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RESEARCH ARTICLE

The acceleration kinematics of cricket-specific starts when completing a quick single

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Abstract
The cricket quick single has received minimal scientific analysis. This study investigated the acceleration kinematics of the non-striking batsmen during a quick single. A total of 20 cricketers completed 17.68-m sprints following three starts: standard (no cricket-specific equipment), static cricket (side-on start, bat held on crease) and rolling cricket (walking start, bat dragged through crease). Timing gates recorded 0–5 m and 0–17.68 m time. Participants wore leg guards and carried a bat during cricket-specific sprints. Joint and step kinematics were investigated through the first and second steps via motion analysis. A repeated measures analysis of variance determined significant ($p < 0.05$) within-participant differences between conditions. The rolling cricket start resulted in faster 0–5 m and 0–17.68 m times, and a 12% longer first, and 8% longer second, step. For cricket-specific sprints, shoulder sagittal plane range of motion (ROM) and elbow extension decreased in the arm carrying the bat. In response to this reduced arm ROM, hip flexion decreased. There were no changes to hip extension. Shoulder and wrist frontal plane ROM, and wrist sagittal plane ROM, increased as a result of carrying the bat. The need for cricketers to use specialised equipment while completing a quick single resulted in specific acceleration kinematic alterations.

Keywords: *biomechanics, leg guards, rolling cricket sprint, cricket batsmen, motion capture*

1. Introduction

Cricket has a number of different match formats, which can range in length from a few hours (e.g. Twenty20 [T20] and one-day cricket) to several days (e.g. Test match cricket). The introduction of T20 cricket has led to a shift in the pivotal physiological and technical demands imposed upon players, due to the reduction in match duration (Petersen, Pyne, Dawson, Portus, & Kellett, 2010). This is evident when investigating the movement demands placed on cricketers, especially running speed. The introduction of the shorter match formats has resulted in an increase in the number of sprint efforts required per hour for all players (Petersen et al., 2010). With regards to a batsman, this refers to running between the wickets. The technique adopted when maximally sprinting between the wickets must allow the batsmen to accelerate as quickly as possible, in order to provide the greatest chance of successfully completing a run.

When running between the wickets, a batsman will need to cover a distance of at least 17.68 m, as this is the length between the creases on a cricket pitch. A maximal sprint over the 17.68-m distance for both the striking (batsman facing the delivery from the bowler) and non-striking (not facing the delivery from the bowler) batsmen is labelled a quick single. The quick single has been identified as an effective means of increasing the scoring rate, while also allowing the rotation of strike between batsmen (Duffield & Drinkwater, 2008). It must be acknowledged that not all singles completed will require a maximal sprint. However, when a quick single is undertaken, the non-striking batsman will generally use a rolling start while the bowler enters their

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delivery stride (Buckley, 2010). As this is a relatively consistent starting position for the commencement of a quick single, this movement pattern will be the focus of this study. Due to the value of the quick single, there is a need to understand the technique mechanisms that could enhance performance during the sprint. This includes the fact that a batsman is required to wear cricket-specific leg guards, and carry and slide a cricket bat through the crease at the start of a quick single.

Webster and Roberts (2011) analysed the implications of various leg guards composition upon the biomechanics of the quick single at the 8-m mark. The researchers found that a traditional construction of leg guards (multiple foam pieces with a piece of cane for added support) led to a decrease in running velocity. This was attributed to a reduction in step length as a result of an increase in step width when compared to a no leg guards control. However, a limitation of the methodology by Webster and Roberts (2011) was that a cricket bat was not instituted into the data capture, which is a necessary component of running between the wickets. The only research which have instituted a cricket bat into testing procedures for cricketers were investigating cricket-specific linear speed tests (Houghton, 2010; Lockie, Callaghan, & Jeffriess, 2013). The initial 5 m of the quick single has not been investigated either, despite its importance to acceleration for field sport athletes (Lockie, Murphy, Knight, & Janse De Jonge, 2011; Murphy, Lockie, & Coutts, 2003). Specifically, the initial 5 m of a quick single contains many unique movements when compared to the typical sprint kinematics of a field sport athlete, such as the batsman sliding the bat behind them, while also wearing leg guards and completing a rolling start to the sprint.

There is a clear need to identify the unique body positioning of a batsman at the start of a quick single (i.e. within the first 5 m), in addition to the kinematic alterations that occur due to the use of cricket-specific equipment such as the bat and leg guards. This information would prove valuable for cricket coaches, as it could provide them with information with which to develop the ability of their cricketers to complete quick singles during a match. This would ultimately improve a team's performance. Therefore, the aim of this study is to outline the implications of cricket-specific equipment (i.e. a cricket bat and leg guards) upon the initial acceleration of a non-striking batsman when performing a match-specific rolling start to a quick single in experienced cricketers. Comparisons will be made to a standard sprint (upright start position typically used in testing field sport athletes with no cricket-specific equipment) and static cricket sprint (static, a typical match start position with cricket-specific equipment), to identify any variations to typical field sport acceleration and current cricket-specific linear speed tests for batsmen.

2. Experiment

2.1. Participants

A total of 20 healthy males (age $= 24.5 \pm 4.8$ years; body mass $= 79.0 \pm 10.7$ kg; height $= 1.80 \pm 0.07$ m), currently playing cricket in a regional competition in Australia, were recruited for this study. Participants were recruited if they: were 18 years of age or older; were currently playing premier league or division one in the regional competition; had at least three years' experience playing cricket; were currently training for cricket (≥ 3 h per week); and did not have any medical conditions that would compromise study participation. The procedures used in this study were approved by the institutional ethics committee. All participants received a clear explanation of the study, including the risks and benefits of participation. Written informed consent was obtained prior to testing.

2.2. Procedures

Participants completed two testing sessions, separated by 48 h. First, a familiarisation session was performed. This provided participants with the opportunity to become accustomed with the testing procedures, laboratory facilities and cricket equipment (cricket leg guards and bat) to be used in this study. The familiarisation session also allowed for the collection of data to access the accuracy of the marker set used; this will be detailed later. The second testing session involved nine maximal sprints over a distance of 17.68 m, with a 3-min recovery between each trial. Three sprints were performed for each starting position in the following order for all participants, with a 3-min recovery between each trial: standard sprint (static, standing start position with no cricket-specific equipment), static cricket sprint (static side-on start position with cricket-specific equipment) and rolling cricket sprint (dynamic walking start with cricket-specific equipment). The mean times and kinematic data of the three sprints for each starting position were used for analysis. Participants wore standardised cricket leg guards and held a standardised bat during the static and rolling cricket sprints. All testing was conducted on an indoor, textured, concrete running track. Participants refrained from intensive exercise and any form of stimulant in the 24-h period before testing.

