International Journal of
Strength and Conditioning

Ryan, C., Uthoff, A., McKenzie, C., Cronin, J. (2022).Profiling Change of Direction Ability Using
Sub-Phase 5-0-5 Analysis
International Journal of Strength and Conditioning
https://doi.org/10.47206/ijsc.v2i1.100

Profiling Change of Direction Ability Using Sub-Phase 5-0-5 Analysis

Chloe Ryan[1], Aaron Uthoff[1], Chloe McKenzie[1], and John Cronin[1]

[1]*Sports Performance Research Institute New Zealand, University of Technology, Auckland, New Zealand*

ABSTRACT

Change of direction (COD) ability is an important component for most field and court sport athletes. The modified 5-0-5 COD test is a commonly used test to measure 180-degree COD performance, the diagnostic value of which can be advanced using a multiple-timing light set-up to divide the test into sub-phases. The aim of this research was to determine what proportion of the 5-0-5 COD test was spent performing the 180-degree COD, whether anthropometry and position of the player influenced the sub-phase performance and provide an alternative approach to improve diagnostics for coaches and practitioners. Ten elite female netball athletes participated in this study. Dual beam timing gates set at 0, 2, and 4 m were used to isolate the phases of the 5-0-5 COD test and quantify COD performance. Independent t-tests were used to assess statistical significance ($p<0.05$) between anthropometry, position, and performance of the sub-phases. Rank-order of sub-phase performance was also conducted to determine individualized performance across phases. The highest percentage of time was spent during the 180-degree turn and reacceleration 1 phase (~23%). Heavier athletes were significantly slower for deceleration (9.26%), 180-degree turn (17.1%), reacceleration 2 (7.32%) and total time (8.68%), however no differences were identified between taller and shorter players. A sub-phase rank order table was used to provide diagnostic and training insights that allow more targeted programming to improve COD performance.

Key Words: 180-degree turn, 5-0-5 test, Netball COD

INTRODUCTION

It is important for field and court sport athletes to have well developed change of direction (COD) ability, as it is considered essential for successful participation in many sports, as well as being one of the determining factors for elite level athletes (Barber, Thomas, Jones, McMahon, & Comfort, 2016; Gabbett, 2006). There are a multitude of different assessments that can be used to map, monitor, and manage changes in COD performance. One test that is commonly used to measure 180-degree COD is the 5-0-5 COD test (Nimphius, McGuigan, & Newton, 2010; Spiteri et al., 2019; Thomas, Dos'Santos, Comfort, & Jones, 2016; Venter, Masterson, Tidbury, & Krkeljas, 2017). This COD test is a relatively simple test that is based on measuring the total time taken to complete a single 180-degree COD over a 15 m out and back course (traditional) (Draper, 1985) or a 5 m out and back course (modified) (Gabbett, Kelly, & Sheppard, 2008). Due to the simplicity and minimal equipment required to run this test, it has been adopted by numerous different sports (Kulakowski, Lockie, Johnson, Lindsay, & Dawes, 2020; Maraga, Duffield, Gescheit, Perri, & Reid, 2018; Pruyn, Watsford, & Murphy, 2014; Sayers, 2015). However, a limitation to these tests is that only a total time is produced, providing limited diagnostic value on how athletes enter, perform a 180-degree turn and exit. Researchers have designed tests such as the COD deficit (Nimphius, Geib, Spiteri, & Carlisle, 2013) and deceleration deficit (Clarke, Read, De Ste Croix, & Hughes, 2020), which aim to isolate the deceleration phase of the traditional 5-0-5 COD test. However, these protocols still do not provide information for the acceleration, 180-degree turn and reacceleration phases.

