Characterising Change of Direction Performance in Elite Team Sport Athletes Using Jump Data and Key Positions of the Turn.

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July 24th 2018, Research submitted is partial fulfilment of the requirements for the Masters of Science, St Mary's University.

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Characterising Change of Direction Performance of Elite Team Sport Athletes Using Jump Data and Key Positions of the Turn.

Changing direction effectively is critical to team sports performance. Understanding the biomechanics that underpin change of direction (COD) may be valuable to the practitioner. Twenty-four elite level field hockey players volunteered for this study. They were analysed performing a 20m shuttle (20S) with a 180-degree turn. This time was analysed alongside the change of direction deficit (CODD) and the pacing strategy approaching the turn (PS). Absolute and relative kinetic measures were analysed during countermovement jumps using force plates and correlations were calculated between these measures and the COD scores. Kinematic analysis was performed using video cameras and analysed using Kinovea software. Magnitude based inferences were calculated to examine possible relationships between movements of the knee, ankle and torso during the brake step, plant step and propulsive step of the turn.

Jump height and concentric kinetic variables showed significant negative correlations with 20S time ($p<0.05$). Eccentric variables showed greater negative correlations with PS and CODD. Subjects that performed better at all COD measures displayed less knee flexion during the plant step of the turn. Subjects that performed better in the CODD and PS displayed a straighter leg during the propulsive step out of the turn.

This study concluded that different movement patterns may be beneficial for COD compared to linear sprinting. It also concluded that maintaining a straight plant leg was beneficial to COD performance. Eccentric strength and power seemed to be the most beneficial improving isolated COD and limiting the PS. This may help the practitioner prescribe training interventions.

Key Words: Biomechanics, Force, Hockey, Momentum, Testing

INTRODUCTION

Change of direction (COD) refers to the physical ability to change direction without considering the decision-making aspect of agility performance (25). It has been suggested that high velocity COD's occur at the most crucial stages of the game (31) and COD tests have been utilised in various field based sports to successfully distinguish between ability of players at an elite level (23). However, how best to test for COD is frequently debated in the literature (20,25). Furthermore, the kinetic and kinematic factors that underpin COD are yet to be fully established (4). A better understanding of the different components of COD and the biomechanics that underpin these, may help to provide training interventions to improve sports performance.

Traditional assessments of COD measure the time it takes to travel a certain distance which involve one or more cutting movements. However, these tests have the potential to be heavily influenced by linear sprint qualities (21). Nimphius (21) suggests calculating the time difference between a maximal sprint of the same distance and the COD test to calculate the change of direction deficit (CODD). This provides the time cost of the turn. However, there are still various ways in which athletes can achieve a good score. which may not translate to sporting performance. For instance, athletes may develop a pacing strategy in anticipation of the turn to allow for an easier acceleration out of the turn (20), this would provide a less efficient strategy in a game situation where an athlete has to respond to an unpredictable stimulus. Linear shuttle tests involving a single 180° turn such as the 505 are frequently referenced in the literature as a valid and reliable measure of COD performance in team sport athletes (7). In contrast, Nimphius (20) suggests that tests that involve too many turns in close proximity or that last for too long, are not suitable for assessing COD performance with team sport athletes due to the lack of specificity in the movement patterns and the relative influence of anaerobic metabolism.

Kinetic measures are commonly assessed via the use of Force Plates (3). This enables researchers to examine a wide variety of force production variables using straightforward testing methods such as the counter movement jump. But there is a lack of a consensus in the literature as to which variables are the most relevant for COD performance in sport. Both vertical jump height and peak power measured using non-specific neuromuscular tests have been shown to correlate with linear acceleration in team sports athletes (16,29) but neither are good predictors of COD (19,22). This discrepancy could be due to the influence that efficient braking has on COD. Eccentric kinetic variables may therefore provide a greater influence on isolated measures of COD. This has been corroborated by the research of Spiteri (28) who demonstrated that eccentric force production measured during a squat was a good predictor of COD performance. Furthermore, Young (29) and Maloney (15) suggest that effective COD involves rapidly producing eccentric force.

Researchers have suggested that unilateral force production qualities are more specific to COD performance (29). Therefore, unilateral jump variables may provide further insight into an individual’s COD (19). Moreover, it is unclear whether relative variables which consider bodyweight provide greater insight into to COD performance. Spiteri and Nimphius (22,28) suggest that lighter athletes with higher relative strength levels can achieve greater COD performance.

Kinematic research has primarily focussed on the movements of the ankle (17,27), knee (6,12) and torso (17,24) during a COD. Regarding the braking phase, Hewit (13) suggests that directing the weight and torso posteriorly and increasing knee and ankle flexion, will allow the effective absorption of eccentric forces across the lower limb and produce a more efficient braking manoeuvre, which will in turn minimise braking forces on the plant leg (6,12). However, this analysis of deceleration may not strictly apply to COD as it refers to the deceleration prior to stopping, which may differ from the movement patterns expected before a COD. During the plant step it is important to distance the centre of mass (COM) from the turn and to redirect it effectively (14). The athlete shouldn't collapse through the lower body or torso during this step as this indicates that they did not efficiently brake prior to the turn and increases the time taken to redirect the COM (6,24). It has been suggested that the propulsive step should resemble the drive phase of a traditional linear sprint model with an athlete accelerating from a low position with a neutral ankle angle and a 90-degree knee flexion angle which enables them to efficiently transmit forces through a powerful triple extension pattern (18). The torso should also lean forward during this step. However, Lockie (18) considers that acceleration mechanics differ between team sports competitors and track and field athletes due to the shorter acceleration times. In a COD test of sufficient distance performance may be enhanced by adopting traditional braking and linear sprint movement patterns entering the turn. Furthermore, athletes that can enter the turn and exit the turn faster but still maintain efficient mechanics to redirect their COM with an extended plant leg should perform better at changing direction.