The participant's age, height, body mass and anthropometric data were collected at the start of the familiarisation session. Height was measured bare-

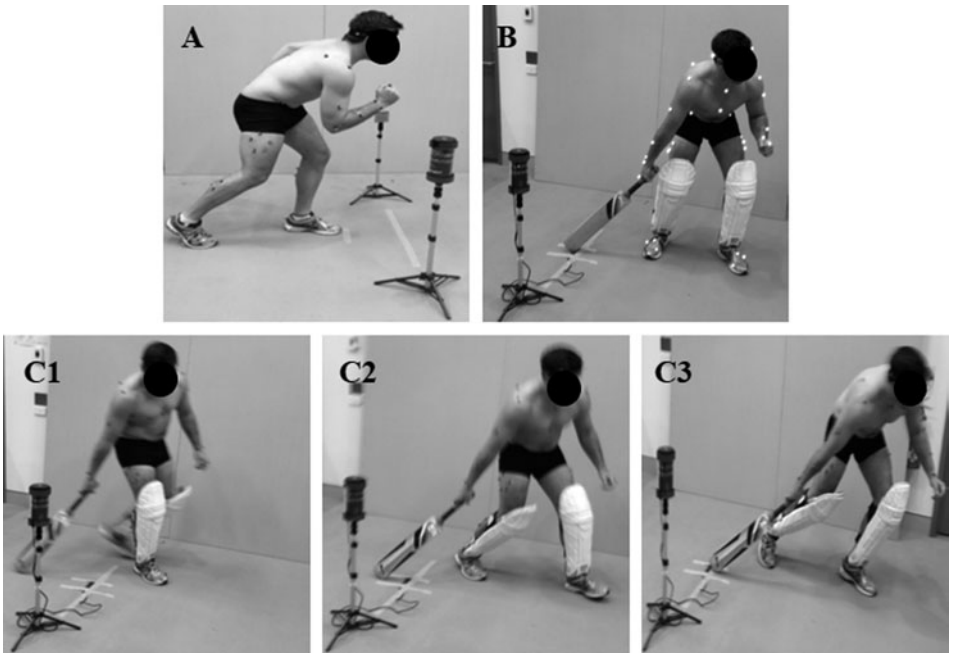

Figure 1. The standardised start position for the standard sprint (A), static cricket sprint (B) and rolling cricket sprint (C1: stage one approach; C2: stage two approach; C3: initial take-off).

foot using a stadiometer (Ecomed Trading, Seven Hills, Australia). Body mass was recorded using digital scales (Tanita Corporation, Tokyo, Japan). Selected limb lengths were measured using a Lufkin Executive Thin-line tape measure (Apex Tool Group, Cleveland, NY, USA) and bone breadths was measured using Harpenden bone callipers (Baty International, London, UK). These measurements were necessary for the motion capture analysis. Prior to data capture in both the sessions, each participant completed a standardised warm-up. This consisted of 5 min of jogging on a treadmill at a self-selected pace, followed by 10 min of dynamic stretching of the lower limbs and progressive speed runs over the 17.68-m testing distance.

2.3. *Standard sprint*

Three trials of a 17.68 m standard sprint were performed. This has previously been used to assess linear speed as a representation of the quick single in cricket (Johnstone & Ford, 2010; Lockie, Callaghan, & Jeffriess, 2013). Time was recorded using a timing lights system (Fusion Sports, Coopers Plains, Australia). Gates were positioned at 0 m, 5 m and 17.68 m, at a height of 0.8 m, to measure the 0–5 m (Lockie et al., 2011; Lockie, Murphy, Schultz, Jeffriess, & Callaghan, 2013; Reilly, Williams, Nevill, & Franks, 2000) and 0–17.68 m (Johnstone & Ford, 2010; Lockie, Callaghan, & Jeffriess, 2013) intervals. Participants began each sprint from a standing start position 30 cm behind the start line in order to trigger the first gate (Figure 1A). Participants were instructed to drive off from the starting position and sprint through all sets of timing gates. If the participant rocked backwards or forwards prior to starting, the trial was disregarded and repeated after the required rest period.

2.4. *Static cricket sprint*

The static cricket sprint was completed following the standard start and has been established in previous research as a means of assessing linear speed specific for cricketers (Lockie, Callaghan, & Jeffriess, 2013). Participants were required to carry a standardised cricket bat and wear standardised cricket leg guards (Iridium 5000, Puma, Herzogenaurach, Germany). The leg guards selected for this study were based on the findings of Webster and Roberts (2011), as they were found to have minimal impact upon typical sprint kinematics. The bat selected was chosen to replicate the typical dimension of a standard cricket bat, and has been used in previous research (Lockie, Callaghan, & Jeffriess, 2013). In accordance with the laws of cricket, a quick single does not commence until both the batsman and the bat are no longer in contact with the crease. Therefore, for the start position, participants stood ahead of the start line, which was a simulated bowling crease, while ensuring the bat was in contact with the start line (Figure 1B). This required the participant to place the back leg parallel to the start line with a degree of knee flexion. The front leg was externally rotated at the hip, and

the knee was flexed. The participants carried the bat with their dominant hand, which was extended at the elbow and abducted at the shoulder. The non-dominant hand was positioned at the side of the participant (Lockie, Callaghan, & Jeffriess, 2013). Participants were instructed to only carry the bat in their dominant hand throughout the entire sprint (Houghton, 2010). If participants carried the bat with two hands, the trial was disregarded and reattempted. Participants were required to sprint maximally to complete the 17.68-m sprint, including sliding the bat through the finish line (simulated batting crease), in a manner typical to completing a run in cricket.

As per the standard sprint, the 0–5 m and 0–17.68 m intervals were measured. A pressure pad (Fusion Sports) was attached to the timing gate level with the start line. The pressure pad allowed for the bat to trigger the gate once pressure was removed from the pad. The timing gate at the 17.68-m mark was lowered and placed in custom stands to a height of 0.06 m. This allowed for the sliding of the bat through the finish line to complete the sprint. The timing gates at the 5-m mark were raised to a height of 1.2 m, to ensure the light beam between the gate and the reflector was broken by the torso of the participant, and not the bat (Loock, Du Toit, Ventner, & Stretch, 2006).