Alternatively, the 5-0-5 COD tests can be divided into sub-phases (i.e., acceleration, deceleration, 180-degree turn and reacceleration) to provide better diagnostic value and guide programming to better effect. One criticism of COD testing is that a large percentage of the current tests are spent linear sprinting, not directly assessing COD, thus any insight into COD ability is masked by the global measure of total time (Nimphius, Callaghan, Spiteri, & Lockie, 2016). Therefore, it would seem useful to understand the time spent in each phase and, most importantly, measure COD ability directly. Secondly, it is important to recognise that not all linear movement is the same. Athletes will accelerate, decelerate, and reaccelerate all within a single test (Jones, Thomas, Dos'Santos, McMahon, & Graham-Smith, 2017). As such, these movement qualities have different neuromuscular requirements and therefore require different programming and training (Harper, Carling, & Kiely, 2019; Hewit, Cronin, Button, & Hume, 2011). Such a contention is supported by the findings of Ryan et al., (2021) who showed that acceleration, deceleration, 180-degree turn and reacceleration, were mostly independent motor qualities in elite female athletes, reporting that only one variable explained more than 50% of the shared variance between sub-phases.

The ability to change direction depends largely on sufficient braking capabilities to halt momentum (Delaney et al., 2015). It could be hypothesised that players with greater body mass would have slower COD performance times as they face a greater neuromuscular challenge to decelerate and re-accelerate their body (momentum = mass x velocity) (Hewit, Cronin, & Hume, 2013). This posit was substantiated by Hewit and colleagues (2012), who highlighted that anthropometric measures contributed to COD performance. To the authors' knowledge there is currently no researcher that has investigated the effects of anthropometry on COD performance in elite female netball athletes. Previous researchers have shown differences in anthropometric measures between playing positions in netball (Graham, Duthie, Aughey, & Zois, 2020; Thomas et al., 2019). Mid-court players are, on average, shorter (171 cm) and have a smaller body mass compared to circle defenders and shooters (177.5 cm). Therefore, it would be hypothesised that these mid-court players would have faster COD times (Graham et al., 2020; Thomas et al., 2019).

Given this information, the authors were interested in the potential insights a modified 505 test, divided into sub-phases (i.e., acceleration, deceleration, 180-degree turn and reacceleration), could provide. Of particular interest was to understand what proportion of the test was actually spent in changing direction, if anthropometry and positional differences influenced sub-phase performance, and whether a sub-phase analysis could provide better diagnostic information to guide individualisation of programming. It was hypothesised that the 180-degree turn sub-phase would be of the greatest duration, that heavier circle-end players and taller players would have slower times for all phases, and that the sub-phase ranking would enable better information to guide programming.

METHODS

Experimental approach to the problem

Ten elite female netball athletes performed three maximal effort trials (each leg) of the modified 5-0-5 COD test, over three testing occasions, separated by seven days. Timing lights were placed at 0, 2 and 4 m and the start line was placed 0.5 m back from the first timing gate, to accommodate for a forward lean and eliminate false triggering of the timing lights. This enabled five distinct sub-phases to be established in order to more accurately detect acceleration, deceleration, and COD performance. The five sub-phases were then investigated in terms of percentage time spent in each phase, as well as the effects of anthropometry and position. A rank order analysis was also included as an exemplar on how to identify individualized player strengths and weaknesses.

Participants

Ten elite female netball athletes (age: 24.9 ± 5.0 yrs, height: 180.1 ± 6.5 cm, weight: 81.3 ± 15.0 kg) participated in this study. Athletes competed in the New Zealand netball premiership league and had a minimum of six years netball experience. Participants were required to be healthy and free of injury at the time of testing. All participants were provided with an information sheet and were required to fill out a written consent form prior to participating in this study. Participants 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 (20/402).

Procedures

Testing was conducted on an indoor netball court.

For the modified 5-0-5 COD test, athletes were required to start in a two-point split-stance with their front foot 0.5 m back from the first timing gate. They were then instructed to sprint 5 m and touch their foot on the COD line, perform a 180-degree turn on a specific leg and sprint 5 m back through the first timing gate. All athletes completed a standardised warmup consisting of lower body activation such as banded walks and squats, a series of different jumps (vertical and horizontal bilateral and unilateral countermovement jumps), dynamic flexibility of the hamstrings, quads, hips and calves, and progressive sprint (5, 10 and 20 m) and COD drills, building the intensity up to maximum effort. After the warmup was completed, each athlete performed three modified 5-0-5 COD test trials on each leg. Three minutes of rest was provided between trials to limit any fatigue effects. To ensure each athlete touched the line, the researchers observed each trial. If the athlete had a mistrial, they were given a retrial after three minutes of rest. They were instructed to perform the test at maximal effort.