This study hypothesises concentric strength and power will correlate with COD performance when measured during a traditional shuttle test due to the influence of linear speed and acceleration. However, when a more isolated element of COD, considering the CODD and the pacing strategy of the athletes is examined, eccentric variables measured with a force plate will provide the most important correlations with performance. Secondly, it is hypothesised that relative measures of force production and unilateral kinetic variables are better predictors of COD performance. Thirdly, it is hypothesised that athletes who have fast 20S and CODD times will show greater knee flexion and dorsi flexion and backwards lean of the torso during the braking phase of the movement which should allow them to keep a straighter plant leg and efficiently redirect their COM. Whereas individuals who approach the turn at a higher relative velocity will collapse more through the plant leg. It is also hypothesized that the movement patterns in the propulsive step should be closer to those observed in a traditional drive pattern, with a neutral ankle position, 90 degrees of knee flexion and a forward leaning torso.

METHODS

Experimental approach to the problem

This study correlates the dependent variables of the 20m shuttle time, CODD and the COD score (CODS) to kinetic values obtained during using a force plate during both bilateral and unilateral counter movement jumps (CMJ). Both eccentric and concentric variables were analysed to examine the respective influence of both on the different COD measures. Both relative and absolute values were recorded to check their respective influences and unilateral correlations were also compared with bilateral ones to discover weather this provided more specific insight. Knee, ankle and torso angles were captured via video camera and analysed using Kinovea software (independent variables). Correlations were also examined between these measures to test whether the assumptions listed in the hypothesis were correct. The trends in the kinematic factors were further analysed using magnitude-based inferences.

Subjects

Twenty four subjects volunteered for this study. All were male international field hockey players and had completed the testing protocols multiple times previously. Athletes were not included if they were considered not physically fit enough to do so by the team's medical staff. All subjects were given a project information sheet and signed an institutionally approved consent form and a PARQ form prior to participation. Subject characteristics can be seen in Table 1. This study was approved by the St. Marys University School of Sport Health and Applied Sciences review board.

Insert Table 1 here

Procedures

COD performance was measured during a 20m shuttle (20S) test. The equipment set up for this test can be seen in Figure 1. The subjects were required to sprint on a 3m wide indoor running track for a total of 40m with a 180 degree turn at the 20m line. After crossing the finishing line there was a 10m active recovery area that the athletes could decelerate into before returning to the starting line (see Figure 2). Time to complete the shuttle was measured using timing gates (Version 2.32.09, Microgate, Bolzano Italy) placed 1m in front of the start line. The 20S was measured as part of a repeat sprint ability test. Part of this process meant that athletes were given 30s to complete each sprint and recover before the following sprint. The athletes were simultaneously assessed for the speed of each sprint and the drop off between sprints. Only the fastest sprint was analysed as the 20S time for this study. Athletes were instructed to start 1m behind the timing gate and to touch the 20m line with one foot. All athletes achieved their fastest time on their first sprint, this meant that fatigue did not influence the results.

Camera A was placed 5m in front of the turning line and 1.7m off the ground. This camera was focused on the entry to the turn, and 1m after the turn line. This camera was used to analyse the plant step of the turn. Camera B was placed on the left-hand side of the track to the athlete approaching the turn. This camera was focussed on the 4m approaching the turning line and 1m after the turn. This camera was placed at a 5m distance from the track and was set at a height of 1.7m. Camera B was used to assess the kinematics on the brake step and propulsive step out of the turn. The camera's used were Panasonic HC V770 HD (Panasonic Manufacturing, Cardiff, UK) and filmed at 50 frames per second. Due to environmental constraints it was only possible to film one side of the running track. Because of this, the camera was only placed on the left side and in front of the track therefore athletes were only analysed if they turned using their right foot as the plant step and facing camera B (see Figure 1).

Insert Figure 1

The kinematics of the athlete's COD were analysed in the brake step, plant step and the propulsion step out of the turn. These were analysed using the Kinovea (0.08.15, Kinovea, France) software that has been frequently used in kinematic research (8,10). The brake step was characterised as the left legged step before the turn in which the athlete decelerated before beginning to rotate their body. This was defined as the step before the toes of the left foot were facing camera B. At this stage the angles of the ankle and knee couldn't be analysed in the sagittal plane using camera B. The plant step was characterised as the step in which the athlete planted their foot on or over the turn line. If an athlete took additional steps between the brake step and the plant step, then these steps would be included in the timing and noted but the specific kinematics were not analysed. All but one athlete took one step between the brake and plant step. The only other athlete took two steps between the brake and plant step. The propulsive step was characterised as the first step after the plant step. At this stage the athlete had redirected their COM towards the finish line. This analysis was always done on the athlete's right leg and enabled 2D kinematic analysis to be performed using camera B. The list of kinematic variables that were analysed are displayed in Table 2

Insert Table 2

Reflective markers were placed on the lateral malleolus on both feet of the athletes and on the lateral femoral condyle on the athlete's legs. Knee flexion angle was assessed from the anterior superior iliac spine as the proximal point with the lateral femoral condyle as the central point and the lateral malleolus as the distal landmark. knee flexion was subtracted from 180 to give the final reading this meant that a knee flexion angle of 0 represented a straight leg. Plantarflexion angle was measured proximally from the lateral femoral condyle with the lateral malleolus as the central point and the lateral side of the cuboid as the most distal landmark. The plantarflexion reading was subtracted from 90 which meant that a higher positive score represented a larger level of plantarflexion and a negative score represented dorsiflexion. Parrallax was minimised as much as possible as the athletes all turned in the central lane of the 3m track (in between the end of the first metre and beginning of the third metre). Ankle angles and knee angles were analysed at the point of ground contact for each of the steps. During the plant step the ankle angle and knee angle were also measured at their deepest position to give an indication of the amount of eccentric work that was being done during this step. Ankle angle and knee angle change was measured by subtracting the difference between the ground contact angles on the plant step and the deepest angle that the athletes achieved. Torso angle was measured from the left anterior superior iliac spine and the left acromioclavicular joints on the entrance to the turn and on the opposite side when returning from the turn. A lower torso angle represented an increased forward lean whereas a larger torso angle represented an athlete that was leaning backwards. In conjunction to the knee and ankle measurements, torso angle was observed on ground contact for both the brake and propulsive steps.