2.5. *Rolling cricket sprint*

The rolling cricket sprint was completed following the static cricket sprint. The quick single in cricket is typically completed with a batsman adopting a rolling, or walking, start to the sprint as the bowler delivers the ball. This requires a batsman to walk up to and past the bowling crease as the bowler enters their delivery stride. The rolling cricket sprint used in this study (Figure 1C) was designed to closely simulate this match situation. Participants wore the same leg guards and carried the same bat (dominant hand only) as used in the static cricket sprint. To gain a walking start into the sprint, participants started 1.5 m behind the crease (Buckley, 2010). Participants were instructed to undertake this action as if they were completing it under match conditions. Thus, participants adopted a relatively standard walking gait past the start line and into the sprint, while extending the elbow and abducting the shoulder of the arm carrying the bat. As per the static cricket sprint, a pressure pad was used to initiate the timing system. Participants slid the bat over the pressure pad to initiate the sprint, and through the finish line to complete the trial. Each sprint was completed maximally, with the same timing light gate configuration as the static cricket sprint used for the rolling cricket sprint.

2.6. *Motion capture data*

All trials were recorded using a Vicon motion capture system (Oxford Metrics Group, Oxford, UK), via six MX infrared cameras mounted on 2.1-m high tripods. The six cameras were fixed about the start position of each trial for the entire study, providing a capture volume of approximately 5 m (length) by 2 m (width) by 2 m (height). The frame rate for each camera was set at 200 Hz (Webster & Roberts, 2011). Prior to all familiarisation and sprint-testing sessions, the laboratory was dynamically calibrated using a five-marker wand and L-frame to define the global coordinate system. The wand was also used to set the volume origin, which was the same for every testing occasion. Following the warm-up and prior to testing, 59 reflective markers (Oxford Metrics Group) were placed on anatomical landmarks on the upper- and lower-body of the participant (see Appendix). Marker locations were determined through palpation, with the markers held in place through double-sided tape. A static capture (anatomical frame) was undertaken prior to sprint testing, and required participants to adopt a stationary T-pose in the centre of the capture volume. This allowed each marker to be labelled and the participant calibrated.

Markers placed on the knee, tibia and ankle were removed following the static capture, as participants wore leg guards during the static cricket and rolling cricket sprints. As a result, a standard marker set-up was not appropriate, and the calibrated anatomical systems technique (CAST) method was used (Cappozzo, Catani, Della Croce, & Leardini, 1995; Webster & Roberts, 2011). The CAST method is an indirect means of calculating marker positions, and consequently joint centre positions. This method uses the static capture to identify the relative position of a cluster of markers in relation to a marker positioned on an anatomical landmark (i.e. the knee, tibia and ankle markers). Once the relative position between the cluster and anatomical markers was calculated, the anatomical markers were removed.

Due to the CAST method and relatively novel marker set-up used in this study, the accuracy of the marker set was assessed. This occurred during the familiarisation session when participants completed three walking and three running trials, without any cricket-specific equipment, at a self-selected pace (Webster & Roberts, 2011). The joint centre positions, joint angles and marker positions at the hip, knee, tibia and ankle were calculated using both the digitised markers in relation to the clusters, and the physical markers on the anatomical landmarks. The root mean squared error (RMSE) between the physical and digitised markers through a complete stride cycle (i.e. from the left foot contact to the

subsequent left foot contact) was used to assess the accuracy of the CAST marker set-up (Faber, 1999; Reinschmidt, van den Bogert, Nigg, Lundberg, & Murphy, 1997; Webster & Roberts, 2011).

2.7. *Data processing and analysis*

After data collection for the accuracy of the marker set-up and sprint testing was completed, all sprint trials were filtered and digitised in Vicon Nexus 1.8.3 software (Oxford Metrics Group) to allow for the retrieval of joint kinematics. Data filtering was then used to address gaps in the data from marker occlusion, and to address small random digitising errors. Initially, smoothing algorithms inherent to the software (spline fill and pattern fill) were selected on individual basis to address each gap in the data. Second, a Woltring filter was passed over the data (Fosang & Baker, 2006). Finally, the Vicon Bodybuilder 3.6.1 software (Oxford Metrics Group) was used to establish and export all kinematic variables for analysis.

The kinematic variables measured within this study were based upon a deterministic model adapted from Hunter, Marshall, and McNair (2004), Maulder, Bradshaw, and Keogh (2008) and Webster and Roberts (2011). Additionally, upper-body kinematics was included to quantify the implications of the cricket bat upon arm range of motion (ROM) during the initial acceleration of a quick single. The kinematic variables assessed were during the first and second step of each sprint condition. The step kinematics analysed were: step length, which was the horizontal distance in the sagittal plane from toe-off to toe-off of consecutive steps; step width, measured as the horizontal distance in the frontal plane between the toe-off of two consecutive steps; step frequency, calculated from the inverse of step time through the equation $step\ frequency = (1 \cdot step\ time) - 1$ (Hunter et al., 2004); and contact time, which was the duration when the foot was in contact with the ground.

The results from joint kinematics are reported in Euler angles, with an axes order rotation of YXZ of the local coordinate system, with respect to the global coordinate system of the laboratory. Maximum values of flexion and extension, abduction and adduction, and ROM about the sagittal and frontal planes were calculated for upper- and lower-body kinematics. The kinematics of the upper-body was divided into dominant and non-dominant to clearly identify which arm was carrying the bat. The following upper-body kinematics was assessed: shoulder ROM, calculated as the difference between maximum values about a plane of motion; elbow angle, which was calculated as the relative angle between the upper arm and the forearm; and wrist ROM, derived from the difference between the peak values about the measured planes of motion.

Lower-body kinematic variables were, first, divided into step one and step two, which were then subdivided into the drive and the swing leg for each step. This was based upon the actions of the limb during the step cycle. The following lower-body kinematics was assessed and defined as: hip angle, which was the relative angle between the trunk and thigh; knee angle, calculated as the relative angle between the thigh and shank; and ankle angle, which was the relative angle between the shank and foot. Continuous data of typical lower-limb joint kinematics in the sagittal plane were also measured through a complete step cycle, in accordance with the recommendations of Bartlett, Wheat, and Robins (2007).

2.8. *Statistical analysis*

All statistical analyses were undertaken using the Statistics Package for Social Sciences Version 19.0 (IBM, Armonk, NY, USA). Descriptive statistics (mean ± standard deviation) were calculated for all variables. Due to the novel nature of the sprint testing, trial-to-trial reliability of sprint times was assessed by an intra-class correlation coefficient (ICC), calculated from a two-way mixed-method consistency model for single measures (Lockie et al., 2011; Sporis, Jukic, Milanovic, & Vucetic, 2010). An ICC equal to or above 0.70 was deemed acceptable (Baumgartner & Chung, 2001). Coefficient of variation (CV) was used to determine the change in the mean between trials, with a CV below 5% defined as being acceptable (Buchheit, Spencer, & Ahmaidi, 2010). Outliers in the data were treated with a Winsorization method (Lien & Balakrishnan, 2005), and normality of the data distribution was assessed using the Kolmogorov–Smirnov test. Sphericity was tested using Mauchly's test of sphericity and where appropriate, a Greenhouse–Geisser adjustment was used. A repeated measures analysis of variance ($p < 0.05$) calculated any differences in sprint times, step and joint kinematics between sprint conditions, with significant within-participant effects investigated via a Bonferroni post hoc adjustment for multiple comparisons.

