD performance, the measures of COD would be more variable relative to linear sprinting performance.

Methods

Experimental approach to the problem

To analyses the reliability of an advanced diagnostic protocol for the pro-agility shuttle, a repeated measures analysis of male field sport athletes was conducted. Subjects performed maximal effort attempts of the pro-agility shuttle, with two additional timing gates placed at 2.28 m (2.5 yards) prior to each COD line. To determine whether between-day performance differed, absolute consistency using Coefficient of Variation (CV) and relative consistency using InfraclassCorrelation Coefficient (ICC) were also used to determine the reliability of total time and sub-test performance.

Subject

Ten male high school field sport athletes (Age: 16.1 ± 0.32 y, Height: 1.81 ± 0.11 m, Body mass: 76.6 ± 18.04 kg) participated in this study. All subjects participated in field sports requiring 180°C CODs, had an average training age of 4.50 ± 0.50 y, and wererequired to be healthy and free of injury at the time of testing. After being orally briefed on the methods and reading the information sheet, subjects provided their written informed consent, or assent, prior to participating in this study and where appropriate, subjects' guardians provided written consent. Subjects were notified that they were free to withdraw from the study at any point. This research was approved by the Auckland University of Technology Ethics Committee (20/67) and conforms to the Declaration of Helsinki.

Procedures

Testing was conducted on an indoor hardwood floor. Wearing the same clothing and footwear, subjects were required to attend four sessions: one familiarization session where the subjects were accustomed with performing the pro-agility shuttle and three testing sessions. By asking the subjects to come in for three testing sessions, this allowed researchers to compare performance between sessions (*i.e.*, session one and two and session two and three) and determine the reliability of sub-test performances with the new diagnostic setup. Testing sessions were conducted seven days apart, at the same time of the day, under the same experimental conditions. Each testing session lasted approximately one hour. During each session, subjects performed a standardized warm up consisting of progressive sprint and COD drills interspersed with dynamic lower body stretching, followed by three pro-agility trials at 70%, 90% and 100% intensity [14].

For the pro-agility run, the subjects started on a centerline facing perpendicular to the running direction [28]. The subjects sprinted 4.55 m to the left, then 9.10 m to the right, and 4.55 m back to finish the test as they crossed the centerline, always turning on their dominant leg. Three trials on each testing session were used to gather average performance data and minimize the effect of best performances confounding the results [29,30]. Three minutes of passive rest was provided between trials to limit performance fluctuations resultant from fatigue and decrease risk of injury [7,31].

Equipment

To quantify COD performance, timing gates (Smart speed, Fusion sport, Finland) were set at the start/finish line and 2.28 m either side of the start line (*i.e.*, 2.28 m between the start/finish and each COD line) (Figure 1) [32,33]. Timing gate height was set at 0.85 m for the start/finish to correspond with approximate center of mass and gates 2.28 meters from each COD were set at 0.75 m to account for subject's lower center of mass during the COD [34]. This set-up enabled total time (*i.e.*, 18.2 m) and associated sub-tests to be measured (Table 1).

Split	Name	Explanation/ Distance	Proposed Quality
1	Acceleration 1	Acceleration from gate 1 to gate 2. Distance=2.28 m.	Starting acceleration
2	COD 1	Timing 2.28 m entry and exit of the first COD. Distance 4.57 m.	Lower velocity entry COD ability
3	Reacceleration 1	Acceleration from gate 2 to gate 1. Distance=2.28 m.	Low load Initial accelerative/ reaccelerative ability

