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Inertial measurement unit analysis for providing greater diagnostic value during the modified 5-0-5 change of direction test

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ABSTRACT

Timing gates are currently the most common piece of equipment for measuring change of direction (COD) performance, however, they provide only a total time metric. A better understanding of the kinematics and kinetics during a COD movement beyond total time would provide coaches with a more comprehensive understanding of COD movement and how it can be improved. Therefore, the aim of this study was to determine the reliability of an inertial measurement unit (IMU) insole for measuring peak acceleration, peak deceleration, maximum speed, and ground contact time during a modified 5-0-5 change of direction (COD) test. Additionally, the strength of association between these IMU variables and timing light metrics was explored. Ten elite female netball athletes (age = 24.9 ± 5.0 years, height = 180.1 ± 6.5 cm, weight = 81.3 ± 15.0 kg) performed a modified 5-0-5 COD test across three testing occasions. Analysis revealed moderate to excellent relative consistency (ICC = 0.57 – 0.94) and acceptable absolute consistency (CV = 1.8 – 9.5%). Correlations ranged from 0.04 to 0.95, with peak acceleration having the strongest correlation with total time (r = 0.95). It appears that IMU insoles can be used to reliably measure performance during a COD task and provide additional diagnostics beyond time metrics.

1. Introduction

Change of direction (COD) movements are prevalent in both team and individual sports, and the ability to execute them effectively is considered crucial for achieving success in most sports (Barber et al., 2016; Morgan et al., 2022; Ryan et al., 2022b; Talty et al., 2022). COD tasks involve different phases such as acceleration, deceleration, turning/cutting, and reacceleration, as described by Ryan and colleagues (2021; 2022a). One common test that is used to measure 180° COD performance is the modified 5-0-5 COD test, however most researchers only quantify performance with total time (Barber et al., 2016; Gabbett, Kelly, & Sheppard, 2008; Taylor et al., 2019). A better understanding of the kinematics and kinetics during a COD movement, rather than just providing total time, would provide practitioners with a more comprehensive understanding of COD test performance and how it can be improved (Nimphius et al., 2018). Ryan and colleagues (2021) have aimed to improve the diagnostic capabilities of the test to provide measures of the different phases, however, more advanced technologies can complement this analysis.

Motion capture systems and force plates are considered the gold standard for movement analysis and are used to measure a suite of kinematic and kinetic variables, such as joint range of motion, movement velocities, step kinematics, magnitude, and orientation of ground reaction forces, and speed of COD movements (Marshall et al., 2014; McFadden, Daniels, & Strike, 2020). However, this equipment can be expensive and not easily applicable to field settings (Alanen et al., 2021). Other technologies such as Optojump has been used to quantify ground contact time during 180° COD tasks, with authors reporting

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moderate to good reliability (intraclass correlation coefficients [ICC's] = 0.52 – 0.89; coefficients of variation [CV's] = 10.0 – 10.6%) (Condello et al., 2020). Though this technology can be used in a field setting, it may be too expensive or impractical to incorporate into some team sport settings.

Inertial measurement units (IMUs) provide a portable and relatively inexpensive alternative to measuring and monitoring an athlete's performance, through the measurement of acceleration, position and orientation during practice and games (Chambers et al., 2015). IMUs may be a practical solution to measuring step kinematics, such as acceleration, deceleration, and ground contact time during in-sport movements such as 180° COD. Practitioners could use this information to guide their exercise prescription and improve athletic performance (Alanen et al., 2021). Many IMU companies use a lease model, for example, IMeasureU starts at $6600 USD per year, while Plantiga foot pods are $2000 USD per year. With IMUs becoming increasingly popular, it seems important to determine if IMU technology can reliably measure COD performance, both within and between sessions.