3. Results

An RMSE of 1.23 ± 0.45 mm, 1.75 ± 0.57 mm and 0.56 ± 0.01 mm was calculated for the marker positions of the ankle, knee and tibia, respectively. This is less than those established by Webster and Roberts (2011), who also used the CAST method and found an RMSE of 1.97 mm and 2.45 mm for

Table I. Sprint times (means ± standard deviation), intra-class correlation coefficients (ICC) and coefficient of variation (CV), for the 0–5 m and 0–17.68 m intervals for the standard sprint, static cricket sprint and the rolling cricket sprint in experienced cricketers ($n = 20$).

	Standard	Static cricket	Rolling cricket
0–5 m			
Time (s)	1.061 ± 0.035	1.071 ± 0.068	0.967 ± 0.066[a,b]
ICC	0.93	0.88	0.91
CV (%)	0.88	2.05	2.77
0–17.68 m			
Time (s)	2.894 ± 0.129	2.949 ± 0.137	2.769 ± 0.102[a,b]
ICC	0.95	0.90	0.93
CV	0.94	1.58	1.26

[a] *Significant (p < 0.05) difference between the standard sprint and the rolling cricket sprint.*
[b] *Significant (p < 0.05) difference between the static cricket sprint and the rolling cricket sprint.*

the ankle and knee, respectively. In addition, the RMSE for the joint angles of the hip (0.49 ± 0.48°), knee (0.60 ± 0.02°) and ankle (0.93 ± 0.02°) was less than those established in Reinschmidt et al. (1997) for the knee (4.6°). Therefore, the CAST method and marker set-up used in this study were deemed appropriate.

Table I displays the sprint times and reliability measures for the 0–5 m and 0–17.68 m intervals for each of the sprint conditions. The reliability measures for the time intervals for all three sprint conditions were acceptable. In the 0–5 m interval, the rolling cricket sprint was significantly faster when compared to both the standard ($p < 0.001$) and static cricket ($p = 0.001$) sprints. The rolling cricket sprint had significantly ($p < 0.001$) faster times for the 0–17.68 m interval when compared to both the standard and static cricket sprint.

Table II outlines the first and second step kinematics from each sprint condition. First step length for the rolling cricket sprint was significantly longer than both the standard ($p < 0.001$) and static cricket ($p < 0.001$) sprints, by 12% and 18%, respectively. The standard sprint had a significantly ($p = 0.014$) longer first step than the static cricket sprint. The second step was also significantly longer for the rolling cricket sprint, when compared to both the standard ($p < 0.001$) and static cricket ($p = 0.001$) sprints. The rolling cricket sprint had greater second step frequency when compared to the static cricket sprint ($p = 0.008$). The step width for the first step in the static ($p < 0.001$) and rolling ($p = 0.003$) cricket sprints was significantly wider when compared to the standard sprint. A significant reduction was found for both the standard ($p = 0.029$) and rolling cricket ($p = 0.008$) sprints' second step contact time when compared to the static cricket sprint.

The ROM in sagittal and frontal plane at the shoulder joint is shown in Figure 2. Both the static cricket and rolling cricket sprints had a significant ($p < 0.001$) 28% and 30% reduction, respectively, in sagittal plane ROM when compared to the standard sprint. In the frontal plane, a significant increase in shoulder ROM was found in the rolling ($p = 0.023$) and static cricket ($p = 0.007$) sprints, when compared to the standard sprint.

Table II. Step length, step frequency, step width and contact time (mean ± standard deviation) for the first and second steps, for the standard sprint, the static cricket sprint and the rolling cricket sprint in experienced cricketers ($n = 20$).

	Standard	Static cricket	Rolling cricket
First step			
Step length (m)	0.98 ± 0.12	0.93 ± 0.12[a]	1.10 ± 0.11[b,c]
Step frequency (Hz)	4.04 ± 0.32	4.05 ± 0.51	4.12 ± 0.26
Step width (m)	0.19 ± 0.04	0.31 ± 0.06[a]	0.27 ± 0.08[b]
Contact time (s)	0.174 ± 0.013	0.167 ± 0.021	0.162 ± 0.017
Second step			
Step length (m)	1.13 ± 0.19	1.15 ± 0.12	1.23 ± 0.12[b,c]
Step frequency (Hz)	4.16 ± 0.33	4.00 ± 0.34	4.26 ± 0.28[c]
Step width (m)	0.21 ± 0.07	0.24 ± 0.08	0.24 ± 0.08
Contact time (s)	0.152 ± 0.156	0.162 ± 0.020[a]	0.149 ± 0.014[c]

[a] *Significant (p < 0.05) difference between the standard sprint and the static cricket sprint.*
[b] *Significant (p < 0.05) difference between the standard sprint and the rolling cricket sprint.*
[c] *Significant (p < 0.05) difference between the static cricket sprint and the rolling cricket sprint.*

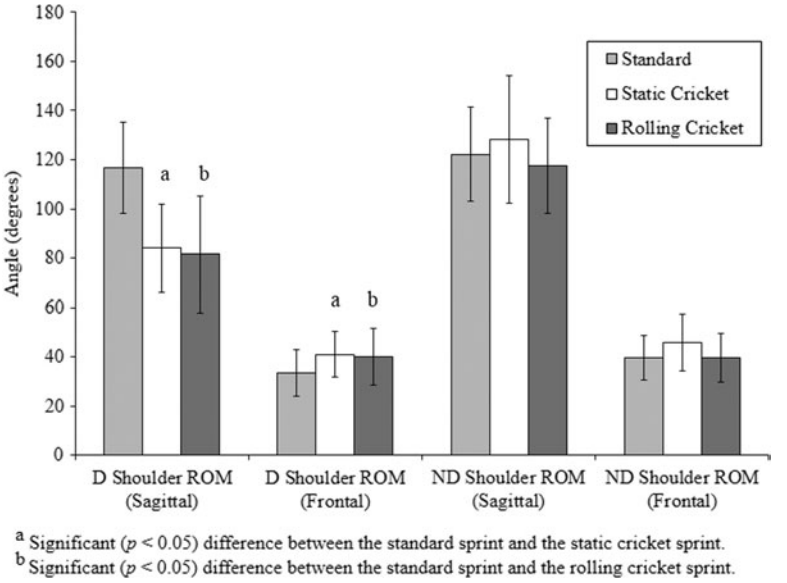

Figure 2. Dominant (D) and non-dominant (ND) shoulder range of motion (ROM) about both the sagittal and frontal planes of motion (mean ± standard deviation) for the standard sprint, static cricket sprint and rolling cricket sprint conditions during the first and second steps of a quick single in experienced cricketers ($n = 20$).