4	Acceleration 2	Acceleration from gate 1 to gate 3. Distance=2.28 m.	Final accelerative ability
5	COD 2	Timing 2.28 m entry and exit of the second COD. Distance =4.57 m.	Higher velocity entry COD ability
6	Reacceleration 2	Acceleration from gate 3 to gate 1. Distance=2.28 m.	High load initial accelerative/ reaccelerative ability
Sub-Test			
Acceleration 1+COD 1	Moderate intensity 501 (MI501)	From gate 1 through gate 2, 180oC COD back to gate 2. Distance=6.84 m.	Stationary 501 (moderate intensity eccentric loading capability)
COD 1+Reacceleration 1	Moderate intensity 105 (MI105)	From gate 2, 180oC COD, through gate 2 to gate 1. Distance=6.84 m.	Moderate reactive accelerative ability
Acceleration 2 +COD 2	High intensity 501 (HI501)	From gate 1, through gate 3, 180oC COD back to gate 3. Distance=6.84 m.	Flying 501 (high intensity eccentric loading capability)
COD 2 +Reacceleration 2	High intensity 105 (HI105)	From gate 3, 180oC COD, through gate 3 to gate 1. Distance=6.84 m.	High reactive accelerative ability
Acceleration 1 +COD 1+Reacceleration 1	Stationary 505	From gate 1 through gate 2, 180oC COD, back through gate 2 to gate 1. Distance=9.14 m.	Moderate intensity eccentric loading and reactive accelerative ability.
Acceleration 2 +COD 2+Reacceleration 2	Flying 505	From gate 1 through gate 3, 180oC COD, back through gate 3 to gate 1. Distance=9.14 m	High intensity eccentric loading and reactive accelerative ability
All	Total time	Pro-agility total time. Distance=18.28 m.	All the above

Table1: Pro-agility diagnostic sub-test categorization and proposed physical qualities measured.

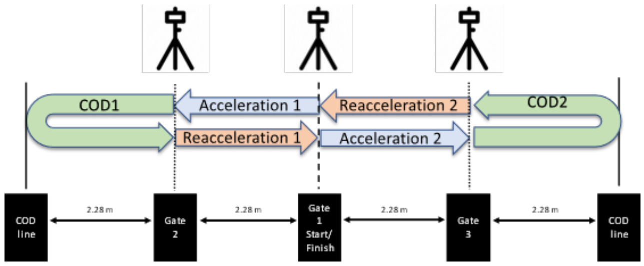

Figure 1: Advanced pro-agility shuttle protocol.

Statistical analysis

The two fastest trials from each session were averaged for all the variables of interest and used for subsequent analysis [35]. Assumptions of normality were assessed using a Shapiro-Wilks test and homogeneity of variance was calculated using the Levene's statistic to test for outliers. Thereafter, descriptive variables were quantified using IBM SPSS statistical software package (version 25.0; IBM Corporation, New York, USA). Data was reported using 95% Confidence Limits (CL) and means. Reliability was established using pairwise analysis. Each dependent variable was investigated between the first and second sessions and between the second and third sessions. A One-way Analysis of Variance (ANOVA) using repeated measures was used to determine whether between-day performance differed for total time and each of the twelve sub-tests. A secondary one-way ANOVA was used to compare between phase performances of relative distances (e.g., Acceleration 1 *vs.* Acceleration 2 and flying 5-0-5 *vs.* stationary 5-0-5) within session 3. To determine if systematic differences were presented between testing sessions one to two and two to three, and between phases of session 3, a Bonferroni pair wise comparison was used. Absolute consistency between sessions was assessed by the root-square-mean method to calculate CV [36,37], mean percentage change and relative consistency using test-retest correlations was measured *via* ICC using a two-way random model and averaged measures [38]. CVs of less than 10% were deemed acceptable as a percent of typical error [39]. Categorization of ICC was deemed as follows: 'very poor' (<0.20), 'poor' (0.20-0.49), 'moderate (0.50–0.74), 'good' (0.75–0.90) or 'excellent' (>0.90) [40].

Results

The mean and standard deviation for each session's sub-test results are displayed in Table 2. The only significant difference observed existed for COD1, moderate intensity 501 (MI501), moderate intensity 105 (MI105), stationary 5-0-5 and flying 5-0-5 between the first two sessions (-7.37%-4.20%, $p<0.05$), with no significant differences being observed between the last two sessions. Between sessions 1-2 mean change in total time ranged from -6.28% to 1.19% and between sessions 2-3 the change in mean was between (-0.38%-1.36%) for all conditions. The change in mean was smaller in sessions 2-3 compared to sessions 1-2 for all variables measured.

Regarding absolute consistency, CVs ranged from (0.95%-10.22%) for both days, averaged CV between session 1 and 2 was 7.15% and between sessions 2 and 3 was 1.74%. Only Acceleration 1 and COD2 had an unacceptable CV (>10%) between sessions 1 and 2, with all measures reporting acceptable CVs (<4.42%) between sessions 2 and 3.

