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# Seasonal Variation of Physical Performance and Inter-limb Asymmetry in Professional Cricket Athletes

## Abstract

The aims of the present study were to: 1) determine the seasonal variation of physical performance in professional cricket players, 2) determine the seasonal variation of inter-limb asymmetries in the same cohort of professional players. Fifteen male professional cricket players (age:  $20.60 \pm 1.59$  years; height:  $1.82 \pm 0.08$  m; body mass:  $78.70 \pm 11.23$  kg) performed unilateral countermovement jumps (CMJ), unilateral drop jumps, 10m sprints and 505 change of direction (COD) speed tests at pre (March), mid (June) and end (September) of the 2018 season. Inter-limb asymmetry was quantified in the unilateral CMJ (jump height and concentric impulse), unilateral drop jump (jump height and reactive strength index – RSI) and 505 (total time and COD deficit). Significant changes ( $p < 0.05$ ) were evident for the following tests: unilateral CMJ (ES range = 0.67 to 1.00), 505 on the right leg (ES = 0.70), 10m (ES range = -1.39 to 0.70) and COD deficit (ES range = 0.70 to 0.80), with the largest changes evident for 10m sprint. No significant differences were evident in drop jump performance throughout the season. For the magnitude of asymmetry, significant changes in jump height asymmetry from the unilateral CMJ were evident from mid to end of season (ES = 0.72). For the direction of asymmetry, levels of agreement ranged from poor to substantial in the unilateral CMJ (Kappa = -0.21 to 0.72), fair to substantial in the unilateral drop jump (Kappa range = 0.33 to 0.74) and slight to moderate during the 505 test (Kappa range = 0.06 to 0.44), with RSI showing noticeably better results than other tests or metrics. These data shows that the largest changes in performance scores throughout the season came from the 10m test, which practitioners may wish to consider implementing if not doing so already. Furthermore, both unilateral jump tests showed their use for asymmetry interpretation, which practitioners may wish to consider implementing in to their test batteries. Specifically, jump height asymmetry during the unilateral CMJ was the only metric to exhibit meaningful changes between time points, whilst RSI was the metric that exhibited more consistent limb dominance characteristics for the direction of asymmetry.

**Key Words:** Between-limb differences; change of direction; jumping; speed.

## Introduction

Cricket is a team sport which takes many formats during competition. Historically, at the international level, test cricket involves countries competing against each other over a maximum of five days, with players often required to perform for multiple hours at a time. In the last 20 years, 50-over and Twenty-Twenty (T20) cricket has been developed, offering a faster pace to the sport in these formats. Bowlers are required to deliver six balls per over, and are often required to perform multiple overs during competition. Typically, fast bowlers can release the ball in excess of 145 km/h (32), often reaching speeds up to  $6.1 \text{ m/s}^{-1}$  during the run-up prior to releasing the ball (1); thus, appropriate physical preparation for such positions seems key (13,14). For batters, an innings can last several hours with repeated sprints and  $180^\circ$  changes of direction (COD) often required between the wickets when attempting to score runs (30), highlighting that physical preparation for batters is also critical. From a fielding perspective, involvement can be sporadic over many hours; however, players are required to perform at any given moment; thus, resistance to fatigue is paramount. Furthermore, the introduction of the faster-paced 50-over and T20 formats have meant that enhanced physical capacity is even more important, in an attempt to gain a competitive advantage over opponents (24). Thus, the inclusion of fitness testing in cricket has become increasingly common and important, enabling practitioners to prepare their players for the different demands faced by each format of the sport.

When critiquing the available body of evidence in cricket, studies have often investigated physical and cricket-specific performance (12,15,21,29). However, data is predominantly conducted at single time points with little literature available relating to the seasonal variation of these physical qualities. Carr et al. (8) reported changes in power and speed in 12 English county cricket players, using the bilateral countermovement jump (CMJ) and 20m sprint performed at the start and end of pre-season, mid and end-season time points. Results showed a progressive decrease in the performance of both tests at both mid and end-season time points, compared to the end of pre-season (CMJ: pre = 44.5cm, mid = 43.5cm, end = 42.6cm; 20m: pre = 3.00s, mid = 3.07s, end = 3.12s). Herridge et al. (19) monitored changes in speed, power, agility and endurance during a 20-week off-season period in elite cricket players. A concurrent approach to physical development was employed with a combination of strength endurance, strength and power training conducted, in conjunction with aerobic endurance and speed sessions. Significant improvements were evident in countermovement jump (CMJ, effect size [ES] = 0.75), single leg CMJ (ES = 0.50-0.67), broad jump (ES = 2.33), reactive strength index

(RSI, ES = 0.83), linear speed (5m, ES = 2.80; 10m, ES = 2.50; 20m, ES = 1.68), but not agility (ES = 0.26) performance (19). Despite these data, further information relating to seasonal variation of physical qualities in cricket is scarce and requires further research to better understand the changing nature of these capacities during a competitive season.

An additional consideration under-researched in the sport of cricket relates to inter-limb asymmetry. Bowlers and batters are likely to favour using one particular side to perform their respective actions; thus, the development of inter-limb asymmetries seems likely in this sport. For example, Kountouris et al. (23) investigated the level of asymmetry in cross-sectional area (CSA) of the quadratus lumborum muscle in 23 elite fast bowlers. Sixty-five percent of the sample showed larger CSA on the dominant (bowling arm) side, with mean asymmetry of 11.5% (range = 0.3-30.7%), highlighting the vast difference in magnitude of CSA asymmetry of the quadratus lumborum muscle. A similar investigation was conducted by Gray et al. (18) who investigated the association between abdominal muscle symmetry and incidence of low back pain in fast bowlers. Interestingly, combined thickness of the internal and external obliques and transverse abdominus muscles was significantly greater ( $p = 0.02$ ) on the non-dominant side, for bowlers with no low back pain. Further to this, those bowlers who reported pain actually exhibited symmetry in combined abdominal muscle thickness; thus, highlighting that asymmetry is likely to be a functional adaptation of the sport, especially for fast bowlers. Despite the usefulness of this information, asymmetry literature relating to the lower body in cricket is scarce, especially when tracked over time. In addition, recent investigations relating to asymmetry have highlighted the importance of monitoring the 'direction of imbalance' (i.e., which limb scores better out of the two) (2,4). This provides practitioners with an understanding of limb dominance for a given task and helps to contextualise whether such data is consistent when monitored over repeated time points (4,5). However, such data for the sport of cricket does not appear to be evident.

Therefore, the aims of this exploratory study were to: 1) determine the seasonal variation of physical performance in professional cricket players, 2) determine the seasonal variation of the magnitude and direction of inter-limb asymmetries in the same cohort of professional players. It was hypothesized that the demands of a long in-season period would invoke significant changes in physical performance. However, meaningful changes in the magnitude of asymmetry have recently been shown not to occur, whilst substantial variation existed in the direction of asymmetry when tracked over time (5). Thus, it was hypothesised that the

magnitude of asymmetry would remain consistent, but levels of agreement for the direction of asymmetry would vary.