Equipment

Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were used to quantify COD performance. Gates were set at 0, 2 and 4 m from the start line to assess acceleration, deceleration, 180-degree turn and reacceleration phases of the 5-0-5 COD test. Timing gate height was set at 1 m, in approximate line with centre of mass. This set up produced five different splits, as well as a total 5-0-5 COD performance time. These times corresponded to the different phases of the 5-0-5 COD test as shown in Figure 1.

Statistical Analysis

No significant differences were found between left and right COD times, and so the data was pooled and all analyses thereafter was performed on the averaged data. Outlier and normality analysis was implemented on the pooled data and means, and standard deviations were reported for all variables of interest, with 95% confidence limits (CL) used where appropriate. Independent t-tests were used to assess statistical significance ($p<0.05$) between anthropometry (weight and height) and performance of the sub-phases. Rank-order analysis was also conducted to provide a visual evaluation of rankings of the dependent variables of interest. Statistical analysis was performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA). Hedges's g effect size was calculated on the mean change between groups

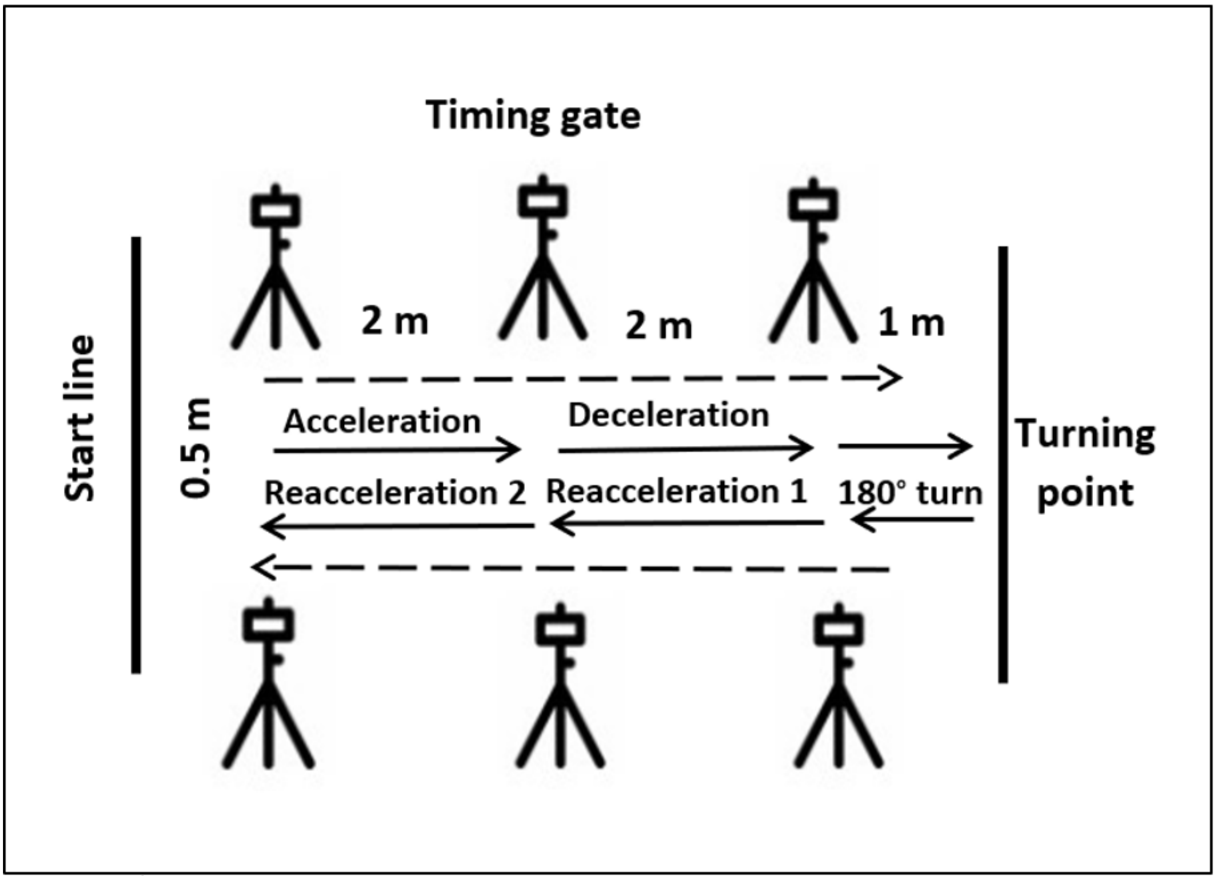

Figure 1. Set up and phases for the modified 5-0-5 change of direction test

and interpreted using the follow criteria; Small effect = 0.2, medium effect = 0.5 and, large effect = 0.8 (Hedges, 1981).

RESULTS

The average times for each sub-phase and average percentage of time spent in that phase (~15 to 23%) can be observed in Table 1. The highest percentage of time was spent during the 180-dergee turn and the reacceleration 1 phases (~23%), with the lowest percentage of time being spent during the reacceleration 2 phase (15.5%).