Relative consistency ranged from ‘poor’ to ‘good’ (ICC=0.23-0.89) for all measures between sessions 1-2 and were “excellent” (ICC=0.90-0.99) between sessions 2-3. Average relative consistency was ‘moderate’ between days 1-2 and ‘excellent’ between days 2-3 (ICC=0.50 *vs.* 0.96 respectively).

A one-way ANOVA showed significant differences on session 3 (Table 2), between phases Acceleration 1 and Acceleration 2 (p<0.001). No significant differences were observed between reacceleration phases one and two (p=0.66). There were no significant differences between COD1 and COD2 time in session 3 (p=0.18). Significant differences were reported for MI501 between MI105 and HI501 (p<0.001) and between MI105 and HI501 (p=0.002). Measures of HI501 and HI105 were significantly different in session 3 (p<0.001), whereas no significant differences were present between MI105 and HI105 (p=0.69). Significant differences were observed between stationary and flying 5-0-5 (p<.001) for session 3.

Phases	**Mean (± SD)**			**% Change in mean**		**CV**		**ICC**	
				(95% CL)		(95% CL)		(95% CL)	
	Day 1	Day2	Day3	Day1-2	Day2-3	Day1-2	Day2-3	Day1-2	Day2-3
Acceleration 1	0.75 ± 0.03	0.69 ± 0.02	0.70 ± 0.01	-8.94%	0.24%	10.03%	1.45%	-0.24	0.98
			†R1, †A2, †R2	(-16.419 -0.787)	(-1.375 – 1.875)	(4.6 – 14.80)	(0.69 – 2.23)	(-1.238 – 0.534)	(0.914–0.994)
COD1	1.59 ± 0.07	1.41 ± 0.08	1.44 ± 0.12	-6.52% *	1.36%	9.32%	1.98%	0.42	0.96
				(-14.574–2.304)	(-0.599 – 3.353)	(4.23–13.66)	(1.00–3.24)	(-0.413 – 0.835)	(0.859–0.989)
Reacceleration 1	0.47 ± 0.03	0.51 ± 0.05	0.51 ± 0.05	7.03%	-0.27%	6.33%	1.00%	0.72	0.99
			†A1, †A2	(2.188–12.108)	(-1.361 – 0.841)	(3.11–10.03)	(0.47–1.52)	(0.111–0.927)	(0.963–0.997)
Acceleration 2	0.42 ± 0.02	0.43 ± 0.02	0.43 ± 0.02	2.54%	-0.38%	2.80%	1.18%	0.89	0.97
			†A1, †R1, †R2	(0.077–5.065)	(-1.661 – 0.910)	(1.32–4.24)	(0.59–1.90)	(0.597–0.974)	(0.874–0.990)
COD2	1.46 ± 0.11	1.43 ± 0.11	1.45 ± 0.12	5.01%	0.94%	10.22%	1.97%	0.54	0.97
				(-5.808 – 17.068)	(-1.151 – 3.066)	(4.09–13.33)	(0.99–3.23)	(-0.235 – 0.874)	(-0.888 – 0.992)
Reacceleration 2	0.47 ± 0.05	0.50 ± 0.03	0.50 ± 0.03 †A1, †A2	4.72%	-0.38%	5.58%	0.95%	0.72	0.99
				(-0.483 – 10.188)	(-1.396 – 0.651)	(2.51–8.10)	(0.47–1.50)	(0.111–0.927)	(0.956–0.997)
Sub-Test									
Moderate intensity 501	2.36 ± 0.05	2.09 ± 0.10	2.13 ± 0.13	-7.37% *	1%	8.40%	1.77%	0.23	0.93
			†M105, †H501, †H105	(-13.829 - -0.421)	(-0.829 – 2.859)	(3.95–12.70)	(0.88–2.82)	(-0.645 – 0.763)	(0.737–0.979)
Moderate intensity 105	2.06 ± 0.05	1.92 ± 0.03	1.96 ± 0.07	-3.27% *	0.95%	6.43%	1.67%	0.47	0.95
			†M501, H501	(-9.563 – 3.453)	(-0.769 – 2.698)	(2.88–9.27)	(0.82–2.63)	(-0.334 – 0.853)	(0.794–0.984)
High intensity 501	1.88 ± 0.08	1.86 ± 0.09	1.88 ± 0.10	4.17%	0.63%	9.83%	4.42%	0.6	0.97