## Methods

### *Experimental Approach to the Problem*

This study used a repeated measures design in a convenience sample of professional cricket players from March to September, during the 2018 cricket season. Unilateral jump tests, linear speed and COD tests were all performed during the end of pre-season (March), mid-season (June) and end of season (September), to monitor both physical performance and jumping asymmetries. When considering the players' weekly schedule, on average, each player undertook: 2-3 competitive matches (1-2 for T20 and 1-2 for county fixtures) 2-3 on-field training sessions (consisting of technical and conditioning based activities such as sprinting and COD drills), 1-2 resistance training sessions (focusing on the maintenance of lower body strength and power). For all three time points, all testing was conducted in a randomized order, on a single day to ensure accuracy in testing, with no training or competition the day before. All athletes were previously familiarized with testing protocols as these formed part of their regular testing battery.

### *Subjects*

Fifteen male professional cricket players (age:  $20.60 \pm 1.59$  years; height:  $1.82 \pm 0.08$  m; body mass:  $78.70 \pm 11.23$  kg) from a Division 1 county club first team squad volunteered to participate in the present study. All players were contracted to the same club during the 2018 cricket season and had a minimum of five years' competitive cricket experience and a minimum of two years' structured strength and conditioning training experience. Players were required to be free from injury for at least four weeks prior to each testing session and deemed fit to participate fully in training and competition by the respective clubs' medical departments. This resulted in the removal of 4 players from the total data set. This 4-week time frame was chosen to limit the impact of any compensatory movement patterns due to previous minor muscle injuries. Further to this, no major injuries (classified as  $> 28$  days) (16) were reported for all players throughout the duration of this study, with the longest period with no training being 7 days for one player. Written informed consent was provided by all subjects and this study was approved by the [*deleted for peer review*] research and ethics committee.

## *Procedures*

All testing was conducted at the same time of day (08:00-10:00) to limit the impact of circadian rhythms (25). A standardized dynamic warm up was performed each time and consisted of a single set of 10 repetitions of multi-planar lunges, inchworms, Spiderman's and bodyweight squats, followed by three practice trials of each respective test, on each limb where applicable. Athletes were asked to perform practice trials at 60, 80 and 100% of their perceived maximal effort, with jump and COD tests practiced on both limbs. Three minutes of rest was provided between the last practice trial and the start of the first test and 60-seconds of rest was provided between trials during jump tests and 3-minutes between trials for the speed and COD tests. For jump tests, athletes performed three trials on each leg at each time point with the mean value taken from all trials on each side, and asymmetry subsequently computed thereafter. Given asymmetry has been shown to be a variable concept (2,4,5), averaging data was deemed appropriate in order to capture some of the variability that may have existed between trials.

*Unilateral Countermovement Jump.* Subjects were instructed to step onto the centre of a single uniaxial force platform (size: 0.42 x 0.42 m; PASPORT force plate, PASCO Scientific, California, USA) sampling at 1000 Hz, with their designated test leg. Hands were placed on hips and were required to remain in the same position throughout the duration of the test. Test instructions were the same at each time point with athletes asked to "jump as high as you can". The jump was initiated by performing a countermovement to a self-selected depth (which was reinforced verbally to the players during practice trials) before accelerating vertically as fast as possible into the air. The test leg was required to remain fully extended throughout the flight phase of the jump before landing back onto the force plate as per the set up. The non-jumping leg was slightly flexed with the foot hovering at mid-shin level, and no additional swinging of this leg was allowed during trials. Recorded metrics included jump height and concentric impulse, with definitions for their quantification conducted in line with suggestions by Gathercole et al. (17) and Chavda et al. (9). Jump height was defined as the maximum height achieved calculated from velocity at take-off squared divided by  $2*9.81$  (where 9.81 equals gravitational force). Concentric impulse was defined as the net force (where net force was calculated by subtracting body weight from vertical force) multiplied by the time taken to produce it; i.e., the area under the net force-time curve. The first meaningful change in force was established when values surpassed  $\pm$  five standard deviations (SD) of each participant's body weight, minus 30 milliseconds to ensure velocity was at zero (27). The force plate was

calibrated prior to each data collection and all force traces were extracted unfiltered, and subsequently copied into a custom-made spreadsheet previously suggested (9). These two metrics were chosen for different reasons. Firstly, jump height is typically the metric that all athletes and technical coaches are interested in and provides a clear understanding of the outcome measure for unilateral vertical jumping. In contrast, this provides no clear understanding of jump strategy, a concept which previous research has shown may be more sensitive at detecting true change between test sessions (17). Consequently, concentric impulse was selected as an additional metric of interest, which has been reported in recent unilateral jump investigations (2,5).

*Unilateral Drop Jump.* The unilateral DJ was performed using the OptoJump™ measurement system (Microgate, Bolzano, Italy), with all athletes required to step off an 18 cm box. This height was chosen in line with previous research using this test (4,5,25). With hands fixed on hips, subjects were required to step off the box with their designated test leg which subsequently landed on the hard rubber flooring between the optimal measurement system below. Upon landing, subjects were instructed to “minimize ground contact time and jump as high as possible” thereafter in line with previous suggestions (4,5,25). Recorded metrics included jump height (calculated from the flight time method) and reactive strength index (RSI), quantified using the equation flight time/ground contact time (4,5,25). Similar to the unilateral CMJ, jump height was selected for ease of understanding and interpretation for technical coaches and athletes. In addition, numerous studies have used drop jumps to measure and report RSI (3,4,5,19,25), which provides an understanding of how high an athlete can jump in as short a time as possible. Thus, RSI also provides more information about an athlete’s jump strategy during this task.

*10 m sprint test.* Dual beam electronic timing gates (Brower Timing Systems, Utah, USA) were positioned at 0 and 10 m, at a height of 1 m, enabling athlete’s acceleration to be measured. Athletes started the test in a staggered 2-point stance with toes positioned 0.3 m behind the start line so as to not break the beam of the timing gates prior to the initiation of the test. When ready, subjects sprinted through the timing gates as fast as they could allowing time to be recorded to the nearest hundredth of a second. Three trials were performed on an outdoor grass



cricket pitch with a mean of three trials used at each time point for further analysis. All players performed sprints and 505 tests in the same footwear used during competitive matches.

*505 change of direction speed test.* A distance of 15 m was measured with electronic timing gates (Brower Timing Systems, Utah, USA) positioned at the 10 m mark and the 15 m point marked out by an existing white line on the pitch, to ensure that players could clearly see the turning point, as they approached. Players sprinted 15 m and then performed a 180° turn. Each player completed six trials (three turning off the right leg and three turning off the left leg) with a consistent turning direction being maintained for three trials in a row, but with the initial direction being randomly allocated at each test session. The time started when players broke the electronic beam at the 10 m mark and after turning 180°, subsequently sprinted back through the timing gates to complete a recorded distance of 10 m. Trials were only deemed successful if the players' foot fully crossed the line during the turn. The mean of three trials were used on each limb at each time point for subsequent data analysis. The change of direction deficit was also calculated for left and right sides, by subtracting the 10 m linear sprint time from the 505 times. In line with previous suggestions, this provided a better indication of each player's change of direction ability (26).