Kinetic data on the athletes was obtained using bilateral Force plates (Force Decks Ltd, London, UK) and then analysed using the Force Decks Performance Technologies software (English Institute of Sport, 1.1.5970, Force Decks, London, UK). The athletes performed three bilateral and three unilateral counter movement jumps (CMJ) each side. The athletes began the test with both feet on the force plate with their hands on their hips and were instructed to "jump as high as possible". The athletes were allowed feedback and to rest and reset in between repetitions. The jump in which the athlete jumped the highest was analysed for the purpose of this study and this process was replicated for the unilateral jumps.

During all jumps the following measures were recorded; body mass (BM), average concentric force (ACF), relative average concentric force (RACF), average eccentric force (AEF), relative average eccentric force (RAEF), average eccentric power (AEP), jump height (CMJh), peak power (PP), relative peak power (RPP). Body mass was measured in kilograms and height in centimetres. All Force measurements were in Newtons and Power was measured in Watts. These measures were calculated automatically by the Force Decks NPT software (Force Decks, London, UK). Due to the potential importance of rate of force development an approximate calculation was used to calculate these measures. This was done by dividing average concentric force by concentric duration to give concentric rate of force development (CRFD) and average eccentric force by eccentric duration to give eccentric rate of force development (ERFD). These were both divided by bodyweight to provide relative concentric rate of force development (ARCRFD) and relative eccentric rate of force development (AERFD). This was measured in N/s.

This study evaluates COD not just using the overall 20S time but also analyses a more acute score of the COD cost, the CODD and also examines the PS which calculates the extent to which the athlete adjusts their speed prior to the COD itself (20). These were calculated using the formulae below.

CODD = 1-(MAX40/20S)

PS = 1- (TAV/ MAX20V)

The turn approach velocity (TAV) was established by measuring the average velocity (m/s) between the start of the test and the BR step. The time and distance of the first step was established using Optojump (v. 1.12.1.0, Microgate, Bolzano, Italy) which was placed for 22m either side of the 3m track with 1m either side of the start and finish line respectively (see Figure 2). This technology has been shown to accurately measure stride related variables during acceleration (9) however this has not been proven during deceleration.

The average velocity from the first step to the brake step was calculated using the Kinovea software using reference points from the track surrounding the athletes. This was then combined with the data from the Optojump to provide the TAV. The difference between the average velocity reached during the MAX20 and the average velocity reached on the approach to the turn was used to estimate how much the athlete was reducing their average velocity over a similar distance to prepare prior to braking.

The Maximum 40m time (MAX40) and Maximum 20m time (MAX20V) were obtained on a separate testing day and measured with timing gates. Following a similar protocol to the shuttle test, the timing gates were placed 1m in front of the start line and then on either side of the track at 20 and 40m. Subjects were required to perform two maximal 40m sprints with a full three-minute recovery between each one. The timing gates recorded the speed at both the 20m and 40m marks. Only the fastest sprint was recorded for this study.

Statistical Analysis

Once this data was collected bivariate Pearson's correlations were calculated to examine the relationships between the specific COD measures (CODD, CODs and 20S) and the various kinetic and kinematic related variables. These calculations were performed on SPSS (version 24). Results were considered significant at a level of (<0.05).

Due to the low number of participants and relatively low subject heterogeneity Hopkins' magnitude-based inferences (2) were calculated to provide further insight into the relationship between the kinematic factors and the various COD measures. This has been suggested in certain literature as a more relevant model to sports science practitioners within an elite environment (5). This was used to establish whether movement patterns seen in linear sprinting were beneficial for the CODD measures and weather a straighter plant leg had any relationship with these scores.

RESULTS

Kinetic measures

Correlations between the measures assessed on the force plates and 20S time can be seen in Table 3. Jump height on each jump was highly correlated with 20S performance (<0.01). Concentric peak force (p=0.001), average concentric force (p=0.001) and concentric rate of force development (p=0.001) showed the highest negative correlation with the bilateral CMJ. Relative kinetic values did not display higher correlations than their absolute equivalents. The counter movement jump on the right leg (RCMJ) and left leg (LCMJ) did not display more significant correlations than the bilateral jump. Although there were differences between the correlations of each unilateral jump and the bilateral jump.

Insert Table 3

Correlations between the measures assessed on the force plates and CODD time can be seen in Table 4. Significant negative correlations (<0.05) were found for eccentric power (p=0.027), eccentric RFD (p=0.011) and relative eccentric RFD (p=0.012) measured during the bilateral CMJ. Only relative eccentric RFD on the right leg was significantly negatively correlated with CODD in the unilateral measures (p=0.025). No concentric variables were significantly negatively correlated with CODD. In contrast to this, relative peak power was significantly positively correlated with CODD on the bilateral (p=0.016) and left legged CMJ (p=0.031). Only in the case of peak power did the relative value show stronger correlation than the absolute values.

Insert Table 4

Correlations between the measures assessed on the force plates and the PS can be seen in Table 5. Eccentric kinetic variables showed a higher negative relationship with PS than concentric variables. Highly significant negative correlations (p=<0.01) were found for average eccentric power (p=0.004) and eccentric rate of force development (p=0.001) on both the bilateral CMJ and the left legged CMJ. In addition, relative eccentric RFD on the left leg was highly significantly correlated with the PS (p=0.001) as was relative average eccentric force on the right leg (p=0.004). Further significant (p=<0.05) negative correlations were found between body weight (p=0.017), average eccentric force on all jumps (CMJ p=0.027, LCMJ p=0.027, RCMJ p=0.046) and peak power (p=0.020) and both eccentric (p=0.048) and relative eccentric RFD (p=0.013) values on the right leg. Average concentric force on the unilateral jumps was significantly correlated with the PS (RCMJ p=0.048, LCMJ p=0.047) but not in the bilateral jump.