			M501, M105, †H105	(-3.497–12.438)	(-1.195–2.480)	(4.07–13.10)	(2.06–6.63)	(-0.122–0.894)	(0.866–0.990)
High intensity 105	1.94 ± 0.07	1.92 ± 0.08	1.95 ± 0.09	4.74%	0.59%	7.88%	1.60%	0.5	0.96
			†M501, †H501	(-3.401–13.555)	(-1.144–2.353)	(3.24–10.45)	(2.59–0.80)	(-0.286–0.863)	(0.854–0.989)
Stationary 505	2.84 ± 0.03	2.61 ± 0.07	2.65 ± 0.08	-4.84%*	0.76%	6.31%	1.59%	0.32	0.9
			†F505	(-10.282–0.929)	(-0.916–2.473)	(2.95–9.47)	(0.77–2.47)	(-0.543–0.798)	(0.623–0.968)
Flying 505	2.36 ± 0.06	2.35 ± 0.06	2.38 ± 0.07	4.20%*	0.41%	6.19%	1.46%	0.59	0.96
			†S505	(-2.010–10.811)	(-1.193–2.041)	(2.62–8.42)	(0.73–2.35)	(-0.144–0.890)	(0.839–0.988)
Total Time	5.23 ± 0.14	4.98 ± 0.14	5.03 ± 0.19	-3.77%	0.51%	3.59%	1.53%	0.7	0.93
				(-6.279-1.191)	(-1.156–2.205)	(1.71–5.49)	(0.75–2.40)	(0.085–0.924)	(0.737–0.979)

Table 2: Pro-agility and sub-test descriptive statistics. Note: significance difference between session p<0.05, †: Significant differences between phases in session 3 p<0.001. A1: Significantly different to Acceleration 1, R1: Significantly different to Reacceleration 1, A2: Significantly different to Acceleration 2, AR2: Significantly different to Reacceleration 2, C1: Significantly different to COD1, C2: Significantly different to COD2, M 501: Significantly different to Moderate Intensity 501, M 105: Significantly different to Moderate Intensity 105, H 501: Significantly different to High Intensity 501, H 105: Significantly different to High Intensity 105, S505: Significantly different to Stationary 505, F 505: Significantly different to Flying 505.

Discussion

In the assessment of COD tests, determining COD performance from absolute performance time is a unique challenge, where independent qualities (*i.e.,*Acceleration and Deceleration, Re-acceleration and COD) are components contributing to the performance assessed [10]. Of interest to the authors was whether an advanced diagnostic protocol could be utilized to assess performance for distinctive phases of the pro-agility shuttle. In doing so, two true acceleration measures, two reacceleration measures, two COD phases and six additional assessments were identified as sub-tests that could provide informative data, in addition to total time measure for the pro-agility shuttle. Prior to any utilization of the sub-tests in the field, it was crucial to determine the reliability of the different phases. The main findings of this study were: 1.Acceleration phase performance measures of Reacceleration 1, Acceleration 2, and Reacceleration 2, HI501, HI105 and total time variables were reliable across all testing sessions; 2. All phases and sub-tests measured met the acceptable thresholds for reliability between sessions 2-3; and 3. There appeared to be a learning effect between sessions 1-2. Given these results, the application of an advanced diagnostic protocol to assess different phases and sub-tests within the pro-agility shuttle may be of utility to strength and conditioning coaches.

Previous research [14] has suggested reliability of phase's within the pro-agility may be improved with the addition of timing lights placed at equal distances between the COD and start/finish lines. Evidence of our findings confirms this in finding all pro-agility phases to be reliable. Each phase and sub-test measures different qualities within the pro-agility shuttle. Measures of Acceleration 1 and Acceleration 2 are not influenced by deceleration or a COD, due to the nature of phases initiating from either a stationary or flying start. Although similar in that Acceleration 1 and Acceleration 2 are measures of accelerative ability, the force-velocity requirements differ between initial 0-5 m and flying acceleration *i.e.,* 5-10 m [41,42]. The reliability of the acceleration phases of the pro-agility shuttle in this study closely align with previous findings that 5 m (ICC=0.65-0.87 and CV ≤ 3.3%) [43,44] and 10 m (ICC=0.85-0.62 and CV ≤ 2.6%) [45] sprints times are reliable performance metrics in athletes. However, in comparison Forster, et al. [14] found measures of acceleration to be “moderate” (ICC=0.51–0.71) when timing lights are placed at 1 m from COD.