### *Statistical Analyses*

All data were initially recorded as means and standard deviation (SD) in Microsoft Excel and later transferred to SPSS (version 25.0; SPSS, Inc., Armonk, NY, USA). Normality was assessed using the Shapiro-Wilk test and showed asymmetry data to be non-normally distributed ( $p < 0.05$ ), whilst test scores were normally distributed. Within-session reliability data was computed at each time point using an average measures two-way random intraclass correlation coefficient (ICC) with absolute agreement and 95% confidence intervals, and the coefficient of variation (CV). Interpretation of ICC values was in accordance with previous research by Koo and Li (22) where values  $> 0.9$  = excellent,  $0.75-0.9$  = good,  $0.5-0.75$  = moderate, and  $< 0.5$  = poor. The CV was calculated via the formula:  $(SD[\text{trials } 1-3]/\text{average}[\text{trials } 1-3]*100)$  with values  $\leq 10\%$  suggested to be considered acceptable (11).

A repeated measures ANOVA was conducted to determine differences in test scores and a Friedmans ANOVA to determine differences in asymmetry scores between time points for all

metrics, with statistical significance set at  $p < 0.05$ . The magnitude of change was calculated between time points using Cohen's  $d$  effect sizes (ES) with 95% confidence intervals using the formula:  $(\text{Mean}_{T1} - \text{Mean}_{T2}) / \text{SD}_{\text{pooled}}$ , where T1 and T2 represent the respective time points in question (e.g., pre, mid or end-season). These were interpreted in line with Hopkins et al. (20) where  $< 0.2 =$  trivial;  $0.2-0.6 =$  small;  $0.6-1.2 =$  moderate;  $1.2-2.0 =$  large;  $2.0-4.0 =$  very large; and  $> 4.0 =$  near perfect.

Mean inter-limb asymmetries were computed from jump tests using a standard percentage difference equation for both jump tests:  $100 / (\text{max value}) * (\text{min value}) * -1 + 100$ , which has been suggested to be accurate for the quantification of asymmetries from unilateral tests (2,6). In order to determine the direction of asymmetry (which provided an indication of limb dominance), an 'IF function' was added on to the end of the formula in Microsoft Excel:  $*\text{IF}(\text{left} < \text{right}, 1, -1)$  (2,4,5). Kappa coefficients were calculated to determine the levels of agreement for how consistently an asymmetry favoured the same side (direction of asymmetry) when comparing the different time points measured. This method was chosen because the Kappa coefficient describes the proportion of agreement between two methods after any agreement by chance has been removed (10). Kappa values were interpreted in line with suggestions from Viera and Garrett (31), where  $\leq 0 =$  poor,  $0.01-0.20 =$  slight,  $0.21-0.40 =$  fair,  $0.41-0.60 =$  moderate,  $0.61-0.80 =$  substantial, and  $0.81-0.99 =$  almost perfect. Given that asymmetry is a ratio number (i.e., calculated as a percentage from left and right scores), use of the Kappa coefficient serves as an alternative statistical method to more traditional methods of reliability (e.g., coefficient of variation and intraclass correlation coefficient), as it is able to account for consistency in the direction of asymmetry, something which traditional measures cannot accomplish when using the absolute percentage value.

## Results

Table 1 shows absolute (CV) and relative (ICC) reliability data for all tests at each individual time point. All CV values were acceptable at each time point (< 10%) and ICC's ranged from moderate to excellent in pre-season (0.72-0.96), moderate to good at mid-season (0.72-0.89) and moderate to excellent at the end of season (0.71-0.93).

Table 2 shows mean and SD for all tests at each time point. For the unilateral CMJ, significant reductions were evident in jump height on the left leg between pre and mid-season (ES = 1.00) and pre and end-season (ES = 0.67) time points. Concentric impulse showed a significant reduction from pre to mid-season (ES = 0.69), for the left leg. For linear speed, the 10m sprint time showed meaningful changes between each time point, getting significantly slower from pre to mid-season (ES = -1.39) and from pre to end-season (ES = -0.86), but significantly faster from mid to end-season (ES = 0.70). For COD speed, significant differences were evident for total time on the right leg between mid and end-season (ES = 0.70). For the change of direction deficit, the right leg also showed significant differences between pre and mid-season (ES = 0.74) and pre and end-season (ES = 0.70), and between pre and mid-season (ES = 0.80) on the left leg. No other significant differences were evident throughout the season.

Table 3 shows mean inter-limb asymmetry data for jump and COD tests throughout the season. The only significant difference was for jump height during the unilateral CMJ between mid and end-season, corresponding to a moderate ES (0.72). All other changes were non-significant. Table 4 shows the Kappa coefficients for the direction of asymmetry. Levels of agreement ranged from poor to substantial for the unilateral CMJ (Kappa = -0.21 to 0.72), fair to substantial for the unilateral drop jump (Kappa = 0.33 to 0.74) and slight to moderate for COD speed metrics (Kappa = 0.06 to 0.44). Given the inherent variability evident in the direction of asymmetry across all tests, individual asymmetry data has been presented in Figures 1-3.

Table 1 Within-session reliability data (i.e., calculated between three repetitions) using the coefficient of variation (CV) and intraclass correlation coefficients (ICC) with 95% confidence intervals (CI) for all test measures at pre, mid and end of season.

<i>Fitness Test</i>	<b>Pre-season</b>		<b>Mid-season</b>		<b>End-season</b>	
	<i>CV (%)</i>	<i>ICC (95% CI)</i>	<i>CV (%)</i>	<i>ICC (95% CI)</i>	<i>CV (%)</i>	<i>ICC (95% CI)</i>
<i>UCMJ:</i>						
Jump height-L	8.0	0.87 (0.74, 0.94)	7.8	0.81 (0.63, 0.91)	8.4	0.79 (0.60, 0.91)
Jump height-R	7.8	0.83 (0.66, 0.92)	8.7	0.83 (0.67, 0.92)	8.1	0.86 (0.71, 0.94)
CON impulse-L	4.7	0.96 (0.92, 0.98)	7.7	0.78 (0.59, 0.90)	9.0	0.74 (0.53, 0.88)
CON impulse-R	6.0	0.90 (0.80, 0.96)	8.1	0.89 (0.77, 0.95)	9.6	0.76 (0.55, 0.89)
<i>UDJ:</i>						
Jump height-L	8.6	0.89 (0.77, 0.95)	8.8	0.84 (0.68, 0.93)	7.3	0.89 (0.78, 0.95)
Jump height-R	9.7	0.81 (0.64, 0.92)	8.5	0.89 (0.78, 0.95)	6.4	0.93 (0.86, 0.97)
RSI-L	5.2	0.88 (0.76, 0.95)	4.6	0.85 (0.70, 0.93)	4.7	0.85 (0.71, 0.93)
RSI-R	5.5	0.75 (0.53, 0.88)	6.8	0.80 (0.61, 0.91)	4.4	0.89 (0.78, 0.95)
<i>COD and Linear Speed:</i>						
505-L	2.4	0.74 (0.53, 0.88)	1.9	0.77 (0.56, 0.89)	1.9	0.82 (0.66, 0.92)
505-R	1.9	0.88 (0.75, 0.95)	2.6	0.81 (0.60, 0.90)	1.6	0.76 (0.55, 0.89)
10m	2.3	0.72 (0.49, 0.87)	2.6	0.72 (0.49, 0.87)	2.3	0.71 (0.48, 0.95)

UCMJ = unilateral countermovement jump; L = left; R = right; CON = concentric; UDJ = unilateral drop jump; RSI = reactive strength index; COD = change of direction; m = metres.

