Short Communication

Relationship between Isometric Strength, Sprint, and Change of Direction Speed in Male Academy Cricketers

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Objectives: The aim of this investigation was to determine the relationships between isometric strength, sprint, and change of direction speed (CODS) performance in academy cricketers.

Design and Methods: Eighteen male academy cricketers (mean ± *SD*; age = 17.1 ± 0.7 years; height = 175.8 ± 6.1 cm; mass = 71.7 ± 11.3 kg) performed tests of bilateral and unilateral stance isometric mid-thigh pull (IMTP), sprint, and change of direction speed (CODS) across two separate testing sessions. Isometric mid-thigh pull testing involved trials with relative peak force (PF [$N \cdot kg^{-1}$]) determined for bilateral stance (IMTP PF), left leg (IMTP L PF), and right leg (IMTP R PF). Sprint and CODS performances was measured using 5-, 10-, and 20-m sprint performance, and traditional 505 (505) and modified 505 (505_{mod}) tests. Relationships between variables (IMTP, sprint and CODS performances) were analysed using Pearson's product – moment correlation.

Results: Results suggest that IMTP R PF displayed the strongest relationships with sprint performance ($r = -0.49$ to -0.52). Times to complete 505 CODS were significantly correlated with bilateral and unilateral stance IMTP PF ($r = -0.47$ to -0.65), whereas modified 505_{mod} CODS performance demonstrated no correlation to either bilateral or unilateral stance IMTP PF ($r = -0.31$ to -0.44).

Conclusions: There are no significant relationships between bilateral and unilateral stance IMTP PF and 505_{mod} CODS. Furthermore, there are no significant relationships between bilateral stance IMTP PF and sprint performance. However, this study identified bilateral and unilateral stance IMTP PF to relate to 505 CODS.

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Key words: short sprint performance ■ acceleration ■ maximal isometric strength ■ dynamic performance

INTRODUCTION

Short sprint performance is of great importance in many sports, with research suggesting that sprinting accounts for approximately 9% of the total distance covered by both fast bowlers and fielders during Twenty20 cricket matches.[13] Additionally, the same authors found mean sprint distances of 14 - 17 m for batsmen, fast bowlers, fielders, and spin bowlers. Thus, the ability to accelerate is important and may strongly influence periods of play, whereby players are running between the wickets, fielding the ball, or increasing velocity when bowling. Thus, short sprint performance requires high levels of relative strength to overcome the inertia of body mass. A number of studies have investigated the relationship between isometric strength-related variables and short sprint performance, demonstrating strong associations.[21,23,24] West et al.[24] found significant correlations between isometric mid-thigh pull (IMTP) strength measures and 10 m sprint performance ($r = -0.54$ to -0.68). Tillin et al.[23] found normalized peak force (PF) at 100 ms during an isometric back squat to correlate to 5- and 20-m sprint performance ($r = -0.54$ to -0.63) in varsity rugby union players. Further, Thomas et al.[21] found a significant correlations between IMTP strength and sprint performance ($r = -0.57$ to -0.78) in collegiate athletes. Together, these studies indicate a strong association between maximal strength and sprint performance. Furthermore, training-induced increases in measures of maximum strength have been shown to transfer positively to sprint performance.[16]

Studies have used various methods to assess strength measures, including isometric,[18,19,21] isokinetic,[10,27] and free weight squats,[12,19] when investigating the relationship between strength and change of direction speed (CODS). Thomas et al.[21] found strong, significant inverse correlations ($r = -0.57$; $p < 0.05$) between isometric midthigh pull peak force (IMTP PF) and modified 505 (505_{mod}) CODS in collegiate athletes. Similarly, Spiteri et al.[19] demonstrated very strong, significant inverse associations ($r = -0.79$; $p < 0.01$) between IMTP relative PF (PF/body mass) and 505 CODS in female basketball athletes. These findings are consistent with findings of past studies by Nimphius et al.[12] and Hori et al.[8] which found relative 3 repetition maximum back squat and one repetition maximum front squat to significantly correlate to 505 ($r = -0.75$ to -0.85; $p < 0.05$) and modified 505 CODS ($r = -0.51$; $p < 0.01$), respectively. Research by Jones et al.[10] also points towards eccentric strength as an important factor of 505 CODS, possibly contributing to shorter braking times and increased propulsive force application during CODS activities.[17,18] Overall, there seems to be some evidence to indicate that efficient CODS requires multiple strength types (eccentric, isometric, and concentric) to position the body appropriately to rapidly decelerate and re-accelerate in a new direc-