Subjects in this study were found to be significantly faster in Acceleration 2 than in Acceleration 1 (0.43 ± 0.02 and 0.70 ± 0.01, p ≤ 0.00, respectively). The difference in performance may be explained by the flying start enabling higher movement velocities to be reached in Acceleration 2, than from initiation of movement from a stationary position, as measured in Acceleration 1. Additionally, variability in mean change and relative consistency (ICC) scores in Acceleration 2 (-0.38%, ICC=0.97) were observed to be marginally higher compared to Acceleration 1 (0.24%, ICC=0.98). These findings are in line with previous literature, that higher movement velocity associated with the flying start may attribute to the increased variability, reducing the reliability of the measurement [24,46,47]. Therefore, the difference in times between Acceleration 1 and Acceleration 2 indicate assessment of musculotendinous capabilities at different velocities and can be used to determine linear accelerative capabilities [7,48-50].

After making a directional change, athletes must reaccelerate. Reacceleration 1 and Reacceleration 2 were deemed to reliably measure low and high load initial reaccelerate ability, respective of COD entrance velocity. Once more, there were no significant differences (p=0.66) in performance between the low and high load reaccelerate session 3 conditions. It appears the reacceleration phases are similarly reliable (CVs=0.95–1.00%; ICCs=0.99), regardless of entry distance prior to COD. In contrast, Forster, et al. [14] found measures of reacceleration to be unreliable (CV=11.5–16.3; ICC=-0.15-0.48) with timing gates placed at 1 m from COD. Furthermore, reacceleration ability was found to be as reliable as acceleration from stationary and flying starts, though significantly (p<0.001) faster than Acceleration 1 and slower than Acceleration 2. Research has shown reacceleration to differ from “pure” acceleration, in that elastic energy, stored during deceleration, increases force output during the propulsive phase [51,53], therefore improving post-COD reaccelerate ability [20]. Therefore, given the differences in times between acceleration phases and reacceleration phases, yet similar reliabilities, strength and conditioning coaches can confidently distinguish between different forms of acceleration ability in their athletes.

It should be noted that, similar to the acceleration performance measures, both low and high velocity COD measures were found to have excellent levels of absolute and relative consistency between session 2-3 (CV<2.03, ICC>0.96). Interestingly, there was no significant difference between mean performance times of COD1 and COD2 in session 3 (1.44 ± 0.12 and 1.45 ± 0.12, p=0.18, respectively). These findings were unexpected, as the higher entry velocity into COD2 would be thought to increase movement variability, due to higher braking force and eccentric strength requirements to decelerate and maintain optimal body positioning during the turn [17,19,20] (as identified above). Though COD1 and COD2 resulted in similar time and reliability, it is unknown whether there were differences between the acceleration and deceleration components within these phases. For example, since Acceleration 2 was faster than Acceleration 1, it is possible that there were higher entry velocities and slower exit velocities in COD2 than COD1. However, continuous timing technology such as radar or laser is needed to explore this posit.

Finally, all sub-tests were established as reliable measures of the different performance components comprising the pro-agility shuttle (Table 1). Modifying the pro-agility enabled the measurement of both stationary and flying 5-0-5 performance, which was found to be similarly reliable to previous research into the stationary start (ICC=0.97) [24] and flying start 5-0-5 tests (ICC=0.88 and 0.95; CV=2.40%) [8,24]. MI501 and HI501, and stationary 5-0-5 and flying 5-0-5 are highly reliable measures, however, the completion times in session 3 should be noted. That is, sub-test performance with moderate intensity eccentric loading capabilities (MI501 and stationary 5-0-5) exhibited longer times (0.25–0.27 s, p<0.001) to complete than the higher intensity sub-tests (HI501 and flying 5-0-5), due to the faster entry velocities in the latter tests [24]. The differences in these sub-test measures are primarily explained by whether the subject is moving or stationary when they enter the testing phase (*i.e.*, Acceleration 1 and Acceleration 2, respectively). The addition of sub-test measures provides a means for practitioners to assess a multitude of athletic fitness qualities using a single test.