Several researchers have reported on the reliability of IMUs to quantify different aspects of COD performance (Balloch et al., 2020; Barreira et al., 2017; Meylan, Trewin, & McKean, 2017). For example, Balloch and colleagues (2020) determined the reliability of using IMU technology attached to the posterior trunk, at the upper thoracic vertebrae (T1–T5). They developed an algorithm that was able to automatically detect and record COD movements ranging from 45 – 180°. They reported good reliability for all angles measured (CV = 1.3 – 4.2%). Barreira and colleagues (2017) investigated the reliability of a trunk-mounted (placed on thoracic spine) accelerometer to measure player load during a side cut movement. The authors reported moderate to high correlations between trials and acceptable limits of agreement (from 17 to 41%). Though these researchers have reported reliable metrics for these IMUs, there appears to be two main limitations. Firstly, the location of the IMUs at the trunk may not give the best representation of the foot-ground interaction. IMUs placed on the trunk may move around due to the jarring associated with fast and explosive movements such as sprinting or changing direction. This could be overcome by using a foot mounted IMU placed in the sole of the shoe since the location is at the interface of the foot and shoe, enabling it to capture the initial impact of the foot during contact with the ground (Napier et al., 2021). The second limitation of trunk located IMUs is data extraction and processing. Many of the IMUs used by researchers do not provide instant performance results and need extensive amounts of post-processing before the data can be interpreted. This may be a disadvantage for many strength and conditioning coaches that work in the field with individual and team sport athletes that would benefit from instantaneous feedback.

There are several commercially available IMUs that are placed on (shoelace mounted) or within the shoes (mid-arch of an insole in placed of a standard running shoe insole) (Napier et al., 2021). Many of these shoelace mounted and insole IMUs are equipped with a 6-axis IMU sensor (3-axis accelerometer and 3-axis gyroscope), allowing researchers to measure individual limb performance and differences across limbs. Additionally, many of these commercially available IMUs come with software that calculates a range of different variables such as player load, maximum speed, peak acceleration, peak deceleration, and ground contact time. With the evolving nature of sports science and athlete monitoring, practitioners need to ensure that the devices and calculation methods used within the software are providing reliable performance metrics that can be used in the field. To the authors knowledge, at the time of this research, there was no study that had determined the reliability of an IMU placed at the foot, for measuring COD performance metrics.

Many authors have highlighted the importance of deceleration and acceleration ability (Hewit et al., 2011; Hewit, Cronin, & Hume, 2013; Ryan et al., 2022a) and ground contact time at the turn during a 180° COD task (Dos' Santos et al., 2017). Therefore, it would seem important to be able to easily quantify these metrics during a COD task. Hence, the aim of this study was to firstly, determine the inter-session reliability of the Plantiga Insole IMU for measuring peak acceleration, peak deceleration, maximum speed, and ground contact time during a modified 5-0-5 COD test. Secondly, it would seem important to determine the strength of association between firstly the different IMU variables and secondly between the IMU variables and timed metrics investigated by Ryan and colleagues (2021) previously. This will help determine whether these IMU variables can predict certain temporal aspects of performance or add further diagnostic value to this COD test. This will provide coaches with greater insight into athletes' performance capabilities and therefore become more targeted with programming and exercise prescription.

2. Methods

2.1. 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. In-shoe IMUs were fitted to each athlete and placed within their normal court shoes before the commencement of the warm-up. The variability of the COD performance was quantified using CVs and ICCs

2.2. Participants

Ten elite female netball athletes (age = 24.9 ± 5.0 years, 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 time. This research was approved by the Auckland University of Technology Ethics Committee (20/402).

2.3. Equipment

2.3.1. Inertial measurement unit

Plantiga IMUs (Plantiga Technologies, Vancouver, Canada; sampling frequency 416 Hz) were used during this research. Plantiga insoles are 6-axis IMUs (triaxial accelerometer and triaxial gyroscope) and are placed under each mid-foot. Each IMU is small (42 × 47 × 3.4 mm), durable, and water and impact resistant (see Figure 1). These insoles were placed in the participants shoes prior to the warmup. Four different metrics were extracted from the IMU cloud and used for analysis. Maximum speed is the highest speed achieved over the course of the modified 5-0-5 COD test. Peak acceleration and deceleration metrics were also extracted from the cloud. Lastly, ground contact time (GCT) of the plant foot at the time of the turn was extracted for each trial.

Figure 1: Plantiga IMU Insole.

2.3.1. Timing lights

Dual beam timing gates (Swift Performance Equipment, New South Wales, Australia) were also used to quantify COD performance. Gates were set at 0, 2, and 4 m to isolate the phases of the 5-0-5 COD test (acceleration, deceleration, 180° turn, and reacceleration), a method previously used by Ryan and colleagues (2021). 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 modified 5-0-5 COD test as outlined in Figure 2. Once all the trials were complete, the IMU data was uploaded into the Plantiga cloud and stored on-board for later analysis.