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tion.[18]

As previously stated, bilateral stance IMTP PF is strongly related to sprint and CODS; however, no study is yet to establish whether these findings hold true for unilateral stance IMTP PF. Furthermore, given the unilateral force production requirements of sprinting and CODS movements, it may be that unilateral stance IMTP PF would be more specific to these dynamic movements. Although performed in a unilateral stance, one would also expect IMTP PF to demonstrate high within-session reliability due to the IMTP position replicating the unilateral stance of sprinting and CODS. Therefore, the aim of this study, firstly, was to examine the relationships between IMTP strength, sprint, and CODS in male academy cricketers. Secondly, to assess the within-session reliability of the unilateral stance IMTP PF measures. It was hypothesized that the relationships between IMTP strength variables and sprint, and CODS would be similar to those previously identified by Thomas et al.[21] and Spiteri et al.[19] because of the CODS tests used within the studies. It was further hypothesized that unilateral stance IMTP PF measures would demonstrate reliability values similar to those previously identified in the bilateral stance IMTP.

METHODS

Experimental Approach to the Problem

This study was designed to investigate the relationships between IMTP strength, sprint (times over 5, 10, and 20 m), and CODS performance (505 and 505_{mod}) in academy male cricketers. The IMTP was chosen as it is commonly used to assess isometric force-related measures.[14] Sprint performances over 5-, 10-, and 20-m were selected because these are representative of sprint distances covered during cricket match-play,[13,15] whereas the CODS protocols were selected as they are commonly used to assess such performance outcomes[19,21]. After data collection was complete, associations between variables were analysed via Pearson's correlations.

Subjects

Eighteen male cricket academy athletes (mean ± *SD*; age = 17.1 ± 0.7 years; height = 175.8 ± 6.1 cm; mass = 71.7 ± 11.3 kg) participated in this study. All players were from the same club and had 3.7 ± 1.2 years of experience competing at this level. Ethical approval was provided by the Institutional Review Board, and all athletes provided written informed consent, with consent from the parent or guardian of all players under the age of 18. All procedures conformed to the Declaration of Helsinki. All individuals were familiar with testing protocols.

Procedures

Testing was conducted in the preseason during which time all participants were training with sessions comprising all the elements of performance including 4-5 cricket-specific training sessions, plus 2 resistance training sessions each week. At the time of testing, participants were at the end of a 4-week general preparation mesocycle.

All testing was performed over two separate days, with anthropometric measurements taken (height and body mass), followed by IMTP testing on day 1, and sprint and CODS performance measures completed on day 2. On arrival, all participants had their height (Stadiometer; Seca, Birmingham, United Kingdom) and body mass assessed (Seca Digital Scales, Model 707) while in bare feet, measured to the nearest 0.1 kg and 0.1 cm, respectively. All athletes rested the day before testing and were asked to attend testing in a fed and hydrated state, similar to their normal practices before training. Before the start of testing, athletes were instructed to perform a standardized warm-up, as directed by the investigator. Further, standardized progressive warm-ups were applied before all tests to control potential variables and improve the reliability of all tests.

Isometric Mid-Thigh Pull Testing

Bilateral and unilateral stance IMTP testing was performed using a portable force platform sampling at 600 Hz (400 Series Performance Force Plate; Fitness Technology). The force platform was interfaced with computer software (BMS) that allows for direct measurement of force-time characteristics and then analyzed using the BMS software. Data were filtered using a fourth-order Butterworth filter with a 16 Hz cut-off frequency. For the bilateral IMTP, athletes obtained self-selected knee and hip angles based on the reports of previous research.[2] For this test, an immovable, collarless steel bar was positioned at approximately mid-thigh, just below the crease of the hip, using a portable IMTP rig (Fitness Technology, Adelaide, Australia). The bar height could be adjusted (3 cm increments) at various heights above the force platform to accommodate different sized athletes. Once the bar height was established, the athletes stood on the force platform, and their hands were strapped to the bar in accordance with previously established methods.[20] Each athlete was provided two warm-up pulls, one at 50% and one at 75% of the athletes perceived maximum effort, separated by one minute of rest. Once body position was stabilized (verified by watching the subject and force trace), the subject was given a countdown of "3, 2, 1, Pull." Minimal pretension was allowed to ensure that there was no slack in the subject's body before initiation of the pull. Athletes performed three maximal IMTP, with the instruction to pull against the bar with maximal effort as quickly as possible, and push the feet down into the force plate; this instruction has been previously found to produce optimal testing results.[20] Each maximal isometric trial was performed for 5 seconds, and all athletes were given strong verbal encouragement during each trial. Two minutes of rest was given between the maximal effort pulls.