Elbow joint kinematics for the three sprint conditions are presented in Table III. The maximum extension angle of the dominant elbow (the arm carrying the bat) was significantly ($p = 0.001$) less for both the static cricket and rolling cricket sprints when compared to the standard sprint. The elbow joint ROM in the sagittal plane in the rolling cricket sprint was significantly ($p = 0.038$) less than that for the standard sprint. The wrist sagittal and frontal plane ROM values are shown in Figure 3. For the dominant wrist, sagittal plane ROM for the rolling cricket and static cricket sprints was significantly ($p < 0.001$) greater than the standard sprint. Additionally, a significant increase was found for the dominant wrist frontal plane ROM for the static cricket (179%; $p < 0.001$) and rolling cricket (181%; $p = 0.001$) sprints, when compared to the standard sprint. No significant differences were present between any of the sprint conditions regarding the kinematics of the non-dominant arm (the arm not carrying the bat) about the shoulder, elbow and wrist ($p = 0.115–1.000$).

Kinematics of the drive and swing leg of each sprint condition during the first step are shown in Table IV. When compared to the standard sprint, maximum hip flexion of the swing leg was significantly lower for both the static cricket (8%; $p = 0.001$) and rolling cricket (7%; $p = 0.005$) sprints. There were no other differences in first step lower-limb kinematics between the sprint conditions ($p = 0.055–1.000$). Table V outlines the second step kinematics for the drive and swing leg. The static cricket ($p = 0.001$) and rolling cricket ($p < 0.001$) sprint conditions demonstrated a significant reduction in swing leg hip flexion when compared to the standard sprint. There was also a

Table III. Dominant and non-dominant maximum elbow flexion, extension and range of motion (ROM) about the sagittal plane (mean ± standard deviation) in degrees (°) during the first and second steps of a standard sprint, static cricket sprint and a rolling cricket sprint in experienced cricketers ($n = 20$).

	Standard	Static cricket	Rolling cricket
Dominant			
Maximum flexion (°)	102.67 ± 10.61	105.66 ± 14.20	102.84 ± 11.49
Maximum extension (°)	50.08 ± 6.90	61.68 ± 12.05[a]	59.27 ± 8.54[b]
ROM (sagittal) (°)	52.36 ± 12.79	46.52 ± 15.17	43.21 ± 9.18[b]
Non-dominant			
Maximum flexion (°)	103.22 ± 9.55	99.85 ± 10.82	98.75 ± 9.17
Maximum extension (°)	44.84 ± 16.03	46.28 ± 16.83	45.97 ± 15.17
ROM (sagittal) (°)	58.25 ± 16.57	55.71 ± 17.13	52.79 ± 17.07

[a] *Significant (p < 0.05) difference between the standard sprint and the static cricket sprint.*
[b] *Significant (p < 0.05) difference between the standard sprint and the rolling cricket sprint.*

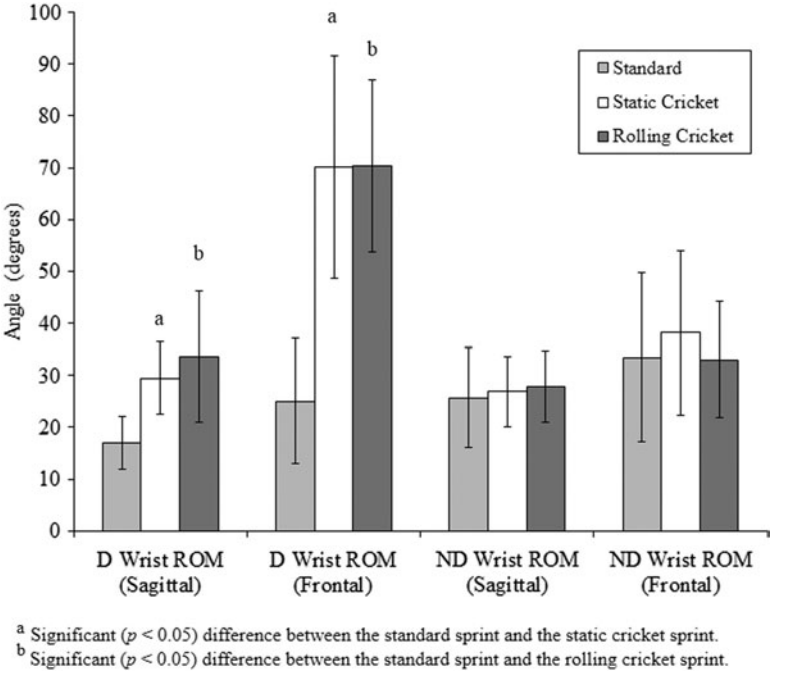

Figure 3. Dominant (D) and non-dominant (ND) wrist range of motion (ROM) about both the sagittal and frontal planes of motion (mean ± standard deviation) for the standard sprint, static cricket sprint and rolling cricket sprint conditions during the first and second steps of a quick single in experienced cricketers ($n = 20$).

41% ($p = 0.005$) and 28% ($p = 0.001$) increase in swing leg hip adduction for the static cricket and rolling cricket sprints, respectively, when compared to the standard sprint. No other significant differences were found for second step kinematics ($p = 0.164–1.000$). To further analyse the lower-limb kinematics, the continuous movements of the left hip, knee and ankle in the sagittal plane for each condition throughout a step cycle for a typical participant are depicted in Figure 4. The sequencing of lower-limb movements identifies that peak extension of the hip, knee and ankle plantar flexion occurs at toe-off within the step cycle. Peak flexion of the knee occurs prior to hip flexion to aid in a faster recovery of the swing leg, while peak dorsiflexion occurs just prior to ground contact. Figure 4 further demonstrates that hip flexion during the cricket-specific sprints was restricted when compared to the standard sprint. All other sagittal plane kinematics was relatively similar between conditions.