Table 2 Mean and standard deviation (SD) data, and Cohen's *d* effect sizes with 95% confidence intervals (CI) between time points.

<i>Fitness Test</i>	<b>Mean ± SD</b>			<b>Cohen's <i>d</i> (95% CI)</b>		
	<i>Pre-season</i> ( <i>March</i> )	<i>Mid-season</i> ( <i>June</i> )	<i>End-season</i> ( <i>September</i> )	<i>Pre-Mid</i>	<i>Pre-End</i>	<i>Mid-End</i>
<i>UCMJ:</i>						
Jump height-L (m)	0.19 ± 0.03	0.16 ± 0.03	0.17 ± 0.03	<b>-1.00 (-1.61, -0.34)</b>	<b>-0.67 (-1.26, -0.03)</b>	0.33 (-0.28, 0.93)
Jump height-R (m)	0.18 ± 0.03	0.17 ± 0.03	0.17 ± 0.04	-0.33 (-0.93, 0.28)	-0.28 (-0.88, 0.33)	0.00 (-0.60, 0.60)
CON impulse-L (N·s)	137.8 ± 27.5	121.2 ± 19.7	125.8 ± 20.9	<b>-0.69 (-1.29, -0.06)</b>	-0.49 (-1.09, 0.13)	0.23 (-0.38, 0.82)
CON impulse-R (N·s)	137.5 ± 26.0	123.2 ± 21.1	126.2 ± 22.2	-0.60 (-1.20, 0.03)	-0.47 (-1.06, 0.15)	0.14 (-0.46, 0.74)
<i>UDJ:</i>						
Jump height-L (m)	0.18 ± 0.04	0.18 ± 0.04	0.18 ± 0.03	0.00 (-0.60, 0.60)	0.00 (-0.60, 0.60)	0.00 (-0.60, 0.60)
Jump height-R (m)	0.18 ± 0.03	0.17 ± 0.04	0.19 ± 0.04	-0.28 (-0.88, 0.33)	0.28 (-0.33, 0.88)	0.50 (-0.12, 1.10)
RSI-L	1.33 ± 0.15	1.32 ± 0.18	1.36 ± 0.17	-0.06 (-0.66, 0.54)	0.19 (-0.42, 0.78)	0.23 (-0.38, 0.82)
RSI-R	1.28 ± 0.15	1.27 ± 0.18	1.32 ± 0.17	-0.06 (-0.66, 0.54)	0.25 (-0.36, 0.85)	0.29 (-0.33, 0.88)
<i>COD and Linear Speed:</i>						
505-L (s)	2.24 ± 0.10	2.29 ± 0.09	2.25 ± 0.11	-0.53 (-1.12, 0.10)	-0.10 (-0.69, 0.51)	0.40 (-0.22, 0.99)
505-R (s)	2.23 ± 0.12	2.29 ± 0.10	2.23 ± 0.07	-0.54 (-1.14, 0.08)	0.00 (-0.60, 0.60)	<b>0.70 (0.06, 1.29)</b>
10m (s)	1.78 ± 0.07	1.90 ± 0.10	1.84 ± 0.07	<b>-1.39 (-2.02, -0.69)</b>	<b>-0.86 (-1.46, -0.21)</b>	<b>0.70 (0.06, 1.29)</b>
CODD-L	0.45 ± 0.08	0.39 ± 0.07	0.40 ± 0.12	<b>0.80 (0.15, 1.40)</b>	0.49 (-0.13, 1.09)	-0.10 (-0.70, 0.50)
CODD-R	0.45 ± 0.09	0.38 ± 0.10	0.39 ± 0.08	<b>0.74 (0.10, 1.34)</b>	<b>0.70 (0.07, 1.30)</b>	-0.11 (-0.71, 0.49)

N.B: Effect sizes in bold indicate significant difference ( $p < 0.05$ ).

UCMJ = unilateral countermovement jump; L = left; R = right; m = metres; N·s = Newton seconds; CON = concentric; UDJ = unilateral drop jump; RSI = reactive strength index; COD = change of direction; s = seconds; CODD = change of direction deficit.

Table 3 Mean inter-limb asymmetry and standard deviation (SD) data for each time point.

<i>Asymmetry Metric (%)</i>	<b>Mean ± SD</b>			<b>Cohen's <i>d</i> (95% CI)</b>		
	<i>Pre-season (March)</i>	<i>Mid-season (June)</i>	<i>End-season (September)</i>	<i>Pre-Mid</i>	<i>Pre-End</i>	<i>Mid-End</i>
<i>UCMJ:</i>						
Jump height	7.5 ± 4.7	8.3 ± 4.1	5.7 ± 2.9	0.19 (-0.42, 0.78)	-0.45 (-1.04, 0.17)	<b>-0.72 (-1.32, -0.09)</b>
CON impulse	5.2 ± 3.6	5.4 ± 3.7	8.3 ± 6.5	0.05 (-0.55, 0.65)	0.58 (-0.05, 1.18)	0.55 (-0.08, 1.14)
<i>UDJ:</i>						
Jump height	10.2 ± 5.8	7.5 ± 4.9	9.8 ± 4.8	-0.51 (-1.11, 0.11)	-0.08 (-0.68, 0.52)	0.48 (-0.15, 1.07)
RSI	9.4 ± 5.7	8.2 ± 6.3	7.0 ± 5.3	-0.20 (-0.80, 0.41)	-0.43 (-1.03, 0.18)	-0.21 (-0.80, 0.40)
<i>COD Speed:</i>						
505	2.2 ± 1.5	2.2 ± 1.1	2.8 ± 2.4	0.00 (-0.60, 0.60)	0.34 (-0.28, 0.93)	0.37 (-0.25, 0.96)
CODD	10.0 ± 6.8	12.3 ± 6.3	15.1 ± 10.8	0.36 (-0.25, 0.96)	0.57 (-0.06, 1.17)	0.32 (-0.30, 0.91)

N.B: Effect sizes in bold indicate significant difference ( $p < 0.05$ ).

UCMJ = unilateral countermovement jump; CON = concentric; UDJ = unilateral drop jump; RSI = reactive strength index; COD = change of direction;

CODD = change of direction deficit.

Table 4 Kappa coefficients and accompanying descriptors for the direction of asymmetry between time points, showing levels of agreement in limb dominance.

<b>Asymmetry Metric</b>	<b>Pre-Mid</b>	<b>Pre-End</b>	<b>Mid-End</b>
<i>UCMJ:</i>			
Jump height	-0.21 (Poor)	0.04 (Slight)	0.41 (Moderate)
Concentric impulse	0.36 (Fair)	0.10 (Slight)	0.72 (Substantial)
<i>UDJ:</i>			
Jump height	0.34 (Fair)	0.34 (Fair)	0.33 (Fair)
Reactive strength index	0.47 (Moderate)	0.72 (Substantial)	0.74 (Substantial)
<i>COD Speed:</i>			
505 & CODD	0.44 (Moderate)	0.06 (Slight)	0.33 (Fair)
UCMJ = unilateral countermovement jump; CON = concentric; UDJ = unilateral drop jump; RSI = reactive strength index; COD = change of direction; CODD = change of direction deficit.			