Unilateral stance IMTP testing followed the same procedures outlined for bilateral IMTP testing, however was only performed with one foot on the force platform, with the other limb unsupported and flexed 90° at the knee. Athletes were positioned at the same hip and knee joint angle established during bilateral testing. Athletes were instructed to maintain balance, pull against the bar with maximal effort as quickly as possible, and push their single foot into the force platform. Athletes performed a total of six unilateral maximum effort trials (3 with left and right limbs each), in a randomized order, interspersed with two minutes of recovery between trials. Any trials whereby subjects lost balance were excluded, and further trials were performed after a further 2-minute rest period. The maximum force recorded from the force-time curve during the 5-second IMTP trial was reported as the PF for both bilateral and unilateral stance conditions, and was presented as a value relative to body mass ($N \cdot kg^{-1}$). The best performance from each of the 3 trials, for each condition was used for further analysis.

Sprint Testing

The 20-m sprint test was administered as a test of acceleration and sprint ability. All athletes performed three trials, with two minutes rest between trials, on a third-generation artificial rubber crumb surface using "Brower photocell timing Gates" (model number BRO001; Brower, Draper, UT, USA) setup at 0-, 5-, 10-, and 20-m. Timing gates were placed at the approximate hip height for all athletes as previously recommended,[26] to ensure that only one body part, such as the lower torso, breaks the beam. Athletes started 0.5 m behind the first gate, to prevent any early triggering of the initial start gate, from a two-point staggered start. The best performance from each of the 3 trials was used for further analysis.

Change of Direction Speed Testing

Change of direction speed was assessed utilising 505, followed by 505_{mod} tests on the same surface as the sprint trials. For both tests, athletes performed 3 trials on each leg, in a randomized order, with a 2-minute rest between trials. Athletes started 0.5 m behind the photocell gates, to prevent any early triggering of the initial start gate, from a two point staggered start. Timing gates were again placed at the approximate hip height for all athletes. For the 505, athletes were instructed to sprint to a line marked 15 m from the start line, placing either left or right foot on the line, depending on the trial, turn 180° and sprint back 5 m through the finish.[4] For 505_{mod} testing, athletes were instructed to sprint to a line marked 5 m from the start line, placing either left or right foot on the line, depending on the trial, turn 180° and sprint back 5 m through the finish.[4] During both tests, if the subject changed direction before hitting the turning line, or turned off the incorrect foot, the trial was disregarded and the subject completed another trial after the rest period. The best performance from each of the 3 trials, for both 505 and 505_{mod} was used for further analysis.

Statistical Analyses

Data are presented as either mean ± SD or mean with 90% confidence intervals (90% CI) where specified. Within-session reliability of dependent variables was examined using the intraclass correlation coefficient (ICC), and typical error of measurement (TE) expressed as a coefficient of variation (CV). Intraclass correlation coefficient, TE, and CV were calculated through an available online spreadsheet.[6] To assess the magnitude of the ICC, the threshold values were 0.1, 0.3, 0.5, 0.7, 0.9, and 1.0 for low, moderate, high, very high, nearly perfect, and perfect, respectively.[7] Normality of data was assessed by Shapiro–Wilk statistic, and Q-Q plot analysis. Relationships between variables (strength, sprint, and CODS performances) were determined using Pearson's product – moment correlation using SPSS software (version 17.0, SPSS, Inc., IL, USA). Correlations were evaluated as follows: small (0.10 - 0.29), moderate (0.30 - 0.49), large (0.50 - 0.69), very large (0.70 - 0.89), nearly perfect (0.90 to 0.99), and perfect (1.0). The criterion for statistical significance of the correlation was set at $p \leq 0.05$.