Sub-phase differences as a function of height, body mass, and position are shown in Table 2. Significant differences were found between heavier (>74 kg) and lighter (<74 kg) athletes for deceleration, 180-degree turn, reacceleration 2 and total time (7.32-17.14%; g = 1.90 – 2.54). However, while weight was not found to significantly influence acceleration and reacceleration 1 sub-phases, there was a very large effect for the reacceleration 1 phase. No significant differences were found between taller (>182 cm) and shorter (<182 cm) players for any of the variables (1.82-3.08%). In terms of the positional analysis, only one significant difference was found between circle players and mid-court players during the reacceleration 1 phase (8.20%; g = 2.24). Additionally, though no significant differences were identified between positions for deceleration and total time, large effects were observed in favour of the mid-court athletes.

The rank order for each of the athletes for each of the sub-phases can be observed in Table 3. The table has been colour coded to show the strength and weaknesses of each athlete, as determined by their sub-phase ranking being ± 2 ranks from their total time rank. For example, Athlete 1 had the fastest total time, however deceleration and re-acceleration have been identified as areas of poorer performance.

Table 1. Average time and percentage of total time and each sub-phase of the modified 5-0-5 COD test

Total Time	
Average time ± SD (s)	2.75 ± 0.16
Range (s)	2.55 – 3.03
Percentage (%)	100
Acceleration	
Average time ± SD (s)	0.55 ± 0.03
Range (s)	0.47 – 0.79
Percentage (%)	19.9
Deceleration	
Average time ± SD (s)	0.51 ± 0.03
Range (s)	0.47 – 0.56
Percentage (%)	18.7
180-degree turn	
Average time ± SD (s)	0.64 ± 0.08
Range (s)	0.53 – 0.79
Percentage (%)	23.1
Reacceleration 1	
Average time ± SD (s)	0.64 ± 0.03
Range (s)	0.60 – 0.71
Percentage (%)	23.3
Reacceleration 2	
Average time ± SD (s)	0.43 ± 0.02
Range (s)	0.39 – 0.46
Percentage (%)	15.5