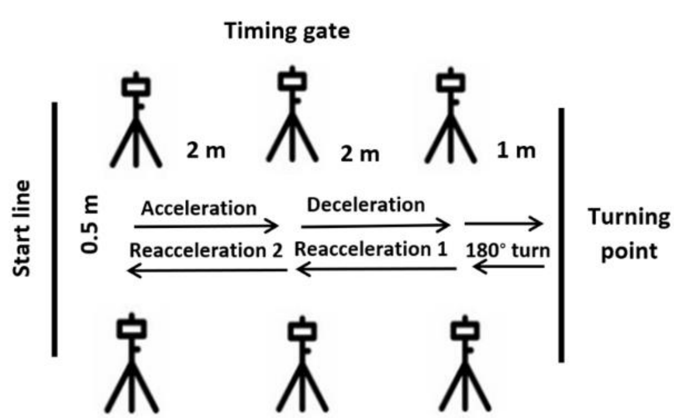

Figure 2: Modified 5-0-5 COD test with additional timing gates, producing five splits and total time.

2.4. Procedures

Testing was conducted on an indoor netball court. Athletes were instructed to wear the same clothing and footwear for all three sessions. All athletes were performing the modified 5-0-5 COD test on a weekly basis as part of their normal programming, and therefore did not require a familiarisation session. Each testing session was performed exactly 7 days apart, at the same location and time of day. Each testing session was 40 minutes, which included a standardised warm up consisting of lower body activation such as banded walks and squats, vertical, horizontal (bilateral and unilateral) jumps, progressive sprints (5, 10, and 20 m) and COD drills, building the intensity up to max effort.

For the modified 5-0-5 COD test, a modified set up was used as described by Ryan and colleagues (2021). Athletes started 0.5 m behind the start line (i.e., first timing gate) in a two-point split stance, with their preferred foot forward and began the test whenever they were ready. 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. Athletes were instructed to sprint 5 m and touch their foot on the COD line, perform a 180° turn on a specific leg and sprint 5 m back through the first timing gate. Three trials within each testing session were performed on each leg. Three minutes of rest was provided between trials to limit any fatigue effects.

2.5. Statistical analysis

All statistical analysis was performed using IBM SPSS statistical software package (version 27.0; IBM Corporation, New York, USA). Outlier and normality analysis was implemented on the raw data and means, and standard deviations were reported for all variables of interest. Absolute consistency between trials and sessions was quantified using CVs, where measures less than or equal to 10% were deemed acceptable (Lloyd et al., 2009). Relative consistency between trials and sessions was determined using ICC, using a two-way random average measures model (Koo & Li, 2016). Classification 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) (Buchheit & Mendez-Villanueva, 2013). Once reliability had been determined, relative left and right leg variables were compared for all IMU and timing lights metrics via paired t-tests. No statistical difference was found between left and right leg performance, therefore data was pooled and further analysed. Pearson correlation coefficients were used to determine the strength of association between IMU variables as well as timing light splits, and coefficients of determination (R^2) were used to quantify shared variance. The authors used a 50% shared variance threshold to determine the independence of variables (Baker, Wilson, & Carlyon, 1994; James et al., 2023; Young, Wilson, & Byrne, 1999).

3. Results

The inter-session variability of the IMU variables can be observed in Table 1. There appeared no systematic change between the variables, with the largest change observed between sessions 3 – 2 for the peak deceleration variable (-7.8%). In terms of absolute

Table 1: Inter-session variability of IMU variables.