RESULTS

Descriptive statistics and within-session reliability for IMTP, sprint, and CODS performances are presented in Table 1. Pearson correlation coefficients between IMTP, sprint and CODS performances are presented in Table 2. Intraclass corre-

Table 1 Descriptive statistics and reliability for strength, sprint, and change of direction speed variables.†

Reliability Variable	Mean	*SD*	ICC (90% CI)	TE (90% CI)	CV% (90% CI)
IMTP					
IMTP PF ($N \cdot kg^{-1}$)	32.24	± 6.40	0.90 (0.80 – 0.95)	2.09 (1.73 – 2.75)	6.4 (5.3 – 8.5)
IMTP L PF ($N \cdot kg^{-1}$)	29.19	± 5.52	0.92 (0.85 – 0.96)	1.61 (1.33 – 2.12)	6.1 (5.0 – 8.1)
IMTP R PF ($N \cdot kg^{-1}$)	29.26	± 4.49	0.95 (0.89 – 0.97)	1.15 (0.95 – 1.51)	4.5 (3.7 – 6.0)
Sprint and CODS					
5 m (s)	1.10	± 0.06	0.60 (0.35 – 0.79)	0.05 (0.04 – 0.06)	3.9 (3.2 – 5.2)
10 m (s)	1.88	± 0.09	0.85 (0.73 – 0.93)	0.04 (0.03 – 0.05)	2.0 (1.7 – 2.6)
20 m (s)	3.24	± 0.18	0.96 (0.92 – 0.98)	0.04 (0.03 – 0.05)	1.2 (1.0 – 1.6)
505 L (s)	2.40	± 0.12	0.82 (0.63 – 0.92)	0.06 (0.05 – 0.08)	2.5 (2.0 – 3.5)
505 R (s)	2.37	± 0.10	0.75 (0.51 – 0.88)	0.07 (0.06 – 0.10)	3.0 (2.4 – 4.3)
505_{mod} L (s)	2.70	± 0.11	0.79 (0.59 – 0.90)	0.06 (0.04 – 0.08)	2.0 (1.6 – 2.9)
505_{mod} R (s)	2.70	± 0.15	0.83 (0.65 – 0.92)	0.07 (0.06 – 0.10)	2.6 (2.1 – 3.7)

† ICC = intraclass correlation coefficient; CI = confidence interval; TE = typical error; CV = coefficient of variation; IMTP = isometric midthigh pull; PF =peak force; CODS = change of direction speed; 505_{mod} = modified 505; L = left leg; R = right leg.

Table 2 Correlations between isometric strength, sprint, and change of direction speed variables.†

	5 m	10 m	20 m	505 L	505 R	505_{mod} L	505_{mod} R
IMTP PF (N·kg⁻¹)	-0.20	-0.24	-0.43	-0.49 *	-0.46	-0.31	-0.37
IMTP L PF (N·kg⁻¹)	-0.28	-0.24	-0.50 *	-0.65 **	-0.47 *	-0.34	-0.36
IMTP R PF (N·kg⁻¹)	-0.52 *	-0.49 *	-0.53 *	-0.65 **	-0.48 *	-0.43	-0.44

† IMTP = isometric mid-thigh pull; PF = peak force; 505_{mod} = modified 505; L = left leg; R = right leg.
* Correlations significant at $p \leq 0.05$.
**Correlations significant at $p \leq 0.01$.

lation coefficients showed high-to-nearly perfect reliability (ICC ≥ 0.60; CV = 1.2 – 6.4%) between trials for IMTP, sprint, and CODS measures (Table 1).

Pearson's correlations demonstrated moderate-to-large inverse correlations ($r = -0.49$ to -0.53) between IMTP R PF and sprint times. In addition, IMTP L PF showed a strong correlation with 20 m sprint performance ($r = -0.50$), whereas IMTP PF demonstrated no correlation to either 5-, 10-, or 20-m sprint performance ($r = -0.20$ to -0.43).