Table 2. Sub-phase differences as a function of height, body mass and position

Variable	Mean ± SD		P Value	Difference (%)	Effect Size
Height	**> 182 cm**	**<182 cm**			
Acceleration	0.54 ± 0.03	0.55 ± 0.03	0.70	1.82	0.33
Deceleration	0.52 ± 0.03	0.51 ± 0.04	0.70	1.92	0.28
180-degree Turn	0.65 ± 0.09	0.63 ± 0.09	0.71	3.08	0.22
Reacceleration 1	0.65 ± 0.03	0.63 ± 0.03	0.20	3.08	0.67
Reacceleration 2	0.43 ± 0.02	0.42 ± 0.03	0.69	2.38	0.39
Total Time	2.79 ± 0.15	2.72 ± 0.17	0.50	2.51	0.44
Body mass	**>74kgs**	**<74kgs**			
Acceleration	0.56 ± 0.35	0.54 ± 0.01	0.20	3.57	0.08
Deceleration	0.54 ± 0.02	0.49 ± 0.03	0.02*	9.26	1.96
180-degree Turn	0.70 ± 0.07	0.58 ± 0.03	0.01**	17.14	2.23
Reacceleration 1	0.66 ± 0.04	0.62 ± 0.02	0.10	6.45	1.26
Reacceleration 2	0.44 ± 0.01	0.41 ± 0.02	0.02*	7.32	1.90
Total Time	2.88 ± 0.12	2.63 ± 0.07	0.00**	8.68	2.54
Position	**Circle Defence/Attack**	**Mid-Court**			
Acceleration	0.55 ± 0.03	0.54 ± 0.01	0.45	1.85	0.45
Deceleration	0.52 ± 0.03	0.49 ± 0.03	0.24	6.12	1.00
180-degree Turn	0.66 ± 0.08	0.61 ± 0.08	0.43	8.20	0.63
Reacceleration 1	0.66 ± 0.03	0.61 ± 0.01	0.04*	8.20	2.24
Reacceleration 2	0.43 ± 0.02	0.42 ± 0.02	0.21	2.38	0.5
Total Time	2.81 ± 0.15	2.67 ± 0.15	0.18	5.24	0.93

* p < 0.05, ** p <0.001

Table 3. Rank order table for total time and each sub-phase for the modified 5-0-5 COD test

	Total Time	Acceleration	Deceleration	180-degree turn	Reacceleration 1	Reacceleration 2
Athlete 1	1	2	🟥 4	1	🟥 4	1
Athlete 2	2	2	2	3	1	3
Athlete 3	3	🟥 5	🟩 1	3	🟥 6	2
Athlete 4	4	🟥 6	3	5	2	4
Athlete 5	5	🟩 1	6	6	🟩 3	🟥 8
Athlete 6	6	6	7	🟩 2	5	7
Athlete 7	7	🟩 2	🟩 5	8	🟥 9	🟩 5
Athlete 8	8	8	8	9	🟩 3	8
Athlete 9	9	10	10	🟩 7	8	10
Athlete 10	10	9	🟩 8	10	🟩 7	🟩 5

Red = 2 SD below total time ranking, Green = 2 SD above total time ranking

DISCUSSION

Providing better diagnostic information to guide programming in a more targeted manner was the primary purpose of this study. The main findings were: 1) the majority of time was spent during the 180-degree turn and reacceleration 1 sub-phases (~23%); 2) there were significant differences and very large effects between heavier and lighter athletes for three out of five sub-phases and total 5-0-5 COD time; and, 3) although athletes may produce a good total time, a sub-phase ranking analysis may provide diagnostic information to guide better and more targeted COD training.

Approximately 23% of the total time for the modified 5-0-5 COD test is spent actually changing direction. Previous research by Ryan et al., (2021) concluded that the 180-degree turn was the best predictor for total time (r= 0.94), which intuitively makes sense if the majority of the time is spent during this phase. Interestingly, a similar amount of time was spent in the reacceleration 1 phase. This may be due to the fact that athletes need to regain momentum after virtually coming to a stop to perform the 180-degree turning movement. These results differ to those found for the traditional 5-0-5 COD test. Nimphius and colleagues (2013) reported that approximately 31% of the time was actually spent changing direction, however, this was calculated via the COD deficit. The COD deficit has been defined as a practical measure to isolate COD ability independent of sprint speed (Nimphius et al., 2016), however the authors feel that by subtracting an athlete's 10 m time from their 5-0-5 COD time does not provide insight into 180-degree COD ability, as the COD deficit does not account for deceleration and reacceleration out of the turn. Possible reasons for this 8% difference between findings could be; 1) the entry velocity going in to the 180-degree turn would likely be higher during the traditional 5-0-5 COD test, as they have an initial 15 m before having to perform the turn, requiring more time to come to a stop and change direction, or 2) the COD deficit method still includes the deceleration and reacceleration phases. Therefore, a sub-phase approach, such as the one used in this study may be more suitable for isolating COD ability.