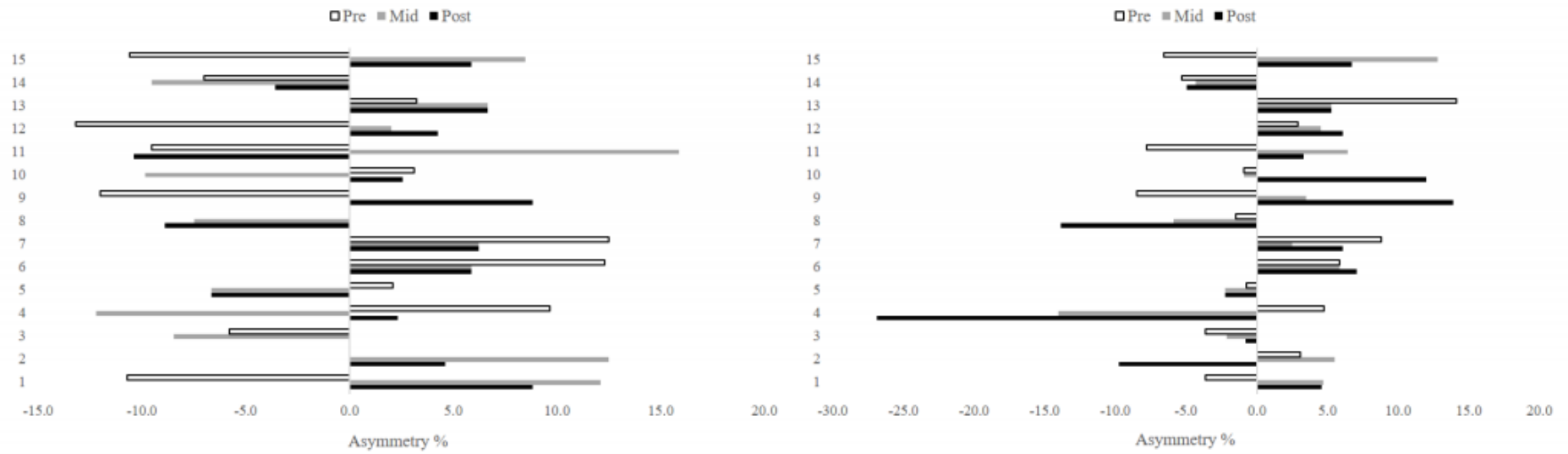


Figure 1 Individual asymmetry values for jump height (left) and concentric impulse (right) during the unilateral countermovement jump test at pre, mid and end of season. N.B: to the right of 0 indicates right limb dominance and to the left of 0 indicates left limb dominance.



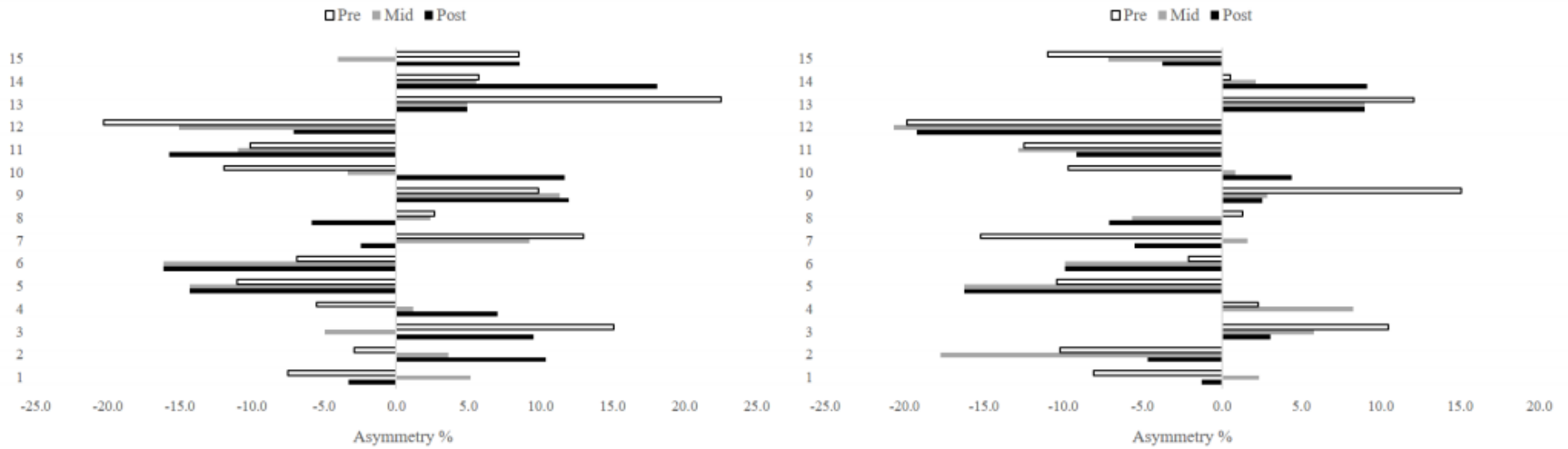


Figure 2 . Individual asymmetry values for jump height (left) and reactive strength index (right) during the unilateral drop jump test at pre, mid and end of season. N.B: to the right of 0 indicates right limb dominance and to the left of 0 indicates left limb dominance.