Left leg IMTP PF revealed moderate-to-large inverse correlations to 505 CODS on both legs (505 L: $r = -0.65$; $p = 0.001$; 505 R: $r = -0.47$; $p = 0.05$). Similarly, IMTP R PF revealed moderate-to-large inverse correlations to 505 CODS on both legs (505 L: $r = -0.65$; $p = 0.001$; 505 R: $r = -0.48$; $p = 0.05$), whereas IMTP PF demonstrated the strongest correlation with 505 L ($r = -0.49$; $p = 0.04$). Additionally, bilateral and unilateral stance IMTP PF measures did not correlate with any measure of 505_{mod} ($r = -0.31$ to -0.44).

DISCUSSION

The aim of this study was to examine the relationships between isometric strength, sprint and CODS performance measures in male academy cricketers. In line with our hypothesis, the results of this study found moderate-to-large relationships between bilateral and unilateral stance measures of IMTP PF and CODS performances ($r = -0.47$ to -0.65), whereas IMTP PF demonstrated small-to-large inverse correlations with sprint performance ($r = -0.20$ to -0.53).

In this study, IMTP PF observed no significant correlations to 5-, 10-, and 20-m sprint times. These findings are in contrast to those by West et al.[24] who found significant correlation between IMTP PF and 10-m time ($r = -0.37$) in professional rugby league players. One possible reason for the contrasting finding is the lower training history and playing level of the athletes in the current study. Additionally, it may be that PF values are secondary to impulse and time-specific force measures during short sprinting. For example, Hunter et al.[9] found velocity at 16 m to observe a strong relationship with net horizontal impulse ($r^2 = 0.61$). However, it should be noted the findings of West et al.[24] equate to a moderate correlation ($r = -0.37$), which may have been influenced by the sample size of the study, and the body mass, physique, technique, and leg strength of the subjects, thus influencing the strength and significance of the relationship. West et al.[24] found IMTP PF at 100 ms to significantly correlate to 10-m sprint performance ($r = -0.68$; $p < 0.01$). Further, Thomas et al.[21] found IMTP impulse at 100 and 300 ms to observe stronger associations to 5- and 20-m sprint performance, as compared to PF measures. These findings demonstrate the importance of the ability of to exert high forces over short periods of time, which may explain the stronger relationships to sprint performance.

The results of this study found unilateral stance IMTP R PF to significantly correlate to 5-, 10-, and 20-m sprint performance ($r = -0.49$ to -0.53), whereas IMTP L PF was demonstrated significant relationships to 20-m sprint time ($r = -0.50$). However, bilateral stance IMTP PF revealing no association to sprint performance ($r = -0.20$ to -0.43). Dynamic tasks such as sprinting, are heavily dependent on an athlete's ability to rapidly apply unilateral force over short time intervals,[9] therefore one would expect these measures to be related as 1) relationships exist between bilateral IMTP PF and sprint performance,[21,24] and 2) the direct measurement of multi-joint isometric force production capabilities replicates the unilateral stance of sprint performance. Therefore, our findings may suggest the importance of developing unilateral force production capabilities in male academy cricketers to contribute to improved sprint performance. Specifically, cricketers cover mean sprint distances of 13-18 m when fielding,[15] and 17.68 m when running between the wickets during batting; therefore during sprint acceleration it is essential to produce high amounts of force during each foot contact to overcome inertia, with the ability to accelerate at greater rates highly related to strength and force production capabilities in youth soccer athletes[1,3,25]. These results seem to be consistent with research which found increases in relative strength were accompanied by improvements in sprint performance.[1] It can thus be suggested that maximal strength and speed development should be emphasized as part of a periodized training programme, ensuring appropriate development of each component dependent on the athletes' specific needs.