It has been proposed that anthropometry could have a potential effect on COD (Brughelli, Cronin, Levin, & Chaouachi, 2008). This study found that athletes with a greater body mass (>74 kgs) were significantly slower during the deceleration, 180-degree turn, reacceleration 2 split, and total time, compared to athletes with a lower body mass (<74 kgs). Larger players have greater momentum (mass x velocity) and therefore require greater eccentric braking strength to decelerate, turn and reaccelerate. These players are disadvantaged within tests that require athletes to essentially come to a stop and change direction. Several studies have reported that body composition (i.e., body mass and percentage of body fat) affects sprint and COD performance (Atakan, Unver, Demirci, Bulut, & Turnagol, 2017; Brechue, Mayhew, & Piper, 2010; Chaouachi et al., 2009; Ostojic, 2003; Toro-Román et al., 2021). However, one limitation of this study is that fat and lean mass was not measured, only body mass. It appears from the results of this study, as well as that of previous researchers, that it is ideal for an athlete to have a low amount of fat mass as a higher fat mass hinders sport performance (Lukaski & Raymond-Pope, 2021). One of the simplest ways an athlete can improve their performance during these tests, as well as sporting performance, is to either improve their relative force capability or decrease their mass, or more specifically their fat mass.

In the initial hypothesis, the authors thought that taller players would produce significantly slower sub-phase and total times during the modified 5-0-5 COD test compared to shorter players, due to taller players usually having larger body mass. Interestingly, no significant differences were found between taller and shorter players for any of the sub-phases or total time.

The ability to change direction rapidly is a requirement for all netball positions (Sweeting, Aughey, Cormack, & Morgan, 2017). Interestingly, only the reacceleration 1 sub-phase was found to differ significantly between circle defence/attack players and mid-court players. This may be because mid-court athletes are more frequently performing COD manoeuvres before quickly accelerating in another direction (Sweeting et al., 2017). Although this is the first study to analyse the five different sub-phases of the modified 5-0-5 COD test, previous researchers have reported significant differences between mid-court athletes and circle defence/shooters for total 5-0-5 COD time (Graham et al., 2020). However, these findings are unsupported by this study. The differences in findings may be due to a range of reasons, such as heterogeneous player levels, number of participants, methods and statistical analysis. It should be noted that the traditional 5-0-5 COD test was used, rather than the modified 5-0-5 COD test. These different factors may play a significant role in the incongruent results from each study.

The sub-phase rank order table (Table 3) was used as an exemplar of how to identify potential strengths and weaknesses in players. The table highlights that Athlete 1 had the fastest total time and the fastest 180-degree turn time, which supports the finding that the 180-degree turn time was the greatest predictor of total time (Ryan et al., 2021). This approach to presenting data may also provide insight into the individualized areas that athletes could work on to improve their COD time. For example, Athletes 3 and 4 could benefit from an acceleration focus, whereas Athletes 1, 3 and 7 could benefit from a re-acceleration focus to training. This is not to say that training cannot be initiated in other areas as well. Furthermore, the training within each phase can have different foci e.g. physical-anthropometric, technical, and/or neuromuscular qualities. All athletes would benefit from reducing fat mass as much as practically possible for all sub-phases, but thereafter the sub-phases have specific technical, and strength demands.

PRACTICAL APPLICATIONS

To the authors' knowledge, at the time of this study, no other research had determined the percentage of each sub-phase for the modified 5-0-5 COD test, as well as presented athlete data in a rank order table to identify areas that could be improved through targeted programming. It is apparent from this analysis that majority of the 5-0-5 COD test is spent in linear motion (i.e., acceleration, deceleration and reacceleration) and not changing direction (~23% of total time). Therefore, the sub-phase analysis is critical in isolating an athlete's COD ability. Furthermore, not all linear motion has similar technique and neuromuscular demands e.g., acceleration and deceleration. Once more the sub-phase analysis is important to measure, map, and monitor the changes in these qualities. By taking such an approach, provides the practitioner with higher level diagnostics, which can inform programming in a more granular manner. Principles of individualisation and specificity are more easily achieved with such an approach. It is evident that body mass does affect a player's ability to perform a 180-degree COD, with heavier players producing significantly slower times during three of the sub-phases, and the total time. Given acceleration is a function of force and mass (a = f/m), coaches can focus on improving accelerative ability by either increasing force capability (in particular, horizontal accelerative and decelerative force capability) and/or decrease fat mass. Lastly, the use of rank order tables for presenting performance times for a sub-phase approach during the 5-0-5 COD test can provide practitioners with insight into an athlete's different strengths and weaknesses. This method of presenting data enables coaches to develop more targeted programming to improve COD performance. The results from this study should be interpreted with caution, as this sample size and population is very specific to elite female netball athletes. Future research should aim to replicate the methodologies used in this current study, within other sports, populations, and sporting level.