Variable	Mean ± SD			% Change in mean [95% CI]		CV [95% CI]		ICC [95% CI]	
	Session 1	Session 2	Session 3	Session 2 – 1	Session 3 – 2	Session 2 – 1	Session 3 – 2	Session 2 – 1	Session 3 – 2
Max speed (m/s)									
Left	5.3 ± 0.6	5.2 ± 0.6	5.2 ± 0.6	-2.8 [-6.2, 0.7]	-1.7 [-5.2, 1.8]	3.6 [2.4, 6.6]	3.4 [2.3, 6.5]	0.94 [0.74, 0.98]	0.93 [0.71, 0.99]
Right	5.3 ± 0.5	5.1 ± 0.6	5.1 ± 0.6	-3.6 [-6.3, -0.9]	-0.9 [-3.9, 2.3]	3.5 [2.5, 5.8]	3.6 [2.6, 6.2]	0.93 [0.79, 0.98]	0.94 [0.80, 0.98]
Peak deceleration (m/s^2)									
Left	-2.6 ± 0.3	-2.5 ± 0.4	-2.4 ± 0.3	-1.3 [-8.4, 6.4	-7.8 [-12.0, -3.5]	9.5 [6.9, 16.2]	5.4 [3.8, 9.4]	0.57 [0.07, 0.84]	0.86 [0.59, 0.95]
Right	-2.6 ± 0.3	-2.5 ± 0.3	-2.4 ± 0.2	-4.0 [-7.8, 0.1]	-5.0 [-8.3, -1.5]	5.2 [3.7, 8.6]	4.2 [3.0, 7.2]	0.86 [0.56, 0.95]	0.90 [0.66, 0.97]
Peak acceleration (m/s^2)									
Left	4.2 ± 0.3	4.0 ± 0.3	4.1 ± 0.4	-3.3 [-4.7, -1.9]	-0.2 [-2.2, 1.9]	1.8 [1.3, 2.9]	2.3 [1.7, 4.0]	0.96 [0.87, 0.99]	0.94 [0.82, 0.98]
Right	4.1 ± 0.3	4.0 ± 0.2	4.0 ± 0.4	-0.8 [-2.3, 0.8]	-0.1 [-2.5, 2.3]	1.9 [1.4, 3.2]	2.8 [2.0, 4.9]	0.93 [0.79, 0.98]	0.90 [0.68, 0.97]
Ground contact time (ms)									
Left	344.5 ± 112.8	310.9 ± 59.6	306.3 ± 74.1	-7.0 [-16.7, 3.9]	-4.9 [-11.0, 1.6]	14.4 [10.3, 24.7]	7.8 [5.5, 13.7]	0.81 [0.51, 0.94]	0.93 [0.78, 0.98]
Right	337.5 ± 69.5	328.6 ± 71.1	301.3 ± 58.3	-2.8 [-7.6, 2.2]	-6.5 [-12.3, -0.4]	6.4 [4.6, 10.7]	7.5 [5.4, 13.2]	0.94 [0.82, 0.98]	0.91 [0.73, 0.97]

consistency, all CVs were less than 10% (1.8 – 9.5%) except for ground contact time left leg between session 2 – 1 (14.4%). With regards to relative consistency, all ICC's were greater than 0.80 (0.81 – 0.96), except for peak deceleration on the left leg turn, between session 2 – 1 (0.57).

A comprehensive matrix examining the strength of association between all right and left leg variables for each IMU, and timing light metric can be found in Supplementary Table 1. There were no statistically significant differences observed between relative right and left leg IMU or timing light variables, therefore the pooled averages were used to examine associations between the variables. The strength of association between the pooled averages for each IMU and timing light variable are presented in the correlation matrix (Table 2). Correlations ranged from 0.04 to 0.95. With regards to total time measured with timing gates, the highest correlation and therefore biggest predictor of total time among IMU variables was found with peak acceleration ($r = 0.95$), and the lowest correlation was found with ground contact time ($r = 0.04$).

The biggest predictor for initial acceleration (split 1) and deceleration (split 2), was peak acceleration ($r = -0.61$, $r = -0.86$). Split 3, which is where the 180° turn occurs, had the strongest correlation with maximum speed ($r = -0.89$), while split 4 and 5 (reacceleration phases) had the strongest correlation with peak acceleration ($r = -0.71$ and 0.68, respectively).

The highest correlation found among IMU variables was between peak acceleration and maximum speed ($r = 0.85$), while the lowest correlation reported was between ground contact time and maximum speed ($r = -0.10$). Ground contact time had trivial to low correlations with all IMU and timing light variables ($r = 0.23$ to -0.44).

Table 2: Correlation matrix between IMU variables and timing light variables during a modified 5-0-5 COD test.