In agreement with previous research,[19,21] the results of this study indicate the importance of maximal isometric strength for CODS performance. The current study found bilateral and unilateral stance IMTP PF measures to significantly correlate to 505 CODS ($r = -0.49$ to -0.65). In contrast, no IMTP PF measure was significantly correlated to 505_{mod} CODS. As the approach distance during the 505 was 15 m, this test may have resembled the activity of running between the wickets when batting (17.68 m sprint followed by a 180° turn), and in turn affected the findings. However, these findings are most likely explained by the fact that the combination of a higher approach velocity in the 505, and resultant momentum, is likely to increase braking demands, thus requiring high levels of relative maximal strength to efficiently decelerate the body. In contrast, a lower approach velocity test (505_{mod}) may exhibit stronger association to dynamic activities, with previous research demonstrating significant correlations between 505_{mod} and countermovement jump height ($r = 0.42$).[8] Therefore, the results of the current study suggest the ability to change direction quickly as when running between the wickets, is highly dependent upon an athlete's ability to absorb and produce high levels of force. Furthermore, the development of strength and its related characteristics should be developed in a periodized manner for cricketers of all levels, as recent work by Carr et al. demonstrate the demands of the competitive cricket season and current in-season training practices do not provide a sufficient stimulus to maintain strength, jump, and sprint performances in English county cricketers.[1*]

The current study found a significant, moderate correlation between IMTP L PF and 505 R ($r = -0.47$; $p = 0.05$), whereas a large, significant correlation was identified with 505 L ($r = -0.65$; $p = 0.001$). Similarly, IMTP R PF revealed moderate-to-strong relationships to 505 L than 505 R ($r = -0.65$ and -0.48, respectively). These findings indicate the importance of strength of both limbs during change of direction tasks.[5,11,17] Spiteri et al.[18] found faster CODS performers to display greater braking force compared with slower athletes during 505 CODS, in addition to spending less time braking during deceleration, and shorter ground contact times during the plant phase. Furthermore, Graham-Smith et al.[11] found that greater peak horizontal braking force at the penultimate contact (the 2nd last foot contact with the ground prior to moving into a new intended direction) was related to faster CODS turn times. The relationships elucidated in this study support the notion that maximal strength of both limbs is an important factor of CODS.

The results of the present study also suggest the unilateral stance IMTP to demonstrate high within-session reliability measures (ICC = 0.92 – 0.95; CV = 4.5 – 6.1%) for isometric PF, comparable to bilateral IMTP reliability measures also reported in the current study (ICC = 0.90; CV = 6.4%) and by previous authors.[21,22] Therefore, scientists and practitioners should consider conducting unilateral stance IMTP assessments following the same protocol implemented in this study as highly reliable measures of unilateral isometric PF are obtained to assess unilateral isometric force production capabilities.

Results of this study demonstrate IMTP PF measures are related to CODS performance in male academy cricketers. Additionally, IMTP PF demonstrated small-to-large inverse correlations with sprint performance. However, further research is warranted to investigate future profiling of isometric strength performance, and its relationship with lower-body dynamic tasks (sprinting, and changing direction) in athletes from various sporting disciplines, and of differing strength levels. Further, our data show unilateral stance IMTP PF measures to observe very high within-session reliability; however, further research is needed regarding its use in the evaluation of unilateral isometric force production capabilities to sprint and CODS performance.

CONCLUSION

Our study demonstrates the bilateral and unilateral stance IMTP to be highly reliable measurements of maximal isometric force production capabilities. The findings of this study indicate there are no significant relationships between bilateral and unilateral stance IMTP PF and 505_{mod} CODS. Furthermore, there are no significant relationships between bilateral stance IMTP PF and sprint performance. However, this study has identified bilateral and unilateral stance IMTP PF to relate to 505 CODS. Therefore, maximal strength, especially relative to body mass, should be developed within the required context of each sport/event, as identified through appropriate assessment and monitoring.

COMPLIANCE

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REFERENCES

1* Carr C, McMahon M, Comfort P. Changes in strength, power and speed across a season in English county cricketers. *Int J Sports Physiol Perform* 2016, in press.