REFERENCES

1. Atakan, M., Unver, E., Demirci, N., Bulut, S., & Turnagol, H. (2017). Effect of body composition on fitness performance in young male football players. Turkish Journal of Sport and Exercise, 19(1), 54-59.
2. Barber, O., Thomas, C., Jones, P., McMahon, J., & Comfort, P. (2016). Reliability of the 505 change-of-direction test in netball players. International Journal of Sports Physiology and Performance, 11(3), 377-380.
3. Brechue, W., Mayhew, J., & Piper, F. (2010). Characteristics of sprint performance in college football players. The Journal of Strength & Conditioning Research, 24(5), 1169-1178.
4. Brughelli, M., Cronin, J., Levin, G., & Chaouachi, A. (2008). Understanding change of direction ability in sport. Sports Medicine 38(12), 1045-1063.
5. Chaouachi, A., Brughelli, M., Chamari, K., Levin, G., Abdelkrim, N., Laurencelle, L., & Castagna, C. (2009). Lower limb maximal dynamic strength and agility determinants in elite basketball players. The Journal of Strength & Conditioning Research, 23(5), 1570-1577.
6. Clarke, R., Read, P. J., De Ste Croix, M. B. A., & Hughes, J. D. (2020). The Deceleration Deficit: A Novel Field-Based Method to Quantify Deceleration During Change of Direction Performance. Journal of Strength and Conditioning Research. doi:10.1519/jsc.0000000000003856
7. Delaney, J., Scott, T., Ballard, D., Duthie, G., Hickmans, J., Lockie, R., & Dascombe, B. (2015). Contributing factors to change-of-direction ability in professional rugby league players. The Journal of Strength & Conditioning Research, 29(10), 2688-2696.
8. Draper, J. A. (1985). The 505 test: A test for agility in horizontal plane. Australian Journal of Science and Medicine in Sport, 17(1), 15-18.
9. Gabbett, T. (2006). A comparison of physiological and anthropometric characteristics among playing positions in sub-elite rugby league players. Journal of Sports Sciences, 24(12), 1273-1280.
10. Gabbett, T., Kelly, J., & Sheppard, J. (2008). Speed,

change of direction speed, and reactive agility of rugby league players. The Journal of Strength & Conditioning Research, 22(1), 174-181.