4. Discussion

To the authors' knowledge, this is the first study to analyse the acceleration kinematics of cricket-specific starts for a quick single. The results of this study

Table IV. Drive and swing leg maximum flexion, extension, abduction and adduction for the hip, knee and ankle in degrees (°) for the first step (mean ± standard deviation) of the standard sprint, static cricket sprint and rolling cricket sprint conditions of a quick single in experienced cricketers ($n = 20$).

	Standard	Static cricket	Rolling cricket
Hip			
Drive leg extension (°)	8.58 ± 6.62	7.95 ± 4.54	7.74 ± 4.90
Drive leg abduction (°)	9.96 ± 4.21	7.33 ± 4.71	8.34 ± 4.26
Swing leg flexion (°)	97.91 ± 9.51	90.36 ± 9.55[a]	91.16 ± 9.82[b]
Swing leg adduction (°)	−21.07 ± 6.90	−23.91 ± 7.31	−22.49 ± 8.48
Knee			
Drive leg extension (°)	25.70 ± 10.38	23.30 ± 9.61	24.28 ± 8.28
Swing leg flexion (°)	125.51 ± 11.89	112.21 ± 11.49[a]	120.67 ± 14.25
Ankle			
Drive leg plantar flexion (°)	−43.47 ± 16.33	−40.97 ± 15.11	−34.77 ± 9.73
Swing leg dorsiflexion (°)	34.70 ± 11.27	39.53 ± 15.36	30.11 ± 6.42

[a] *Significant (p < 0.05) difference between the standard sprint and the static cricket sprint.*
[b] *Significant (p < 0.05) difference between the standard sprint and the rolling cricket sprint.*

Table V. Drive and swing leg maximum flexion, extension, abduction and adduction for the hip, knee and ankle in degrees (°) for the second step (mean ± standard deviation) of the standard sprint, static cricket sprint and rolling cricket sprint conditions of a quick single in experienced cricketers ($n = 20$).

	Standard	Static cricket	Rolling cricket
Hip			
Drive leg extension (°)	6.41 ± 4.83	6.79 ± 4.62	9.42 ± 6.96
Drive leg abduction (°)	9.54 ± 5.56	6.70 ± 4.53	8.38 ± 5.45
Swing leg flexion (°)	96.29 ± 9.10	87.10 ± 9.02[a]	88.47 ± 7.13[b]
Swing leg adduction (°)	−15.48 ± 4.55	−21.89 ± 5.68[a]	−19.80 ± 4.17[b]
Knee			
Drive leg extension (°)	23.22 ± 7.45	26.22 ± 11.95	25.47 ± 9.8
Swing leg flexion (°)	125.97 ± 8.50	119.32 ± 8.83	124.75 ± 9.74
Ankle			
Drive leg plantar flexion (°)	−35.74 ± 11.04	−32.68 ± 12.30	−32.37 ± 12.55
Swing leg dorsiflexion (°)	30.24 ± 8.62	34.27 ± 12.22	35.10 ± 12.18

[a] *Significant ($p < 0.05$) difference between the standard sprint and the static cricket sprint.*
[b] *Significant ($p < 0.05$) difference between the standard sprint and the rolling cricket sprint.*

indicated that the cricket-specific equipment and unique starting position resulted in specific changes to acceleration kinematics for the cricket-specific sprints when compared to a standard sprint. Nonetheless, the rolling cricket sprint was the fastest means of completing a quick single. When considering the 0–5 m interval of a quick single, a batsman should attempt to cover this distance as quickly as possible to increase their chances of a successful run. This is in accordance with previous research which has established the importance of the initial steps to acceleration performance in field sport athletes (Lockie et al., 2011; Murphy et al., 2003). The rolling cricket sprint recorded significantly faster times for the 0–5 m interval when compared to the standard and static cricket sprints (Table I). There are several reasons for this. First, the rolling start involved the participant completing a moving start to the sprint. Second, the participants dragged the bat behind themselves at the start of a quick single. This is because a single has not commenced until both the bat and the player have left the crease. This reduced the actual distance between where the participant began their sprint in the current study and the distance to the timing gate at the 5-m mark. This reduced distance was also present for the static cricket sprint. Therefore, the results illustrate the benefit of the additional reach afforded to the batsmen at the commencement of a quick single, which are further emphasised when batsmen adopt a rolling start.

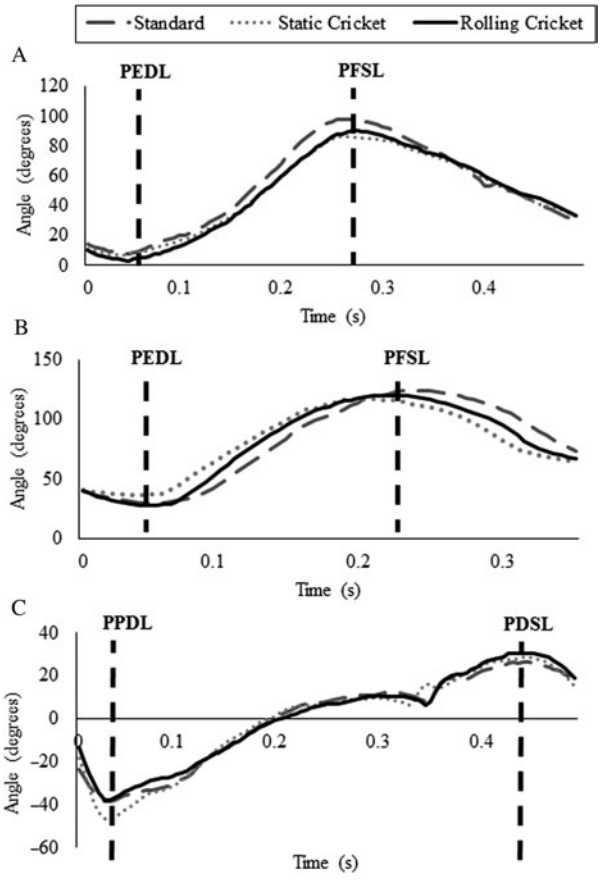

Figure 4. The left lower-limb continuous kinematics of the hip (A), knee (B) and ankle (C) in the sagittal plane for a complete step cycle during initial acceleration for a typical participant in the standard sprint, static cricket sprint and rolling cricket sprint. Note: PEDL, peak extension of the drive leg; PFSL, peak flexion of the swing leg; PPDL, peak plantar flexion of the drive leg; PDSL, peak dorsiflexion of the swing leg.