Variable	1	2	3	4	5	6	7	8	9
1. Max speed	–								
2. Peak decel	0.65*	–							
3. Peak accel	0.85**	0.54	–						
4. GCT	-0.10	0.24	-0.13	–					
5. 5-0-5 split 1	-0.57	-0.44	-0.61	-0.20	–				
6. 5-0-5 split 2	-0.59	-0.39	-0.86**	0.23	0.65*	–			
7. 5-0-5 split 3	-0.89**	-0.59	-0.81**	-0.04	0.68*	0.60	–		
8. 5-0-5 split 4	-0.69*	-0.55	-0.71*	-0.18	0.33	0.34	0.53	–	
9. 5-0-5 split 5	-0.57	-0.50	-0.68*	-0.44	0.39	0.82**	0.40	0.27	–
10. 5-0-5 total	-0.91**	-0.64*	-0.95**	-0.04	0.74*	0.79**	0.94**	0.64*	0.60

Note: Correlation coefficient of 0 to 0.5 represents low correlation, 0.5 to 0.7 represents moderate correlation, 0.7 to 1.0 represents high correlation. decel = deceleration, accel = acceleration, GCT = ground contact time. * $p < 0.05$. ** $p < 0.001$.

4. Discussion

The aim of this study was to firstly, determine the intra-session reliability of the various IMU variables during a modified 5-0-5 COD test and secondly, determine the strength of inter-relationship between the different IMU and timing light variables. The main findings were: (1) there appeared to be no systematic change between the variables across sessions; (2) absolute consistency was acceptable for all variables, except for GCT on the left leg at the turn, between session 2 – 1 (14.4%) and all ICC's were greater than 0.80, with the exception of peak deceleration left; (3) no significant differences were observed between right and left leg variables, therefore the data was pooled to determine the strength of interrelationships; (4) the biggest predictor for total time measured with timing gates was peak acceleration (r = 0.95); and (5) Ground contact time had trivial to low correlations with all IMU and timing light variables (r = 0.04 to 0.44). These key findings may be of importance to coaches and practitioners when considering how to assess COD performance for court-sport athletes.

To the authors knowledge, this is the first study to look at the reliability of firstly an insole IMU, as well as these specific variables during a modified 5-0-5 COD test. All variables were found to have good to excellent relative consistency (ICC = 0.81 to 0.96), except for peak deceleration on the left turn between session 2 – 1, which had moderate relative consistency (ICC = 0.57). In terms of absolute consistency, all variables had CV's less than 10%, with the exception of ground contact time left (CV = 14.5%). Previously, Balloch and colleagues (2020) investigated the reliability of trunk-mounted IMUs to measure COD angles ranging from 45 – 180°, reporting similar reliability (CV = 1.3 – 4.2%). Barreira and colleagues (2017) also investigated the use of a trunk-mounted IMU, however they were looking specifically at the reliability of tracking player load, during a COD task. They reported good to excellent reliability for Player Load (ICC = 0.83 – 0.95) and Player Load per minute (ICC = 0.80 – 0.92), which were similar to the results reported in the current study. Lastly, there was very little systematic bias between sessions in the current study, however it needs to be noted that the participants of this study were elite level athletes that performed the modified 5-0-5 COD test on a regular basis and did not require any familiarisation.

With regards to the strength of association, it is first important to compare the IMU variables against timing light variables, specifically total time, which is currently the most common piece of equipment and metric used to measure 5-0-5 COD performance (Ryan et al., 2022b). This comparison will provide insight into whether foot-mounted IMUs provide additional diagnostic information. Total time, measured with timing gates, had the highest correlation with peak acceleration (r = -0.95) explaining 90.3% of total time, which intuitively makes sense, as a majority of the modified 5-0-5 COD test is spent accelerating, firstly from the start point, and secondly out of the 180° turn. In other words, peak acceleration, measured with the IMU, appears to be the greatest predictor for total time during the modified 5-0-5 COD test. To the authors knowledge, no previous research has investigated the relationship between timing light variables and IMU variables. However, Jones and colleagues (2009) previously investigated the correlation between the traditional 5-0-5 COD test and several other performance tests. The largest predictor for 5-0-5 time was sprint speed (r = 0.77), followed by eccentric flexor strength (r = 0.63). Eccentric flexor strength is thought important for decelerative ability and interestingly, had a similar relationship with total time, as seen in the current study with peak deceleration and total time (r = 0.64). Conversely, the lowest correlation reported for the total time measure, was with GCT (r = 0.04), explaining only 0.16% of total time. This is to be expected, as the GCT variable is only providing a small snapshot of what is occurring at the foot at the time of the 180° turn, whereas total time is providing a metric that represents the entirety of the test.