Insert Table 5

Kinematic measures

Mean kinematic angles observed at each stage can be seen in Table 8. For the 20S the actions of the knee during the plant step seemed to have the most meaningful impact on performance. Namely showing a larger change in knee flexion angle (86.2% likely positive (+)) and flexing the knee to a lower position at the bottom of the turn (89.5% +) displayed a positive relationship with 20S time. In addition, having a more plantarflexed ankle (64.4% likely negative (-)) and a more upright torso (63.2% -) during the propulsion step away from the turn showed minor trends as being beneficial to 20S performance. A graph displaying the r values and the lower and upper confidence limits for the kinematic values can be seen in Figure 2.

Insert Figure 2

For the CODD, displaying a higher level of knee extension on the propulsive step showed a highly significant correlation with performance (p=0.008). Furthermore, a more plantarflexed ankle angle during the brake step was significantly correlated with a slower CODD (p=0.033). This trend was also observed during the plant step (75% +). Maintaining knee extension during the plant step also seemed to be beneficial to the CODD. This can be seen from the relationship observed between the deepest knee angle (92.4% +) and the change in knee angle on this step (75.6% +). Correlation coefficients and their confidence intervals for the kinematic values and the CODD are displayed in Figure 3.

Insert Figure 3

When PS was compared with kinematic measurers a significant negative relationship ($p<0.05$) was found between the amount of knee flexion observed in the deepest position in the plant step and the PS ($p=0.038$). Athletes that had higher pacing strategies also seemed to show a larger change in knee angle following ground contact on the plant step (79.7% +) and displayed higher levels of knee flexion on the propulsive step of the turn (85% +). All other kinematic measures displayed a trivial relationship with the PS. Correlation coefficients and their upper and lower confidence intervals can be seen in Figure 4.

Insert Figure 4

DISCUSSION

The results demonstrated that athletes who were stronger both concentrically and eccentrically performed better in the 20S but as predicted concentric variables showed higher negative correlations with 20S, whereas the opposite was true for the PS and CODD. Absolute variables were better than relative values at predicting 20S time and relative values showed no advantage for prediction of PS and CODD. The unilateral CMJ kinetic measures showed no more significant correlations than the bilateral CMJs. Despite this, the differences in significant kinetic values observed between the left and right leg did provide some interesting areas for further investigation. The kinematic analysis indicated that athletes that were more proficient in all COD measures managed to maintain a high level of knee extension after ground contact on the plant step. In contrast to the hypothesis, athletes that had a more flexed knee during the propulsive step were less likely to achieve a good CODD score. No clear patterns were observed for the knee angle during the braking step but having a more dorsi flexed ankle in this position did seem to benefit the CODD.

Concentric force production and power production was highly negatively correlated with the 20S time, in contrast to the CODD and the PS. This may explain some of the disparity observed in previous research between kinetic correlations with COD in comparison to correlations with linear sprint qualities . These findings corroborate with the research of Sheppard and Young (25) who demonstrated that COD performance (as observed in traditional COD tests) was a combination of linear sprint ability and specific turning ability. However, isolating which areas of the COD an athlete needs to improve and understanding how to influence this may provide some further insight to the practitioner. Nimphius (20) suggests that calculating the CODD and the PS can provide a more detailed analysis of the athlete’s ability to turn and this research provides some insight as to how to train individuals for these qualities. For example, the ability to produce eccentric force quickly was critical to both the CODD and the PS of the athlete. This indicates that improving eccentric power and rate of force development may lead to improvements in these measures and consequent improvement in performance.

An interesting finding observed during the study was the positive correlation with CODD time and relative peak power. This is surprising as this variable did not show a similar relationship with the 20S shuttle time. Relative measures of power have frequently been correlated with linear sprinting in team sport athletes (1). Moreover, peak power and relative peak power on the unilateral jumps showed strong negative correlations with 20S time. An athlete travelling faster into the turn would automatically have to produce higher braking forces to control their momentum however the positive correlation between the PS and relative peak power was not significant. This implies that these athletes were also less efficient during the turn and acceleration out of the COD. Different acceleration strategies may influence the CODD score relative to the 20S score, however whether this is related to relative peak power is unclear. More research with larger subject numbers would be needed to see if this correlation was observed consistently within elite athletes and to explain the potential reasons for this result.

Relative measures of force production did not show any clearer correlations than the more absolute values for the CODD and PS and showed less significant correlations than absolute values with the 20S. This was in contrast to previous research by Baker (1) and Spiteri (28). Bodyweight did seem to show a negative correlation with the pacing strategy of the athlete. This was surprising as these athletes would have had to control a higher momentum due to their larger mass. Spiteri's research had stated that excess body fat had limited the individuals COD performance and this could have been why relative measures of strength and power showed more significance (28). The cohort examined in this study, may have been less restricted by this which may have indicated that heavier athletes were stronger. However, whether this trend is specific to this cohort or represents a wider pattern within elite hockey players is inconclusive.

Despite unilateral strength measures previously having been correlated with COD (19) this pattern was not clearly observed within these results. There were some interesting differences between the correlations that were observed between the right and the left leg. For example, all COD measures showed a negative correlation with AEF on the left leg whereas PP was negatively correlated with all values on the right leg which was particularly surprising for the CODD measure. This could represent the different roles provided by each leg as all athletes were right footed turners in this study. This meant that all athletes had to use their left leg as their main brake step and pushed off on the right leg when accelerating. However, the information in this study is not conclusive enough to make strong assumptions in this area. More research would be needed with athletes turning on both legs to see whether these patterns were specifically relevant to COD performance. A more detailed look into the muscle activity and movement strategies of each leg during the turn could also provide further insight.

The measurement used to calculate the ERFD and CRFD including their relative equivalents has not been suggested previously in the literature. This measure is an approximation of RFD and may reflect different results to alternative measures of RFD that have been previously described (11,30). This would be an interesting area for future study.