The advantages of using the rolling cricket sprint upon the time to complete a quick single are also evident when investigating the 0–17.68 m interval. The rolling cricket start produced faster times when compared to the standard and static cricket sprints (Table I). This can partially be attributed to the benefit derived from carrying and using the bat within the rolling cricket sprint. Not only do batsmen reach behind themselves towards the crease with the bat before starting the sprint, they will also slide their

bat through the crease at the end of the sprint (Lockie, Callaghan, & Jeffriess, 2013). This technique of sliding the bat effectively shortens the required sprint distance. The additional reach, in conjunction with the moving start, could increase the likelihood of a successful single during cricket match-play.

The faster times recorded for the 0–5 m interval for the rolling cricket sprint in this study was partially a function of the increase in step length for both the first and second steps when compared to the two other conditions (Table II). The use of a walking start during the rolling cricket sprint allowed batsmen to lengthen their step sooner within the quick single, which has been found to be advantageous to acceleration performance (Hunter et al., 2004). The relationship between step length and step frequency has also been shown to be a pivotal factor to acceleration performance, with a greater step frequency associated with a faster acceleration (Hunter et al., 2004; Lockie et al., 2011; Murphy et al., 2003). In the current study, the step frequency recorded for the second step of the rolling cricket sprint (4.26 ± 0.28 Hz) was comparable to other team sport athletes at a later stage of a short sprint. Hunter et al. (2004) measured a step frequency of 4.31 ± 0.21 Hz at the 16-m mark of a 25-m sprint in field sport athletes, while a step frequency of 4.17 ± 0.31 Hz was recorded by Lockie et al. (2013) at the 5–10 m interval of a 10-m sprint in field sport athletes. Therefore, batsmen should utilise a rolling start to develop advantageous step kinematics to aid acceleration performance during a quick single.

An inverse relationship has also been established between step frequency and contact time (Murphy et al., 2003). A smaller ground support duration indicates that less time is required to overcome the inertia of body mass and propel the body forward during a sprint. The contact times recorded for the rolling cricket sprint (0.149 ± 0.014 s) for the second step are comparable to other field sport athletes during a short sprint. Indeed, Murphy et al. (2003) and Lockie, Murphy, and Spinks (2003) recorded contact times of 0.17 ± 0.01 s and 0.18 ± 0.02 s, respectively, for faster field sport athletes in the second stride (i.e. during the fourth step) of a short sprint. These results indicate that the use of a rolling start to commence a quick single can aid in reducing contact time during the initial stages of a quick single, which is beneficial for acceleration performance (Hunter et al., 2004; Murphy et al., 2003).

The step width adopted by batsmen when performing a quick single has been shown to be influenced by the leg guards selected (Webster & Roberts, 2011). Consequently, the leg guards selected for this study were based on the findings of Webster and Roberts (2011) to minimise the impact upon sprint kinematics. However, a significantly wider first step for the cricket-specific sprints was found in the current study (Table II). The wider step width may have also been a function of the more side-on starting position (Figure 1) when compared to the standard sprint. This starting position, particularly when used during a static start, required the participants to reorientate their body in the direction of the sprint. This may lead to the first foot strike landing further away from the base of support provided by the contralateral leg. Nonetheless, no difference in the second step width was evident between the sprint conditions (Table II). This indicated that participants had shifted into a more typical sprint step by this stage of the cricket-specific conditions. The practical application of this is that batsmen should ensure the correct selection of leg guards, which minimise the impact upon step width during the initial acceleration of a quick single.

The need for batsmen to carry a bat while completing a quick single will affect the kinematics of the dominant arm. Within this study, it was found that the additional weight and length of the cricket bat reduced ROM in the sagittal plane at the shoulder, as well as maximum elbow extension (Figure 2 and Table III). Batsmen appeared to restrict the movements of the dominant arm, rather than attempt to generate any extra torque to attempt to maintain a typical sprinting upper-body movement pattern (Ropret, Kukolj, Ugarkovic, Matavulj, & Jaric, 1998). In contrast, shoulder and wrist ROM in the frontal plane was significantly increased, in addition to a significant increase in wrist sagittal plane ROM in both cricket-specific sprints (Figures 2 and 3). This can be largely attributed to the cricket bat and the mechanics of the starting position for the quick single. The unique actions of the upper limbs during initial acceleration within a quick single may lead to changes in the stress placed upon the musculature about the upper body. Future research is needed to quantify the effects of the cricket bat on the muscles responsible for decelerating and accelerating the arm carrying the bat during a quick single.

The study results demonstrated that carrying the bat when accelerating at the start of a quick single also affects leg kinematics. There was a significant decrease in maximum hip flexion for the first and second steps for the static cricket and rolling cricket sprints (Tables IV and V; Figure 4). Hinrichs (1992) stated that one of the primary purposes of the arms during a sprint is to aid in the forward drive of the legs. The reduction in sagittal plane ROM at the shoulder, in addition to maximum extension at the elbow, restricted the ability of the drive leg to transfer into the swing phase for the batsmen in this study. A further issue affecting the drive of the swing leg

would be the additional weight of the leg guards (Ropret et al., 1998). This is notable for cricketers, as the hip flexors have been suggested to be the primary muscle group accountable for increases in step frequency and running speed (Mann, Moran, & Dougherty, 1986). As a result, batsmen should ensure appropriate hip flexor strength to reduce the effects of carrying a bat and wearing leg guards when sprinting. This should be a focus of speed and strength training specific to cricketers.

There was a significant increase in second step hip adduction of the swing leg for the cricket-specific sprints (Table V). The significantly wider first step of the cricket-specific sprints may provide an explanation for the increase in hip adduction (Table II). To counteract the wider step width, participants ensured that the hip was adducted further to transition into a more typical sprinting gait by the second step. The increase in hip adduction identifies a mechanism by which batsmen will adapt their kinematics in an attempt to optimise running speed. The results also re-emphasise the need for batsmen to select appropriate leg guards. If batsmen select leg guards which do not allow the hip to make appropriate movements in the frontal plane, step width will potentially increase, which would be detrimental to the success of a quick single (Webster & Roberts, 2011).

Drive leg extension is important for short sprint performance, with the hip extensors viewed as the prime movers for acceleration (Belli, Kyröläinen, & Komi, 2002). The results indicated no significant differences between the sprint conditions for maximum hip extension for either the first step or the second step (Tables IV and V; Figure 4). This indicates that the various cricket-specific start positions, leg guards and bat used within this study did not affect one of the primary mechanisms by which acceleration is enhanced. Furthermore, there were few differences found for the actions of the knee or ankle between any of the sprint conditions (Tables IV and V; Figure 4). This would suggest that the cricket-specific equipment used, and the initial starting position had minimal impact upon typical ankle and knee function during initial acceleration. Therefore, batsmen should select leg guards which have minimal impact upon the kinematics of the lower limbs, particularly in the sagittal plane, to increase the likelihood of successful quick singles during cricket match-play.