Practical applications

The advanced analysis using multiple timing lights can be used to consistently differentiate between phases of acceleration, reacceleration, and COD performance, and sub-tests within the pro-agility shuttle. Based on the findings of this research, we recommend that two familiarization sessions be conducted to mitigate any learning effects and allow for reliable performance measurement. The ability to distinguish between the speed components of the pro-agility and utilizing the established sub-tests have the potential to provide novel information relating to the different athletic capabilities of performance within the pro-agility shuttle. However, this contention needs to be investigated and a correlational analysis is needed to determine how much shared variance there is between the new measures and thereafter refine the testing battery to provide high level diagnostic information to guide better programming.

Conclusion

To the researchers’ knowledge, this study is the first to empirically test whether an advanced diagnostic protocol could be used to reliably distinguish between different sub-tests within the pro-agility shuttle. However, coaches and practitioners should be aware of several limitations of the current study: 1. Timing lights were set at 0.75 m in this study, in practice we suggest adjusting timing light height to be appropriate relative to the population being assessed, as for those who exhibit a very low COD position a timing light height of 0.75 m may not be appropriate, 2. Subjects only turned on their preferred leg, therefore it is unknown whether there are differences between the phases, sub-tests, or reliability measures between the legs, and 3. Using a timing light set-up at 2.28 m either side of the COD lines was unable to completely isolate deceleration and immediate reacceleration. Therefore, to further the diagnostic capabilities of the pro-agility shuttle, it would be recommended that future researchers compare performance between the preferred and non-preferred leg and investigate the use of alternative technologies which use constant timing, such as laser or radar technology to include velocity profiling to detect changes in velocity over the different phases of the pro-agility (*i.e.,* Acceleration, Reacceleration, and COD). While the subject sample for reliability in this study was small (n=10), Buchheit et al. asseverate that in finding good reliability, an expansion in sample size may not affect the results. Finally, we suggest that two familiarization sessions are required prior to performance testing, to ensure consistent and accurate data is captured.

Declarations of Interest

None of the authors report any financial or personal conflict of interest with regard to this study.

Acknowledgements

The authors would like to thank all the subjects for participating in this research and wish to extend our gratitude to the SPRINZ research lab, Athlete Factory and Tauranga Boys’ College for the use of facilities and equipment for this research.

References

1. Gil SM, Gil J, Irazusta J, Casis L, Gil J, et al. (2007) Physiological and anthropometric characteristics of young soccer players according to their playing position: Relevance for the selection process. J Strength Cond Res 21: 438-445.
2. Gabbett TJ (2005) A comparison of physiological and anthropometric characteristics among playing positions in junior rugby league players. Br J Sports Med 39: 675-680.
3. Reilly T, Williams AM, Nevill A, Franks A (2000) A multidisciplinary approach to talent identification in soccer. J Sports Sci 18: 695-702.
4. Nimphius S, McGuigan M, Newton R (2010) Relationship between strength, power, speed, and change of direction

performance of female softball players. J Strength Cond Res 24: 885-895.