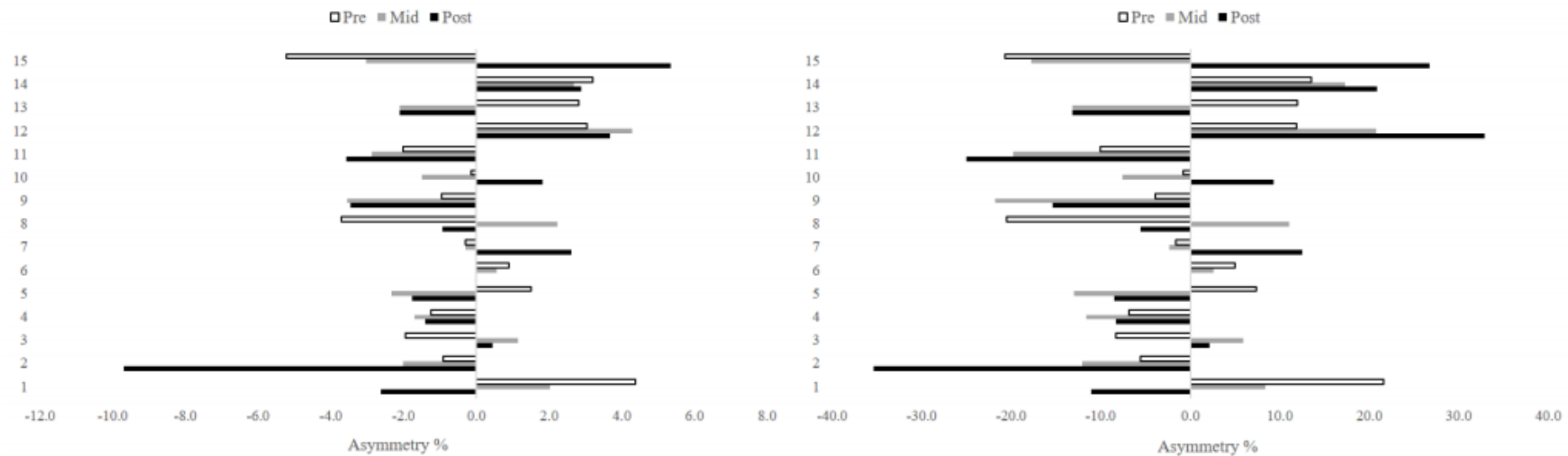


Figure 3 Individual asymmetry values for total time (left) and change of direction deficit (right) during the 505 test at pre, mid and end of season. N.B: to the right of 0 indicates right limb dominance and to the left of 0 indicates left limb dominance.

## Discussion

The main aims of the present study were to: 1) determine the seasonal variation of physical performance in professional cricket players, 2) determine the seasonal variation of inter-limb asymmetries in the same cohort of professional players. Significant differences were evident throughout the season in unilateral CMJ, linear and COD speed metrics, with the largest variation seen for 10m sprint time. The magnitude of asymmetry was largely consistent throughout the season; however, the direction of asymmetry was highly variable, regardless of test or metric reported. This study highlights that jump, linear and COD speed tests were able to detect changes in performance throughout a competitive cricket season and how the direction of asymmetry may be a more appropriate line of investigation for understanding the associated variation in existing side-to-side differences, compared to the magnitude alone.

When considering the first aim in the present study, 10m sprint times demonstrated the largest seasonal variation of all tests and is in part agreement with previous research (8). Carr et al. (8) showed consistent reductions in sprint times throughout a competitive season, whereas the present sample showed a reduction from pre to mid-season ( $ES = -1.39$ ) but were able to improve 10m sprint performance from mid to end of season ( $ES = 0.70$ ). Providing a true reasoning for the reduction in performance during mid-season is somewhat challenging; however, fixture density was slightly higher in the middle of the season, as all domestic cup competitions had started in addition to the usual league schedule, which may have had a detrimental effect on acceleration performance. This is a concept which has also been noted in other team sports, such as soccer (7). Additional significant differences were noted for the unilateral CMJ from pre to mid-season ( $ES = 0.67$  to  $1.00$ ) and for 505 times ( $ES = 0.70$ ) from mid to end-season. When viewing the data collectively in Table 2, it is evident that any meaningful differences were a result of performance being worse at the mid-season time point, for all tests. Furthermore, when the fixture list of the present sample was considered around mid-season, it was clear to see that the players were involved in multiple formats (e.g., county championship and T20 competitions) and had an increase in the number of matches compared to earlier in the season. Whilst other tests and metrics only experienced significant differences between two time points, the 10m test showed significant differences at each time point, with a large reduction in performance (i.e., slower speeds;  $ES = -1.39$ ) between pre and mid-season. Given the increased volume of matches in mid-season, this will have also resulted in reduced time for training, which in turn, would have impacted the ability for players to maintain their pre-season acceleration performance. Interestingly, the unilateral drop jump showed no

meaningful differences between time points, indicating a somewhat lack of sensitivity in this test to detect changes in test scores throughout the season.

When considering the second aim, the magnitude of asymmetry remained largely consistent for all tests and metrics throughout the season, with only a moderate reduction in asymmetry between mid to end-season for CMJ height (ES = 0.72). A recent study by Bishop et al. (5) found similar results with no significant differences in jump asymmetry across a competitive season in elite academy soccer players. In fact, this study suggested that the mean asymmetry values may provide a “false impression of consistent scores over time” and something similar could be concluded in the present study. Table 3 highlights very large SD relative to the mean (always > 50%), which likely precluded meaningful differences from often being found. This is supported by all ES values (with the exception of one) being trivial to small (ES range = - 0.58 to 0.51). Thus, it appears that the magnitude of asymmetry may not be the most viable measure when aiming to comprehend the inherent variability that accompanies mean asymmetry values (2,4,5).

In addition to the magnitude, the present study also established levels of agreement for the direction of asymmetry. The Kappa coefficient provides an understanding of the proportion of agreement between two time points, once any agreement by chance has been removed (10). Put simply, if an athlete favoured their right limb at one time point, it enabled us to statistically quantify whether the same limb was favoured at another time point and has been used in multiple studies pertaining to asymmetry recently (2,3,4,5). This study showed that almost all tests exhibited large amounts of variability in the direction of asymmetry throughout the season, as shown by poor to moderate levels of agreement, and is in agreement with recent studies using the same form of analysis for asymmetry (3,5). Interestingly though, Kappa values for the unilateral drop jump (especially reactive strength) were noticeably better than other tests, and examination of Figure 2 shows that 73% of the cohort maintained a consistent direction of limb dominance across the season. This has also been found in a recent study using basketball athletes, which determined the consistency of asymmetry in a test-retest design using smartphone apps (3). The direction of asymmetry for jump height (unilateral CMJ) and the 505 COD test, showed Kappa values of 0.29 and 0.18, respectively. However, the unilateral drop jump exhibited a Kappa value of 0.72, suggesting that the direction of asymmetry was largely consistent between test sessions. Similar findings were found in the present study when tracked over time, which may suggest that the unilateral drop jump is a useful test for monitoring consistency in limb dominance (and the direction of asymmetry) throughout a competitive

season. Although challenging to fully explain, previous research has highlighted that the drop jump is a more technically demanding task than the CMJ (28) and exhibits larger stiffness asymmetries than repeated hopping (25). Thus, the increased complexity and likely increased forces experienced during drop jumps compared to other jump tasks, may make it harder task for athlete's to manipulate their jump strategy. In turn, this may result in more consistent limb dominance characteristics, when measured between test sessions. It should be noted that this suggestion is only based off the present study and one other (3); thus, further research is likely needed to fully corroborate this theory.

There are a number of limitations to the present study which must be acknowledged. Firstly, the sample size was small and results can only be attributed to the present cricket club. Second, with the present study largely being observational in nature, a more detailed analysis of workload data was not available for the present study; thus, changes in performance or asymmetry scores are challenging to fully understand. Future research should aim to establish internal and external workload data, which may provide a more meaningful understanding of why certain tests are more sensitive to change than others. Related to this, our data analysis involved averaging scores prior to any subsequent analyses that were conducted. Although this method has been used in previous research (4,5,25), such initial analysis prevents inter-day reliability from being calculated in the present study design. This must be acknowledged as limitation because it prevents changes in our data from being interpreted within the context of inter-day variability. In essence, future research should not only aim to establish whether significant changes are evident for the selected tests, but to also determine whether such changes are greater than the associated error in the tests themselves. Finally, prospective research studies which aim to determine whether larger inter-limb differences are associated with an increased risk of injury would also be a useful line of investigation, especially in a sport where such limb differences are expected.