Previous research has determined the strength of association between the timing light phases (Ryan et al., 2021), however to the authors knowledge, there is currently no research that has determined the strength of association between timing light phases and IMU variables. Several interesting observations were made in the current study with regards to the strength of association between timing light phases and IMU variables. Firstly, split 1 which can be defined as the initial acceleration had the strongest correlation with peak acceleration (r = 0.61), explaining 37.0% of the shared variance. This is a moderate correlation, and the shared variance was below 50%, indicating that these metrics are relatively independent of one another. Secondly, peak acceleration also had the largest correlation with split 2 (r = 0.86) explaining 74% of this split, which would be expected, as athletes are likely to be hitting their peak acceleration between split 1 and 2. Thirdly, split 3 has been previously identified as the 180° turn split (Ryan et al., 2021), and one of the highest correlations between split times and IMU variables was reported between split 3 and maximum speed (r = 0.89), explaining 79% of the shared variance. These findings suggest one of two things. First, the higher the max speed reached during the test, the faster the time of the 180° turn split. Second, the faster the 180° turn split, the faster max speed reached during the test. The latter is likely the case, as athletes should be reaching their maximum speed during the end of the reacceleration phase of the test, and if an athlete performs the 180° turn well, this should set them up for a better reacceleration. When taking into consideration the population used in this study (elite athletes), this makes sense, as those reaching higher max speeds are likely having faster entry velocities coming into the turn and have the ability to decelerate quickly and effectively coming into the turn. It is also likely that these athletes have well developed reactive strength to push out of the turn and therefore also have fast exit velocities (McLeod & James, 2018).

With regards to the relationship between the four IMU variables reported, peak acceleration and maximum speed had the strongest correlation (r = 0.85), with peak acceleration explaining 72.3% of maximum speed. This intuitively makes sense, as those athletes with greater peak acceleration, will usually reach the higher maximum speeds during the test. Conversely, GCT at the turn and maximum speed had the weakest relationship (r = -0.10), explaining only 1% of one another. This was to be expected, as GCT variable is measured at the time of the turn when the GCT will be the longest throughout the entire test, however the athlete has more steps to reaccelerate after the turn and achieve maximum speed (Dos' Santos et al., 2020). If average GCT was explored during the different phases such as acceleration, a stronger correlation would likely be observed. These results indicate that GCT is providing additional diagnostic information, as it had a weak relationship between both IMU variables and timing light variables (*r* = -0.44 to 0.23). It seems that GCT is an important variable to track with regards to COD performance, as it is thought that faster GCT result in better COD performance (Dos' Santos et al., 2020). This diagnostic information could provide practitioners with information regarding an athlete's reactive abilities when pushing out of the turn and inform further programming to minimise GCT and enhance an athlete's 180° turning ability. Peak deceleration also had moderate to low correlations with other IMU variables and timing light metrics (*r* = -0.64 to 0.59), suggesting that this IMU variable is providing additional diagnostic information that can be used by coaches and practitioners to further refine their exercise prescription.

Authors have detailed the importance of linear speed, deceleration, and reacceleration during COD manoeuvres (Ryan et al., 2022a; Sheppard & Young, 2006). Specifically with the 5-0-5 COD test beginning with acceleration, then deceleration to a complete stop and reacceleration into the new direction (Clarke et al., 2022), it would seem important to monitor these variables. The IMU insoles used in this study were found to provide a reliable way to measure acceleration, maximum speed, deceleration, and ground contact time during a modified 5-0-5 COD test. Though some high correlations were reported between timing gate splits and IMU variables, it appears that most of the IMU variables are relatively independent ($R^2 < 50\%$), therefore can be used in addition to timing gates, to increase the diagnostic value of the modified 5-0-5 COD test.