During the kinematic analysis all COD measures seemed to favour athletes that displayed higher levels of knee extension at the deepest position of the plant step and less of a change in knee angle following ground contact. This is in accordance with the research of Dos Santos (6) who suggested that to achieve good COD performance athletes should be perform the eccentric part of the COD prior to the plant step. This allows the athlete to keep an extended leg during the plant step which helps to quickly reposition the COM in the required direction of travel. Furthermore, this has various implications for injury prevention as this strategy would reduce the amount of ground reaction force on the plant leg which has been indicated as a risk factor for knee injury (12). Athletes that can reduce their PS prior to the turn without collapsing through the knee joint of the plant leg may be able to perform at a higher level with a lower risk of injury. Contrary to the hypothesis, athletes that showed a lower PS tended to keep a more extended knee joint during this step. This is surprising as a higher relative velocity prior to the turn gives the athlete less time to brake during the step prior to the turn and make force them to sink down during the plant step. However, the fact that this pattern was not observed indicates that these athletes were adapting their PS in accordance with their own physical capacities.

During the propulsive phase of the turn a higher level of knee flexion was positively associated with the CODD and the PS. This represented a different pattern to the traditional model for acceleration that is observed within linear sprinting. Lockie observed that team sport athletes generally reach top speeds over shorter distances and display different movement patterns to those observed in track and field. Furthermore, Hewit (13) found that Netballers increased stride frequency and increased hip angle in a COD task in order to keep their COM nearer to their base of support. This strategy enabled the athletes to get up to a greater percentage of their maximal speed in less time. Furthermore, this strategy has been suggested to enable a quicker COD as the weight of the athlete can quickly be redistributed due to reductions in flight time. In contrast to this, track and field sprinters need to increase stride length during the drive phase to allow for enough time in contact with the ground. This means that this stage of the movement is actually may be relatively slower but it allows them to reach faster speeds later on during the sprint (19). The difference in these two strategies may explain the difference between the movement patterns observed between athletes with good times in the 20S and the CODD and PS.

Unfortunately, the analysis of the brake step was limited in this study. Because the athlete was turning following the ground contact of this step and due to the cameras two-dimensional viewpoint, the analysis of the braking movement was insufficient to analyse this step in detail.

There seemed to be some indication that a higher level of dorsiflexion was linked to a lower CODD. However how this was related to the following steps could not be clearly established during this research. A recommendation for further research would be to examine this portion of the movement using more advanced three-dimensional equipment.

PRACTICAL APPLICATIONS

The relationship between these 20S, CODD and PS variables may provide valuable insight for the strength and conditioning practitioner. For example, if an athlete can achieve a fast 20S but has a poor CODD this could indicate that they have achieved this score via superior linear sprint qualities. In this case they may need to work on specific eccentric variables such as their eccentric power production or alternatively, they may need to improve their COD technique. Similarly, if an athlete can achieve a low CODD but demonstrates a high PS score this may indicate that they can accelerate very well but may be less proficient at decelerating from a high velocity. Team sports performance contains many sprints of varying lengths and intensities (26). An athlete that has a high maximal speed and can accelerate and decelerate efficiently should be more proficient in the game environment. This research may provide some insight as to the physical parameters an athlete might need to increase their ability in each of these areas. Further research is needed to understand whether these measurements correspond to in game performance.

These results support the theory that athletes who are better at changing direction can brake efficiently prior to the plant step and can therefore keep a straighter leg during this stage of the movement. This gives coaches further insight into the movement patterns that should be encouraged in their athletes to aid performance and help to reduce injury risk. Furthermore, an interesting trend was observed between athletes that achieved a good CODD and PS and their propulsive knee flexion angle when exiting the turn. These athletes displayed a straighter leg which would have led to a more upright posture and limited stride length. This behaviour has been observed in athletes that have to change direction over smaller distances and may be beneficial within certain situations in the on-field performance. Educating and training the athletes as to which movement strategies may aid different scenarios could provide a useful exercise for the strength and conditioning practitioner.

In summary, this research has provided some valuable insight into the biomechanics that characterise different elements of COD performance. This could be used as a reference point to help the strength and conditioning coach improve in game performance depending on the specific athlete's limitations. This research was limited by the two-dimensional analysis of the braking step and the small number of athletes analysed and the lack of three-dimensional analysis of the kinematic factors. Further research should focus on whether these scores correlate with on-field performance and whether the training interventions indicated generate positive impacts on the test results.

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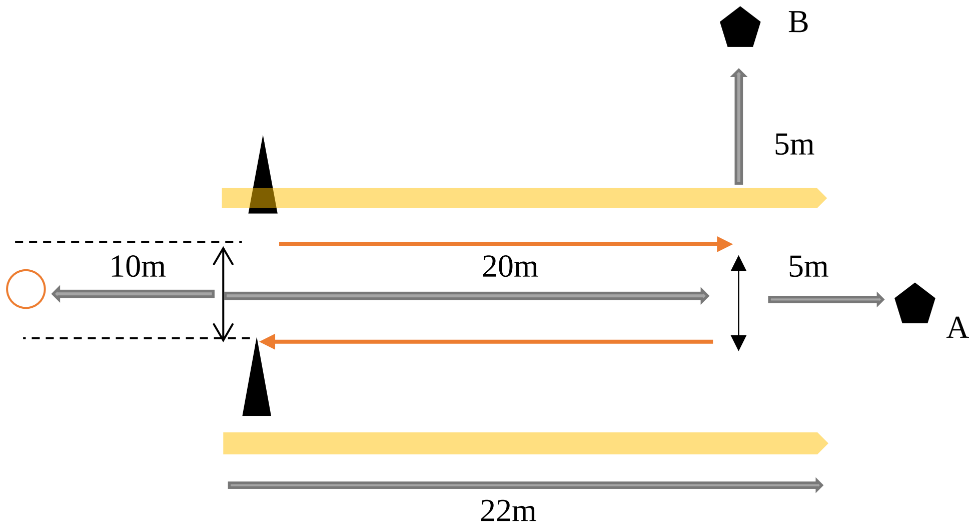
Table 1) Subject Characteristics

Variable	**Mean, ± SD**
Number (n)	24
Age (years)	26 (±4)
Weight (kg)	79.6 (±7.8)

Figure 1) 20S area diagram



Key

Sprint direction

Deceleration /active recovery area

Timing Gates

Start Line

Turn Line

Recovery cone

OPTOJUMP

Camera (1.7m off the ground).