1. Comfort P, Haigh A, Matthews MJ. Are Changes in Maximal Squat Strength During Preseason Training Reflected in Changes in Sprint Performance in Rugby League Players? *J Strength Cond Res* 2012; 26: 772-776.
2. Comfort P, Jones PA, McMahon JJ et al. Effect of knee and trunk angle on kinetic variables during the isometric midthigh pull: test-retest reliability. *Int J Sports Physiol Perform* 2015; 10: 58-63.
3. Comfort P, Stewart A, Bloom L et al. Relationships Between Strength, Sprint, and Jump Performance in Well-Trained Youth Soccer Players. *J Strength Cond Res* 2014; 28: 173-177.
4. Gabbett TJ, Kelly JN, Sheppard JM. Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res* 2008; 22: 174-181.
5. Graham-Smith P, Atkinson L, Barlow R et al. Braking characteristics and load distribution in 180 degree turns. Presented at The Proceedings of the 5th annual UKSCA conference, 2009.
6. Hopkins W. Reliability from consecutive pairs of trials (Excel spreadsheet). *A new view of statistics*, 2000.
7. Hopkins W, Marshall S, Batterham A et al. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 2009; 41: 3.
8. Hori N, Newton RU, Andrews WA et al. Does Performance of Hang Power Clean Differentiate Performance of Jumping, Sprinting, and Changing of Direction? *J Strength Cond Res* 2008; 22: 412-418.
9. Hunter JP, Marshall RN, McNair PJ. Relationships between ground reaction force impulse and kinematics of sprint-running acceleration. *J Appl Biomech* 2005; 21: 31-43.
10. Jones P, Bampouras T, Marrin K. An investigation into the physical determinants of change of direction speed. *J Sports Med Phys Fitness* 2009; 49: 97-104.
11. Jones PA, Herrington LC, Graham-Smith P. Technique determinants of knee abduction moments during pivoting in female soccer players. *Clin Biomech* 2016; 31: 107-112.
12. Nimphius S, McGuigan MR, Newton RU. Relationship Between Strength, Power, Speed, and Change of Direction Performance of Female Softball Players. *J Strength Cond Res* 2010; 24: 885-895.
13. Petersen C, Portus D, Dawson M. Quantifying positional movement patterns in Twenty20 cricket. *Int J Perform Anal Sport* 2009; 9: 165-170.
14. Petersen C, Pyne DB, Portus MR et al. Variability in movement patterns

during One Day Internationals by a cricket fast bowler. *Int J Sports Physiol Perform* 2009; 4: 278-281.
15. Petersen CJ, Pyne D, Dawson B et al. Movement patterns in cricket vary by both position and game format. *J Sports Sci* 2010; 28: 45-52.
16. Seitz LB, Reyes A, Tran TT et al. Increases in lower-body strength transfer positively to sprint performance: a systematic review with meta-analysis. *Sports Med* 2014; 44: 1693-1702.
17. Spiteri T, Cochrane JL, Hart NH et al. Effect of strength on plant foot kinetics and kinematics during a change of direction task. *Eur J Sport Sci* 2013; 13: 646-652.
18. Spiteri T, Newton RU, Binetti M et al. Mechanical Determinants of Faster Change of Direction and Agility Performance in Female Basketball Athletes. *J Strength Cond Res* 2015; 29: 2205-2214.
19. Spiteri T, Nimphius S, Hart NH et al. Contribution of Strength Characteristics to Change of Direction and Agility Performance in Female Basketball Athletes. *J Strength Cond Res* 2014; 28: 2415-2423.
20. Stone MH, Sands WA, Carlock J et al. The Importance of Isometric Maximum Strength and Peak Rate-of-Force Development in Sprint Cycling. *J Strength Cond Res* 2004; 18: 878-884.
21. Thomas C, Comfort P, Chiang C et al. Relationship between isometric mid-thigh pull variables and sprint and change of direction performance in collegiate athletes. *J Trainol* 2015; 4: 6-10.
22. Thomas C, Jones PA, Rothwell J et al. An Investigation into the Relationship between Maximum Isometric Strength and Vertical Jump Performance. *J strength Cond Res* 2015; 29: 2176-2185.
23. Tillin NA, Pain MTG, Folland J. Explosive force production during isometric squats correlates with athletic performance in rugby union players. *J Sports Sci* 2013; 31: 66-76.
24. West DJ, Owen NJ, Jones MR et al. Relationships Between Force–Time Characteristics of the Isometric Midthigh Pull and Dynamic Performance in Professional Rugby League Players. *J Strength Cond Res* 2011; 25: 3070-3075.
25. Wisloff U, Castagna C, Helgerud J et al. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 2004; 38: 285-288.
26. Yeadon M, Kato T, Kerwin D. Measuring running speed using photocells. *J Sports Sci* 1999; 17: 249-257.
27. Young WB, James R, Montgomery I. Is muscle power related to running speed with changes of direction? *J Sports Med Phys Fitness* 2002; 42: 282-288.