## **Practical Applications**

There are two key findings from the present study which may enhance practitioners' day-to-day practice. Firstly, the 10m sprint test showed large changes in time throughout the season, so if practitioners are not implementing this test already, it could be worth doing so, as it appears to be a useful performance marker for monitoring change in professional cricket athletes, especially during times of congested fixtures. Secondly, the magnitude of asymmetry does not seem to differ much between the unilateral CMJ and drop jump tests. However, the direction of asymmetry appears more consistent for the unilateral drop jump test, specifically, RSI; thus, it is suggested that the unilateral drop jump can also be implemented for monitoring asymmetry. That said, practitioners should be mindful of the higher forces experienced during the unilateral version of this test and modify the box height from which athletes start on, to ensure appropriate technique is adhered to for such an advanced test.

## References

1. Bartlett R, Stockill N, Elliott B and Burnett A. The biomechanics of fast bowling in men's cricket: A review. *J Sports Sci* 14: 403-424, 1996.
2. Bishop C, Lake J, Loturco I, Papadopoulos K, Turner A and Read P. Interlimb asymmetries: The need for an individual approach to data analysis. *J Strength Cond Res* (Published ahead of print).
3. Bishop C, Perez-Higueras M, Gullon I, Maloney S and Balsalobre-Fernandez C. Jump and change of direction speed asymmetry using smartphone apps: Between-session consistency and associations with physical performance. *J Strength Cond Res* (Published ahead of print).
4. Bishop C, Read P, Chavda S, Jarvis P and Turner A. Using unilateral strength, power and reactive strength tests to detect the magnitude and direction of asymmetry: A test-retest design. *Sports* 7: 58-71, 2019.
5. Bishop C, Read P, Chavda S, Jarvis P, Brazier J, Bromley T and Turner A. Magnitude or direction? Seasonal variation of interlimb asymmetry in elite academy soccer players. *J Strength Cond Res* (Published ahead of print).
6. Bishop C, Read P, Lake J, Chavda S and Turner A. Inter-limb asymmetries: Understanding how to calculate differences from bilateral and unilateral tests. *Strength Cond J* 40: 1-6, 2018.
7. Carling C, Le Gall F and Dupont G. Are physical performance and injury risk in a professional soccer team in match-play affected over a prolonged period of fixture congestion? *Int J Sports Med* 33: 36-42, 2012.
8. Carr C, McMahon J and Comfort P. Changes in strength, power, and speed across a season in English county cricketers. *Int J Sports Physiol Perform* 12: 50-55, 2015.
9. Chavda S, Bromley T, Jarvis P, Williams S, Bishop C, Turner A, Lake J and Mundy P. Force-time characteristics of the countermovement jump: Analyzing the curve in Excel. *Strength Cond J* 40: 67-77, 2018.
10. Cohen J. A coefficient of agreement for nominal scales. *Educ Psych Meas* 20: 37-46, 1960.
11. Cormack S, Newton R, McGuigan M and Doyle T. Reliability of measures obtained during single and repeated countermovement jumps. *Int J Sports Physiol Perform* 3: 131-144, 2008.
12. Duffield R and Portus M. Comparison of three types of full-body compression garments on throwing and repeat sprint performance in cricket players. *Brit J Sports Med* 41: 409-414, 2007.
13. Feros S, Young W and O'Brien B. Efficacy of combined general, special, and specific resistance training on pace bowling skill in club-standard cricketers. *J Strength Cond Res* (Published ahead of print).
14. Feros S, Young W and O'Brien B. Relationship between selected physical qualities, bowling kinematics, and pace bowling skill in club-standard cricketers. *J Strength Cond Res* 33: 2812-2825, 2018.

15. Foden M, Astley S, Comfort P, McMahon J, Matthews M and Jones P. Relationships between speed, change of direction and jump performance with cricket specific speed tests in male academy cricketers. *J Trainology* 4: 37-42, 2015.
16. Fuller C, Ekstrand J, Junge A, Andersen T, Bahr R, Dvorak J, Hagglund M, CcCroy P and Meeuwisse W. Consensus statement on injury definitions and data collection procedures in studies of football (soccer) injuries. *Scand J Med Sci Sport* 16: 83-92, 2006.
17. Gathercole R, Sporer B, Stellingwerff T and Sleivert G. Alternative countermovement jump analysis to quantify acute neuromuscular fatigue. *Int J Sports Physiol Perform* 10: 84-92, 2015.
18. Gray J, Aginsky K, Derman W, Vaughan C and Hodges P. Symmetry, not asymmetry, of abdominal muscle morphology is associated with low back pain in cricket fast bowlers. *J Sci Med Sport* 19: 222-226, 2016.
19. Herridge R, Turner A and Bishop C. Monitoring changes in power, speed, agility and endurance in elite cricketers during the off-season. *J Strength Cond Res* (Published ahead of print).
20. Hopkins W, Marshall S, Batterham A and Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sports Exerc* 41: 3-13, 2009.
21. Houghton L and Dawson B. Short report: Recovery of jump performance after a simulated cricket batting innings. *J Sports Sci* 30: 1069-1072, 2012.
22. Koo T and Li M. A guideline of selecting and reporting intraclass correlation coefficients for reliability research. *J Chiro Med* 15: 155-163, 2016.
23. Kountouris A, Portus M and Cook J. Cricket fast bowlers without low back pain have larger quadratus lumborum asymmetry than injured bowlers. *Clin J Sports Med* 23: 300-304, 2013.
24. MacDonald D, Cronin J and Macadam P. Key match activities of different fielding positions and categories in one-day international cricket. *Int J Perform Anal Sport* 18: 609-621, 2018.
25. Maloney S, Fletcher I and Richards J. A comparison of methods to determine bilateral asymmetries in vertical leg stiffness. *J Sports Sci* 34: 829-835, 2016.
26. Nimphius S, Callaghan S, Spiteri T and Lockie R. Change of direction deficit: A more isolated measure of change of direction performance than total 505 time. *J Strength Cond Res* 30: 3024-3032, 2016.
27. Owen N, Watkins J, Kilduff L, Bevan H and Bennett M. Development of a criterion method to determine peak mechanical power output in a countermovement jump. *J Strength Cond Res* 28: 1552-1558, 2014.
28. Pedley J, Lloyd R, Read P, Moore I and Oliver J. Drop jump: A technical model for scientific application. *Strength Cond J* 39: 36-44, 2017.
29. Portus M, Sinclair P, Burke S, Moore D and Farhart P. Cricket fast bowling performance and technique and the influence of selected physical factors during an 8-over spell. *J Sports Sci* 18: 999-1011, 2000.
30. Stretch R, Bartlett R and Davids K. A review of batting in men's cricket. *J Sports Sci* 18: 931-949, 2000.