Distance measure

Table 2) Recorded kinematic variables.

Stage of the Turn	**Kinematic Variables Measured**
Braking Step	Ground contact knee flexion angle. * Ground contact ankle plantar flexion angle. ** Torso ground contact angle.
Plant Step	Ground contact knee flexion angle. * Ground contact ankle plantar flexion angle. ** Deepest knee flexion angle. * Deepest ankle plantarflexion angle. ** Change in knee angle. Change in ankle angle.
Propulsion Step	Ground contact knee flexion angle. * Ground contact ankle plantarflexion angle. ** Ground contact torso angle.
Key	*=180°- angle observed. **=90°-angle observed Change in angle = Ground contact angle – Deepest angle observed during the plant step

Table 3) Correlations between force plate variables and 20S

Anthropometric	BW												
r value	-0.404												
n	24												
CMJ	CMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.538**	-.626**	-.501*	-.415*	-.212	-.503*	-.652**	-.417*	-.210	-.621**	-.440*	-.483	-.295
n	24	24	24	24	24	24	24	24	24	24	24	24	24
LCMJ	LCMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.576**	-.541**	-.382	-.429*	-.268	-.657**	-.601**	-.615**	-.425*	-.093	.067	.176	.032
n	24	24	24	24	24	24	24	24	24	24	24	24	24
RCMJ	RCMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.515**	-.415*	-.095	-.389	-.336	.248	-.382	-.619**	-.629**	-.093	.067	-.176	.032
n	24	24	24	24	24	24	24	24	24	24	24	24	24

Key

*=p<0.05

**=p<0.01

Table 4) Correlations between force plate variables and CODD

Anthropometric	BW												
r value	-.208												
n	24												
CMJ	CMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	.125	-.061	-.229	-.235	-.203	-.450*	-.207	.162	.486*	-.043	.048	-.512*	-.502*
n	22	22	22	22	22	22	22	22	22	22	22	22	22
LCMJ	LCMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.009	-.116	-.106	-.230	-.180	-.359	-.021	.202	.442*	-.085	.011	-.297	-.225
n	22	22	22	22	22	22	22	22	22	22	22	22	22
RCMJ	RCMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.016	-.129	.092	-.185	-.399	-.399	-.110	-.102	-.033	-.003	.076	-379	-.456*
n	22	22	22	22	22	22	22	22	22	22	22	22	22
Key													
*=p<0.05													
**=p<0.01													

Table 5) Correlations between force plate variables and PS

Anthropometric	BW												
r value	-.503*												
n	22												
CMJ	CMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.062	-.380	-.133	-.471*	-.074	-.594**	-.428*	-.190	.211	-.240	-.026	-.642**	-.426*
n	22	22	22	22	22	22	22	22	22	22	22	22	24
LCMJ	LCMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.009	-.461*	-.025	-.472*	-.180	-.654**	-.348	.198	.161	-.347	-.101	-.658**	-.484*
n	22	22	22	22	22	22	22	22	22	22	22	22	22
RCMJ	RCMJh	ACF	RACF	AEF	RAEF	AEP	CPF	PP	RPP	CRFD	RCRFD	ERFD	RERFD
r value	-.300	-.427*	.053	-.429*	-.590**	-.314	-.422	-.491*	-.343	-.162	.094	-.427*	-.522*
n	22	22	22	22	22	22	22	22	22	22	22	22	22
Key													
*=p<0.05													
**=p<0.01													