5. Conclusion

The rolling cricket sprint led to faster times in completing a quick single. This was a function of commencing a sprint from a walking position, in addition to the reach afforded to a batsman by the use of a cricket bat. The faster times for the initial acceleration were also attributable to longer step lengths and greater second step frequency for the rolling cricket sprint. The need for batsmen to carry a bat while performing a quick single significantly reduced dominant shoulder sagittal plane ROM and maximum elbow extension. The reduction in the dominant arm ROM limited the maximum flexion of the hip during the sprint step. Cricket coaches and strength and conditioning practitioners should ensure their athletes train the hip flexors to ensure an appropriate degree of hip flexion can be maintained through initial acceleration during a quick single. Importantly, the unique starting positions and cricket-specific equipment used when performing a quick single did not affect maximum hip extension, which is an action essential for effective acceleration. Further research should investigate the sprint kinematics produced throughout the entire quick single, with particular reference to the final stages, where the batsmen will slide the bat into the opposing crease. The analysis of the effects of carrying the bat on muscle activity and stress on the upper body is also of interest. Nonetheless, the findings from the current study outline the effects of cricket-specific equipment on initial acceleration kinematics during the quick single, as well as the advantages of the additional reach and moving start provided by a rolling cricket sprint in producing a faster quick single.

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Appendix: Marker-set location

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Marker	Definition	Position
LFHD	Left front head	Located approximately over the left temple
RFHD	Right front head	Located approximately over the right temple
LBHD	Left back head	Placed on the back of the head, on the horizontal plane of the front head markers
RBHD	Right back head	Placed on the back of the head, on the horizontal plane of the front head markers
C7	7th cervical vertebrae	Spinous process of the 7th cervical vertebrae
T10	10th thoracic vertebrae	Spinous process of the 10th thoracic vertebrae
CLAV	Clavicle	Jugular notch where the clavicles meets the sternum
STERN	Sternum	Xiphoid process of the sternum
RBAK	Right back	Middle of the right scapula
LSHO	Left shoulder	Acromioclavicular joint
LUPA	Left upper arm	Upper arm between elbow and shoulder – left lower
LELB	Left elbow	Lateral epicondyle of the humerus
LFRA	Left forearm	Lower arm between elbow and wrist – left lower
LWRA	Left wrist marker A	Lateral epicondyle of the radius
LWRB	Left wrist marker B	Medial epicondyle of the ulna
LFIN	Left finger	Dorsum of the hand just below head of second metacarpal
RSHO	Right shoulder	Acromioclavicular joint
RUPA	Right upper arm	Upper arm between elbow and shoulder – right higher
RELB	Right elbow	Lateral epicondyle of the humerus
RFRA	Right forearm	Lower arm between elbow and wrist – right higher
RWRA	Right wrist marker A	Lateral epicondyle of the radius
RWRB	Right wrist marker B	Medial epicondyle of the ulna
RFIN	Right finger	Dorsum of the hand just below head of second metacarpal
LASI	Left anterior superior iliac spine (ASIS)	Directly over left ASIS
RASI	Right anterior superior iliac spine	Directly over right ASIS
LPSI	Left posterior superior iliac spine (PSIS)	Directly over left PSIS
RPSI	Right posterior superior iliac spine	Directly over right PSIS
LTHI	Left thigh	Between hip and knee on the lateral side – left lower
LSATHI	Left superior anterior thigh	Lateral superior anterior surface of the proximal-third of the thigh
LSPTHI	Left superior posterior thigh	Lateral superior posterior surface of the proximal-third of the thigh
LIATHI	Left inferior anterior thigh	Lateral inferior anterior surface of the proximal-third of the thigh
LIPTHI	Left inferior posterior thigh	Lateral inferior posterior surface of the proximal-third of the thigh
LKNE	Left knee	Lateral epicondyle of the femur (calibration only)
RTHI	Right thigh	Between hip and knee on the lateral side – right higher
RSATHI	Right superior anterior thigh	Lateral superior anterior surface of the proximal-third of the thigh
RSPTHI	Right superior posterior thigh	Lateral superior posterior surface of the proximal-third of the thigh
RIATHI	Right inferior anterior thigh	Lateral inferior anterior surface of the proximal-third of the thigh
RIPTHI	Right inferior posterior thigh	Lateral inferior posterior surface of the proximal-third of the thigh
RKNE	Right knee	Lateral epicondyle of the femur (calibration only)
LTIB	Left tibia	Between knee and ankle – left lower (calibration only)
LSLTIB	Left superior lateral tibia	Superior lateral posterior surface of the middle-third of the calf
LSMTIB	Left superior medial tibia	Superior medial posterior surface of the middle-third of the calf
LILTIB	Left inferior lateral tibia	Inferior lateral posterior surface of the middle-third of the calf
LIMTIB	Left inferior medial tibia	Inferior medial posterior surface of the middle-third of the calf
LANK	Left ankle	Lateral malleolus of the fibula (calibration only)
RTIB	Right tibia	Between knee and ankle – left lower (calibration only)
RSLTIB	Right superior lateral tibia	Superior lateral posterior surface of the middle-third of the calf
RSMTIB	Right superior medial tibia	Superior medial posterior surface of the middle-third of the calf
RILTIB	Right inferior lateral tibia	Inferior lateral posterior surface of the middle-third of the calf
RIMTIB	Right inferior medial tibia	Inferior medial posterior surface of the middle-third of the calf
RANK	Right ankle	Lateral malleolus of the fibula (calibration only)
LFootCen	Left-foot centre	Second metatarsal head, on mid-foot side of equines break between forefoot and mid-foot
LHEEL	Left heel	Place on calcaneus at the same height above plantar surface of foot as foot centre marker
LFootMed	Left-foot medial	Medial surface of the foot anterior to the LFootCen marker
LFootLat	Left-foot lateral	Lateral surface of the foot posterior to the LFootCen marker
RFootCen	Right-foot centre	Second metatarsal head, on mid-foot side of equines break between forefoot and mid-foot
RHEEL	Right heel	Place on calcaneus at the same height above plantar surface of foot as foot centre marker
RFootMed	Right-foot medial	Medial surface of the foot anterior to the RFootCen marker
RFootLat	Right-foot lateral	Lateral surface of the foot posterior to the RFootCen marker

Note: Redundant makers for static capture only in bold. Cluster markers (as identified in italics) did not require exact anatomical landmarks as they were not required for segment definition, and were influenced by leg guard position.