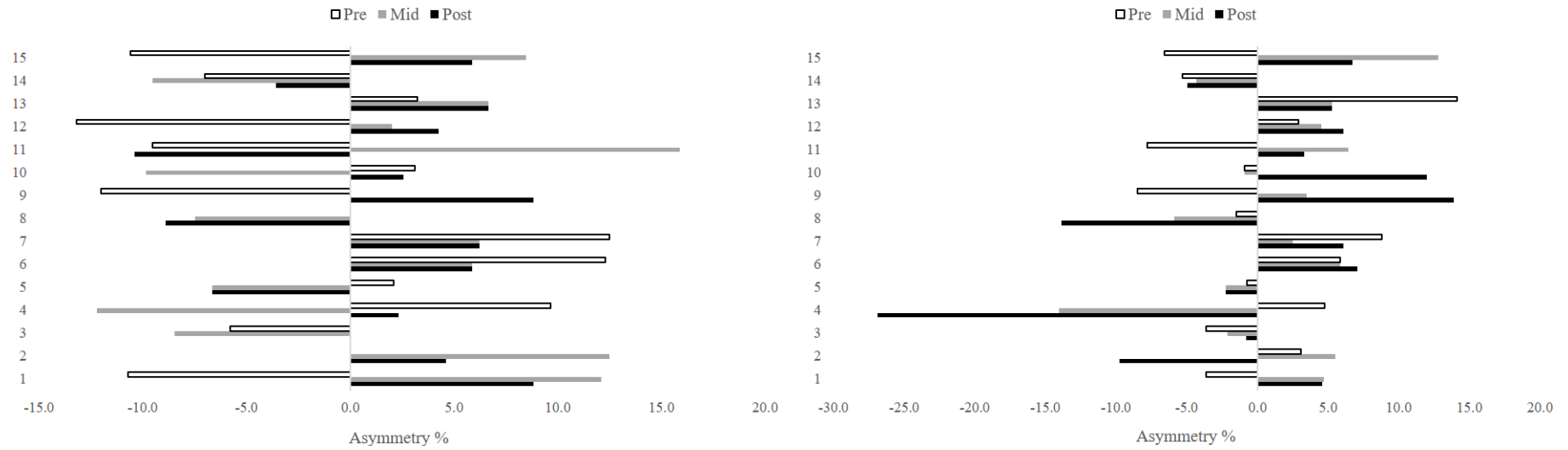


31. Viera A and Garrett J. Understanding the interobserver agreement: The kappa statistic. *Family Med* 37: 360-363, 2005.
32. Worthington P, King M and Ranson C. Relationships between fast bowling technique and ball release speed in cricket. *J Appl Biomech* 29: 78-84, 2013.

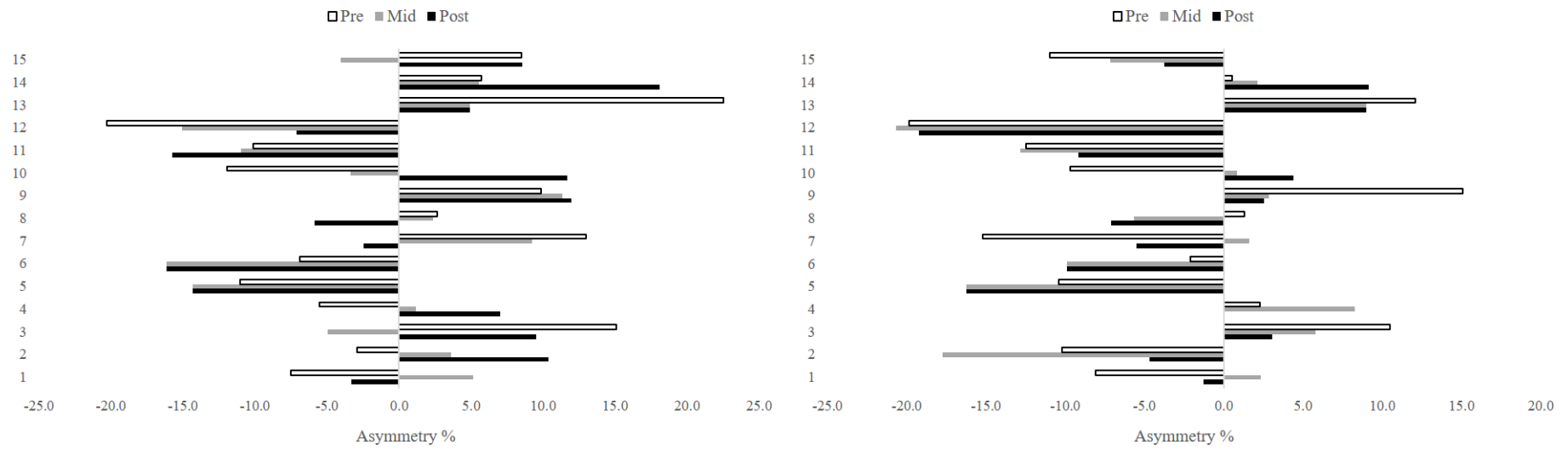
**Table 2.**

**Table 3.**

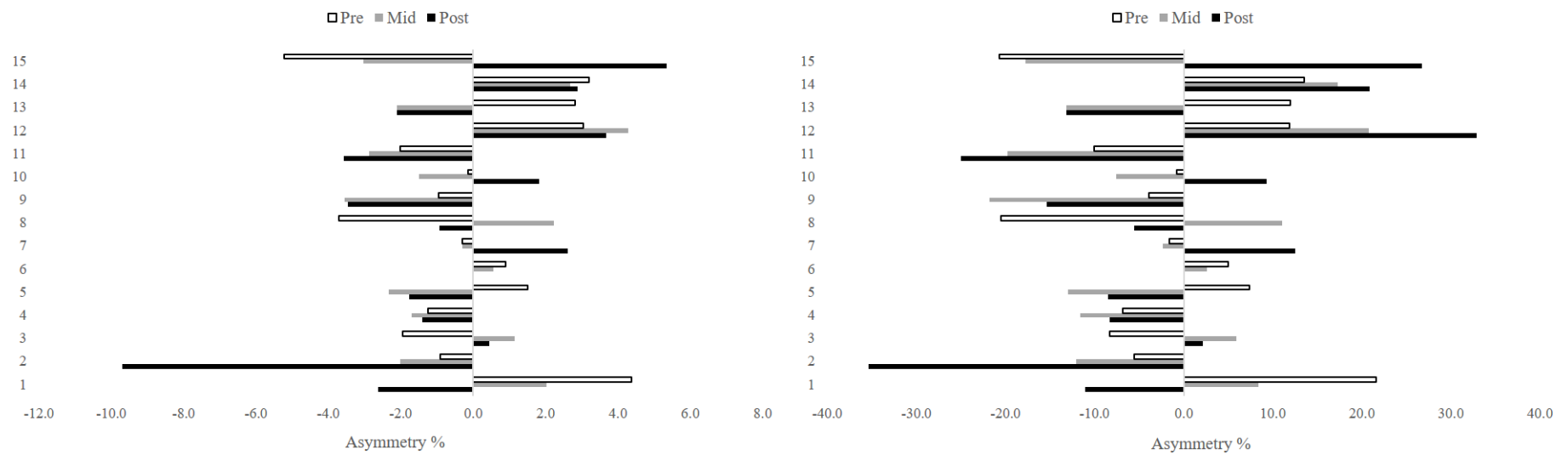
**Table 4.**



**Figure 1.**



**Figure 2**



**Figure 3.**