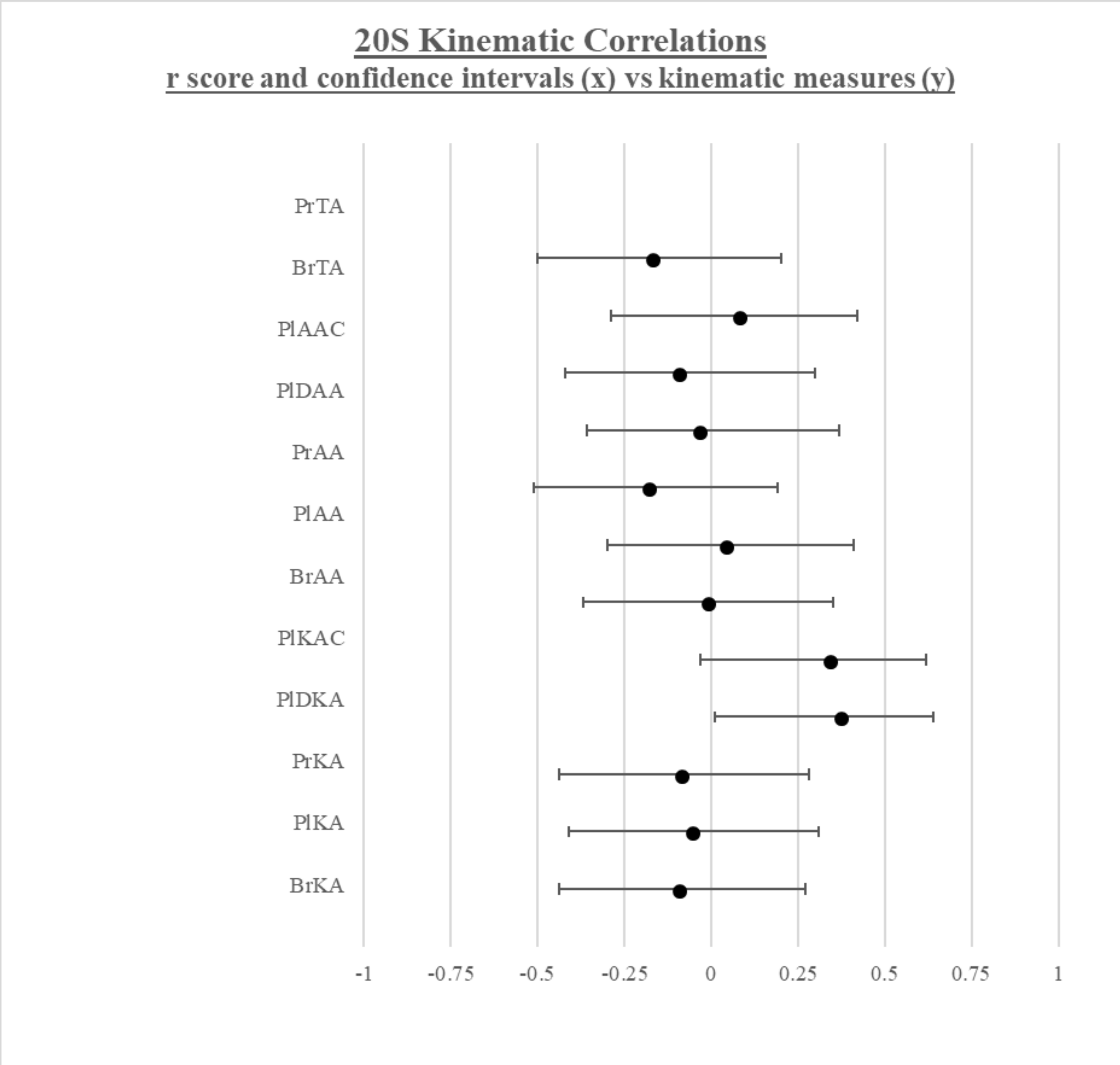
Table 6) Mean kinematic values with standard deviations.

PrTA	BrTA	PlAC	PlDAA	PrAA	PlAA	BrAA	PlKAC	PlDKA	PrKA	PlKA	BrKA
103.9 ±12.3	135.6 ± 10.6	12.2 ± 6.2	94.6 ± 12.2	25.9 ± 11.9	8 ± 7.3	26.5 ± 7.9	28.2 ± 9.5	-4.6 ± 8.4	61 ± 7.8	47.2 ± 8.5	30.5 ± 6.2

N=22

Key: PrTA= Propulsive Torso Angle BrTA= Brake Step Torso Angle PlAC=Plant Step Change in Ankle Angle, PLDAA= Plant Step Deepest Plantarflexion Angle, PrAA= Propulsive Step Plantarflexion Angle, PlAA= Plant Step Ground Contact Plantarflexion Angle, BRAA= Brake Step Plantarflexion Ankle Angle, PlKAC= Plant Step Change in Knee Flexion Angle, PlDKA= Plant Step Deepest Knee Flexion Angle, PrKA= Propulsive Step Knee Flexion Angle, PlKA= Plant Step Ground Contact Knee Flexion Angle, BrKA= Brake Step Knee Flexion Angle.

Figure 2)



20S Kinematic Correlations
r score and confidence intervals (x) vs kinematic measures (y)
PrTA
BrTA
PlAAC
PlDAA
PrAA
PlAA
BrAA
PlKAC
PlDKA
PrKA
PlKA
BrKA
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1

Figure 3)