4.1. Conclusion, limitations, and practical applications

It appears that an IMU mounted on the insole of a shoe can be used to reliably measure peak acceleration, peak deceleration, max speed, and ground contact time during a modified 5-0-5 COD test. The information reported in this study provides coaches and practitioners with valuable information, for example, peak acceleration seems the biggest predictor for total 5-0-5 COD time. This information can help coaches become more specific with their programming. Additionally, a majority of the IMU variables are relatively independent to the timing light variables, therefore providing a rationale for the inclusion of this IMU insole to provide additional diagnostic information during a modified 5-0-5 COD test. The results of this study need to be interpreted with caution, as this study used elite level netball athletes, and therefore the results may be different for athletes of a different level, sport, or gender. Based off the results of the current study, it appears that use of the IMU insole can advance the diagnostic ability of the protocol for the modified 5-0-5 COD test. This advancement will enable coaches and practitioners to reliably track different metrics deemed important for COD performance. Additionally, it may help coaches identify areas of strengths and weakness for their athletes. These insights could assist with improving COD performance; however, such hypothesis needs to be validated using longitudinal designs.

Conflict of Interest

The authors declare no conflict of interests.

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Supplemental materials

Supplementary Table 1: Correlation matrix between IMU variables and timing light variables for left and right leg turns during a modified 5-0-5 COD test.

Variable	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Max speed left	–																		
2. Peak decel left	-0.71*	–																	
3. Peak accel left	0.82**	-0.48	–																
4. GCT left	-0.01	-0.25	-0.16	–															
5. Max speed right	0.98**	-0.72*	0.81**	-0.03	–														
6. Peak decel right	-0.48	0.79**	-0.44	-0.17	-0.52	–													
7. Peak accel right	0.84**	-0.55	0.97**	-0.02	0.86**	-0.56	–												
8. GCT right	-0.21	-0.13	-0.26	0.81**	-0.13	-0.30	-0.04	–											
9. Left 5-0-5 split 1	-0.50	0.32	-0.56	0.27	-0.59	0.43	-0.67*	-0.06	–										
10. Left 5-0-5 split 2	-0.59	0.28	-0.89**	0.35	-0.60	0.34	-0.86**	0.27	0.71*	–									
11. Left 5-0-5 split 3	-0.76*	0.63	-0.67*	-0.11	-0.79**	0.65*	-0.78**	-0.12	0.73*	0.60	–								
12. Left 5-0-5 split 4	-0.78**	0.44	-0.79**	0.05	-0.71*	0.33	-0.71*	0.33	0.23	0.48	0.42	–							
13. Left 5-0-5 split 5	-0.65*	0.59	-0.77**	0.25	-0.63	0.54	-0.77**	0.22	0.60	0.85**	0.54	0.47	–						
14. Left 5-0-5 total	-0.86**	0.62	-0.91**	0.07	-0.89**	0.63	-0.96**	0.10	0.70*	0.82**	0.90**	0.63*	0.73*	–					
15. Right 5-0-5 split 1	-0.51	0.33	-0.53	-0.06	-0.60	0.53	-0.68*	-0.34	0.89**	0.53	0.75*	0.35	0.39	0.68	–				
16. Right 5-0-5 split 2	-0.54	0.34	-0.79**	0.28	-0.62	0.41	-0.83**	0.05	0.73*	0.89**	0.48	0.38	0.82**	0.72*	0.59	–			
17. Right 5-0-5 split 3	-0.90**	0.55	-0.78**	-0.05	-0.92**	0.35	-0.83**	0.12	0.53	0.62	0.84**	0.57	0.52	0.89	0.53	0.53	–		
18. Right 5-0-5 split 4	-0.37	0.49	-0.40	-0.71*	-0.36	0.49	-0.46	-0.51	0.12	0.12	0.46	0.51	0.11	0.41	0.43	0.09	0.33	–	
19. Right 5-0-5 split 5	-0.54	0.47	-0.69*	0.55	-0.57	0.30	-0.61	0.50	0.49	0.76*	0.29	0.40	0.83**	0.56	0.18	0.79**	0.42	-0.13	–
20. Right 5-0-5 total	-0.89**	0.63	-0.90**	-0.01	-0.93**	0.57	-0.97**	0.00	0.74*	0.78**	0.88**	0.65*	0.70*	0.97**	0.75*	0.75*	0.91**	0.46	0.56

Note: Correlation coefficient of 0 to 0.5 represents low correlation, 0.5 to 0.7 represents moderate correlation, 0.7 to 1.0 represents high correlation. decel = deceleration, accel = acceleration, GCT = ground contact time. * $p < 0.05$. ** $p < 0.001$.