5. MaioAlves JM, Rebelo AN, Abrantes C, Abrantes C (2010) Short-term effects of complex and contrast training in soccer players' vertical jump, sprint, and agility abilities. J Strength Cond Res 24: 936-941
6. Sierer SP, Battaglini CL, Mihalik JP, Shields EW, Tomasini NT, et al. (2008) The national football league combine: Performance differences between drafted and no drafted players entering the 2004 and 2005 drafts. J Strength Cond Res 22: 6-12.
7. Vescovi J, McGuigan M (2008) Relationships between sprinting, agility, and jump ability in female athletes. J Sports Sci 26: 97-107.
8. Stewart PF, Turner AN, Miller SC (2014) Reliability, factorial validity and interrelationships of five commonly used change of direction speed tests. Scand J Med Sci Sports 24: 500-506.
9. Nimphius S,Geib G,Spiteri T, Carlisle D (2013) Change of direction deficit measurement in Division I American football players. Journal of Australian Strength & Conditioning 21: 115-117.
10. Nimphius S, Callaghan SJ, Spiteri T, Lockie RG (2016) Change of direction deficit: A more isolated measure of change of direction performance than total 505 times. J Strength Cond Res 30: 3024-3032.
11. Salaj S, Markovic G (2011) Specificity of jumping, sprinting, and quick change-of-direction motor abilities. J Strength Cond Res 25: 1249-1255.
12. Kerdaoui Z, Sammoud S, Negra Y,Attia A, Hachana Y,et al. (2021) Reliability and time-of-day effect on measures of change of direction deficit in young healthy physical education students. J Biol Rhythms 38: 103-108.
13. Taylor JM, Cunningham L, Hood P, Thorne B (2019) The reliability of a modified 505 test and change-of-direction deficit time in elite youth football players. Science and Medicine in Football 3: 157-162.
14. Forster J, Uthoff A, Rumpf M, Cronin J(2021) Advancing the pro-agility test to provide better change of direction speed diagnostics. The Journal of Sport and Exercise Science 5: 101-106.
15. Chaabene H, Prieske O, Negra Y, Granacher U (2018) Change of direction speed: Toward a strength training approach with accentuated eccentric muscle actions. Sports Med 48: 1773-1779.
16. Markovic G,Jukic I, Milanovic D,Metikos D (2007) Effects of sprint and plyometric training on muscle function and athletic performance. J Strength Cond Res 21: 543-549.
17. Spiteri T, Nimphius S, Hart NH, Specos C, Sheppard JM,et al. (2014) Contribution of strength characteristics to change of direction and agility performance in female basketball athletes. J Strength Cond Res 28: 2415-2423.
18. Jones P, Thomas C, Dos'Santos T, McMahon JJ (2017) The role of eccentric strength in 180° turns in female soccer players. Sports. 5: 1-11.
19. Dos' Santos T, Thomas C, Jones PA, Comfort P (2018) Asymmetries in isometric force-time characteristics are not detrimental to change of direction speed. J Strength Cond Res 32: 520-527.
20. Spiteri T, Cochrane JL, Hart NH, Haff GG, Nimphius S, et al. (2013) Effect of strength on plant foot kinetics and kinematics during a change of direction task. Eur J Sport Sci 13: 646-652.
21. Spiteri T, Newton RU, Binetti M, Hart NH, Sheppard JMet al. (2015) Mechanical determinants of faster change of direction and agility performance in female basketball athletes. J Strength Cond Res 29: 2205-2214.
22. Clarke R, Read P, Hughes J (2020) Phases of the traditional 505 Test: Between session and direction reliability. Movement and Sports Sciences - Science et Motricite 110: 21-27.
23. Brughelli M (2008) Understanding change of direction ability in sport. Sports Med 38: 1045-1063.
24. Barber OR, Thomas C, Jones PA, Comfort P (2016) Reliability of the 505 change-of-direction test in netball players. Int J Sports Physiol Perform 11: 377-380.
25. Jones P, Bampouras T, Marrin K (2009) An investigation into the physical determinants of change of direction speed. J Sports Med Phys Fitness 49: 97-104.
26. Bourgeois FA, Gill ND, McGuigan M, Gamble P (2017) Physical characteristics and performance in change of direction tasks: A breif review and training considerations. Journal of Australian Strength & Conditioning 25: 104-117.
27. Nimphius S, Callaghan SJ, Bezodis N, Lockie RG (2018) Change of direction and agility tests: Challenging our current measures of performance. J Strength Cond Res 40: 26-38.
28. Gillen ZM, Miramonti AA, McKay BD, Leutzinger TJ, Cramer JT, et al. (2018) Test-retest reliability and concurrent validity of athletic performance combine tests in 6–15 year-old male athletes. J Strength Cond Res 32: 2783-2794.
29. Simperingham KD, Cronin JB, Pearson SN, Ross A (2019) Reliability of horizontal force–velocity–power profiling during short sprint-running accelerations using radar technology. Sports Biomech 18: 88-99.
30. Meylan C, McMaster T, Cronin J, Mohammad NI, Rogers C, et al. (2009) Single-leg lateral, horizontal, and vertical jump assessment: Reliability, interrelationships, and ability to predict sprint and change-of-direction performance. J Strength Cond Res 23: 1140-1147.
31. Lockie RG, Davis DL, Beiley MD, Hurley JM, Stage AA, et al. (2016) Physiological characteristics of incoming freshmen field players in a men’s division I collegiate soccer team. Sports 4: 34.
32. Sayers M (2014) Does the 5-0-5 test measure change of direction speed? J Sci Med Sport 18: 60.
33. Sayers M (2015) Influence of test distance on change of direction speed test results. J Strength Cond Res 29: 2412-2416.
34. Morrison K, Albert WJ, Kuruganti U (2015) Biomechanical assessment of change of direction performance in male university soccer players in ISBS-Conference Proceedings Archive. Poitiers, France.
35. Garson GD (2012) Testing statistical assumptions, Asheboro, NC: Statistical Associates Publishing.
36. Bland J (2006) How should I calculate a within-subject coefficient of variation. Frequently asked questions on the design and analysis of measurement studies.
37. Kang CW, Lee MS, Seong YJ, Hawkins DM (2007) A control chart for the coefficient of variation. J Qual Technol 39: 151-158.