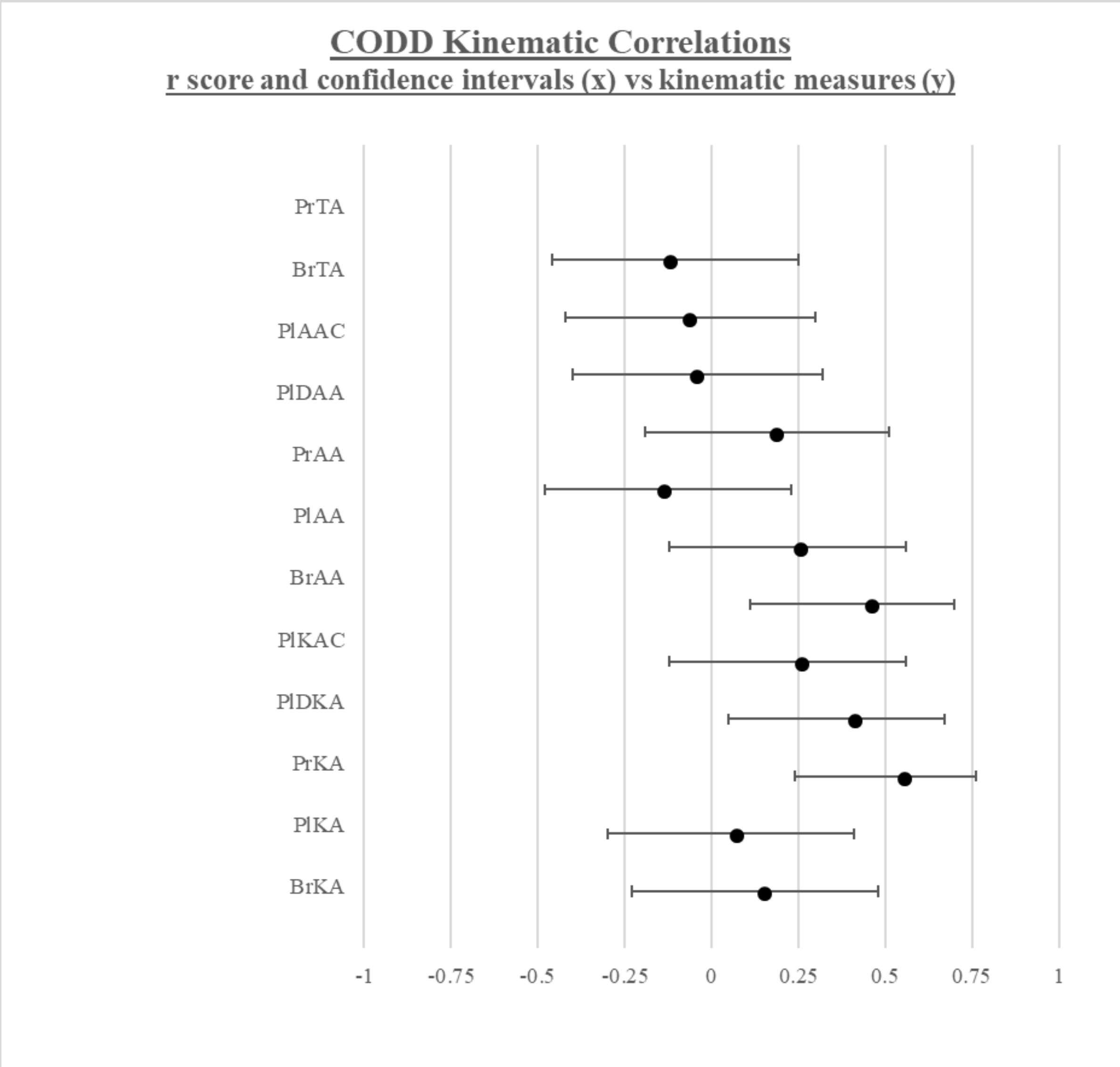
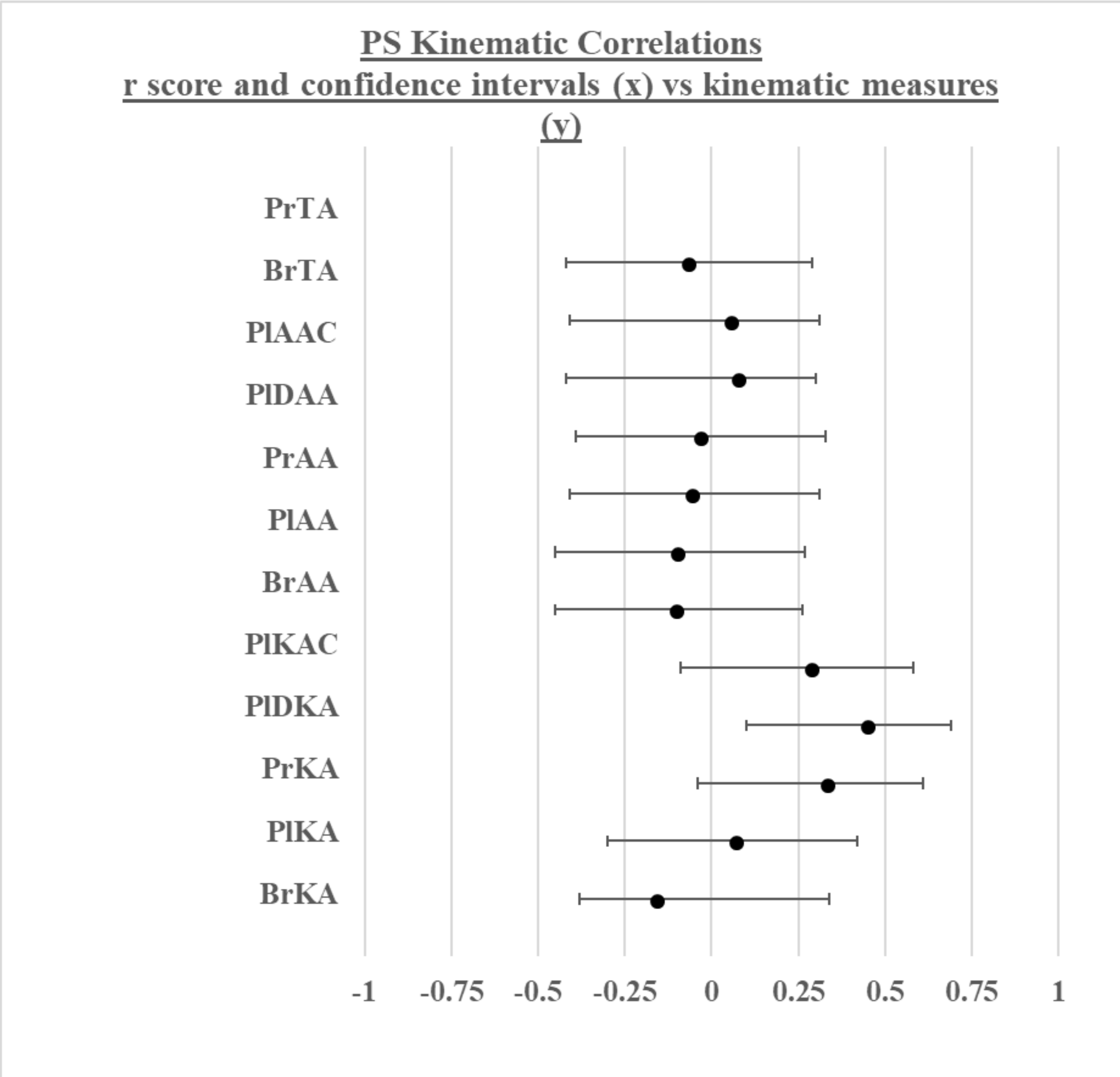

CODD Kinematic Correlations
r score and confidence intervals (x) vs kinematic measures (y)
PrTA
BrTA
PlAAC
PlDAA
PrAA
PlAA
BrAA
PlKAC
PlDKA
PrKA
PlKA
BrKA
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1

Figure 4)


PS Kinematic Correlations
r score and confidence intervals (x) vs kinematic measures (y)
PrTA
BrTA
PlAAC
PlDAA
PrAA
PlAA
BrAA
PlKAC
PlDKA
PrKA
PlKA
BrKA
-1
-0.75
-0.5
-0.25
0
0.25
0.5
0.75
1