11. Graham, S., Duthie, G., Aughey, R., & Zois, J. (2020). Comparison of physical profiles of state-level netball players by position. The Journal of Strength & Conditioning Research, 34(9), 2654-2662.
12. Harper, D., Carling, C., & Kiely, J. (2019). High-intensity acceleration and deceleration demands in elite team sports competitive match play: a systematic review and meta-analysis of observational studies. Sports Medicine, 49(12), 1923-1947.
13. Hedges, L. V. (1981). Distribution theory for Glass's estimator of effect size and related estimators. journal of Educational Statistics, 6(2), 107-128.
14. Hewit, J., Cronin, J., Button, C., & Hume, P. (2011). Understanding deceleration in sport. Strength & Conditioning Journal, 33(1), 47-52.
15. Hewit, J., Cronin, J., & Hume, P. (2012). Understanding change of direction performance: a technical analysis of a 180 ground-based turn and sprint task. International Journal of Sports Science & Coaching, 7(3), 493-501.
16. Hewit, J., Cronin, J., & Hume, P. (2013). Kinematic factors affecting fast and slow straight and change-of-direction acceleration times. The Journal of Strength & Conditioning Research, 27(1), 69-75.
17. Jones, P., Thomas, C., Dos'Santos, T., McMahon, J., & Graham-Smith, P. (2017). The role of eccentric strength in 180 turns in female soccer players. Sports, 5(2), 42.
18. Kulakowski, E., Lockie, R. G., Johnson, Q. R., Lindsay, K. G., & Dawes, J. J. (2020). Relationships of Lower-body Power Measures to Sprint and Change of Direction Speed among NCAA Division II Women's Lacrosse Players: An Exploratory Study. Int. International Journal of Exercise Science, 13(6), 1667.
19. Lukaski, H., & Raymond-Pope, C. (2021). New Frontiers of Body Composition in Sport. International Journal of Sports Medicine.
20. Maraga, N., Duffield, R., Gescheit, D., Perri, T., & Reid, M. (2018). Playing not once, not twice but three times in a day: the effect of fatigue on performance in junior tennis players. International Journal of Performance, 18(1), 104-114.
21. Nimphius, S., Callaghan, S., Spiteri, T., & Lockie, R. (2016). Change of direction deficit: A more isolated measure of change of direction performance than total 505 time. The Journal of Strength & Conditioning Research, 30(11), 3024-3032. doi:10.1519/JSC.0000000000001421
22. Nimphius, S., Geib, G., Spiteri, T., & Carlisle, D. (2013). Change of direction" deficit measurement in Division I American football players. JASC, 21(S2), 115-117.
23. Nimphius, S., McGuigan, M., & Newton, R. (2010). Relationship between strength, power, speed, and change of direction performance of female softball players. The Journal of Strength & Conditioning Research, 24(4), 885-895.
24. Ostojic, S. (2003). Seasonal alterations in body composition and sprint performance of elite soccer players. Journal of exercise physiology, 6(3), 11-14.
25. Pruyn, E., Watsford, M., & Murphy, A. (2014). The relationship between lower-body stiffness and dynamic performance. Applied Physiology, Nutrition, and Metabolism. Physiologie Appliquée, Nutrition et Métabolisme, 39(10), 1144-1150.
26. Ryan, C., Uthoff, A., McKenzie, C., & Cronin, J. (2021). Sub-phase analysis of the modified 5-0-5 test for better change of direction diagnostics. The Journal of Sport and Exercise Science, 5(5). In Press.
27. Sayers, M. (2015). Influence of test distance on change of direction speed test results. JThe Journal of Strength & Conditioning Research, 29(9), 2412-2416.
28. Spiteri, T., Binetti, M., Scanlan, A. T., Dalbo, V. J., Dolci, F., & Specos, C. (2019). Physical Determinants of Division 1 Collegiate Basketball, Women's National Basketball League, and Women's National Basketball Association Athletes: With Reference to Lower-Body Sidedness. The Journal of Strength & Conditioning Research, 33(1), 159-166.
29. Sweeting, A. J., Aughey, R. J., Cormack, S. J., & Morgan, S. (2017). Discovering frequently recurring movement sequences in team-sport athlete spatiotemporal data. Journal of Sports Sciences, 35(24), 2439-2445.
30. Thomas, C., Dos'Santos, T., Comfort, P., & Jones, P. (2016). Relationship between isometric strength, sprint, and change of direction speed in male academy cricketers. Journal of Trainology, 5(2), 18-23.
31. Thomas, C., Ismail, K. T., Simpson, R., Comfort, P., Jones, P., & Dos' Santos, T. (2019). Physical profiles of female academy netball players by position. Journal of Strength and Conditioning Research, 33(6), 1601-1608.
32. Toro-Román, V., Siquier-Coll, J., Bartolomé, I., Grijota, F. J., Maynar, M., & Muñoz, D. (2021). Relationship between body composition and velocity, acceleration and changes of direction tests in university students. . Journal of Sport & Health Research, 13(1).
33. Venter, R. E., Masterson, C., Tidbury, G. B., & Krkeljas, Z. (2017). Relationship between functional movement screening and performance tests in elite university female netball players. South African Journal for Research in Sport, Physical Education, 39(1), 189-198.