38. Koo TK, Li MY (2016) A guideline of selecting and reporting infraclass correlation coefficients for reliability research. J Chiropr Med 15: 155-163.
39. Uthoff A, Oliver J, Cronin J, Winwood P, Harrison C, et al. (2018) Prescribing target running intensities for high-school athletes: Can forward and backward running performance be auto regulated? Sports 6: 1-10.
40. Buchheit M, Mendez VA (2013) Reliability and stability of anthropometric and performance measures in highly-trained young soccer players: Effect of age and maturation. J Sports Sci 31: 1332-1343.
41. Lockie RG, Jalilvand F, Callaghan SJ, Jeffriess MD, Murphy AJ, et al. (2015) Interaction between leg muscle performance and sprint acceleration kinematics. J Hum Kinet 49: 65-74.
42. Callaghan JS, Jeffriess DM, Mackie LS, Jalilvand F, et al. (2015) The impact of a rolling start on the sprint velocity and acceleration kinematics of a quick single in regional first grade cricketers. Int J Perform Anal Sport 15: 794-808.
43. Comfort P, Stewart A, Bloom L, Clarkson B (2014) Relationships between strength, sprint, and jump performance in well-trained youth soccer players. J Strength Cond Res 28: 173-177.
44. Enright K, Morton JP, Iga J, Lothian D (2018) Reliability of “in-season” fitness assessments in youth elite soccer players: A working model for practitioners and coaches. Science & Medicine in Football 2: 177-183.
45. Standing RJ, Maulder PS (2017) The biomechanics of standing start and initial acceleration: Reliability of the key determining kinematics. J Sports Sci Med 16: 154-162.
46. Duthie GM, Pyne DB, Marsh DJ, Hooper SL (2006) Sprint patterns in rugby union players during competition. J Strength Cond Res 20: 208-214.
47. Hader KD, Palazzi, Buchheit M (2015) Change of direction speed in soccer: How much braking is enough? Kinesiology 47: 67-74.
48. Cavagna GA, Komarek L, Mazzoleni S (1971) The mechanics of sprint running. J Physiol 217: 709-721.
49. Lai A, Schache AG, Brown NA, Pandy MG (2016) Human ankle plantar flexor muscle & tendon mechanics and energetics during maximum acceleration sprinting. J R Soc Interface 13.
50. Falch H, Raedergard H, Tillaar R (2020) Effect of approach distance and change of direction angles upon step and joint kinematics, peak muscle activation, and change of direction performance. Front Sports Act Living 2: 594567.
51. Ettema GJC (2001) Muscle efficiency: The controversial role of elasticity and mechanical energy conversion in stretch-shortening cycle. Eur J Appl Physiol 85: 457-465.
52. McCarthy JP, Wood DS, Bolding MS, Roy JL, Hunter GRet al. (2012) Potentiation of concentric force and acceleration only occurs early during the stretch-shortening cycle. J Strength Cond Res 26: 2345-55.
53. Buchheit M, Lefebvre B, Laursen PB, Ahmaidi S (2011) Reliability, usefulness, and validity of the 30–15 intermittent ice test in young elite ice hockey players. J Strength Cond Res 25: 1457-1464.