Kinematic attributes associated with overarm throwing performance in cricket

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The purpose of this study was to identify the kinematic attributes associated with throwing performance (ball velocity and accuracy) in cricket. Three-dimensional motion analysis of sixteen cricketers performing 30 ground-fielding attempts towards a target from three approach directions (straight, non-dominant and dominant) was captured. Vertical release angle, stride length, trunk flexion velocity & forward trunk tilt angle at release were significant predictors of ball velocity across the three approach conditions. Horizontal release angle was a significant predictor of throw accuracy in all three approaches. ANOVAs revealed that throws were significantly quicker from the straight approach, and significantly more accurate in the dominant and straight conditions. Throwing performance and mechanical attributes of throwing technique differ by approach direction constraint.

KEYWORDS: ground-fielding, ball velocity, accuracy, approach direction, 3D motion capture

INTRODUCTION: Fielding is one of three fundamental areas of the game of cricket, alongside batting and bowling. Consisting of catching, running and throwing skills, the goal of a fielding player is to retrieve a ball struck by a batter and return it to the wicket. Though a fielder can return the ball in a number of ways, the overarm throw is typically the quickest and most effective way of returning the ball when fielding from the edge of the infield. A successful throw can reduce run-scoring opportunities and even result in a batter being run-out if they fail to make their ground in time. The overarm throw is, therefore, critical to fielding performance (Freeston et al., 2007), though is relatively unexplored in cricket research.
The overarm throw has been studied extensively (e.g. Dillman et al., 1993; Fleisig et al., 1996), with a number of key kinematic parameters associated with throwing performance being described in baseball literature. However, this literature has mainly focussed on pitching. Consequently, there is a distinct lack of research into fielding from positions which might be directly comparable to those used in cricket (infield and outfield). Additionally, this research has mainly focussed on variables linked with ball velocity, not accuracy. One might argue that this is because baseball pitching has a preference for speed over accuracy, thus studies of the latter have not necessarily been required. In sports such as cricket though, where throws must be both fast *and* accurate, it is surprising that accuracy has not yet been investigated thoroughly. Furthermore, cricket throws are not performed from a set position, instead fielders move towards the ball from various locations on the outfield due to fielding positions and restrictions.
The lack of cricket-specific research surrounding throwing has left two main questions which have not yet been answered. Firstly, what are the kinematics associated with throwing performance in cricket? Secondly, how is throwing performance affected when throws are made from different approach directions? Therefore, the purpose of this study was to explore kinematic attributes associated with ball velocity and throw accuracy in cricketers from three approach directions: straight, non-dominant and dominant. The findings of this study will provide insights into cricket throwing performance during representative throwing conditions and the techniques associated with throwing performance.

Methods: Sixteen male university/2nd XI county cricketers volunteered for this study (mean ± SD: age 21.6 ± 2.4 years; body mass 84.5 ± 15 kg; height 1.84 ± 0.05 m). All participants gave written informed consent and filled in a physical activity readiness questionnaire before completing protocols which had been approved by the institution's Ethics Committee. A 14-camera Vicon Vantage V5 motion capture system (Vicon, Oxford, UK) synchronised with a high-speed camera (320Hz) was used to record the trajectories of 76 retroreflective individual, cluster and digital markers in order to model body segments, joints and the ball. In total, 13 segments (full body) were constructed adapted from the lower limb model of Leardini et al.

(2011) and the Plugin Gait upper-body model. The ball was covered in retro-reflective tape and represented as a single marker so it could be tracked through the motion capture system. After a short, self-selected warm-up and familiarisation with the procedure, participants were instructed to gather a stationary cricket ball from the ground (in a manner comfortable to them) and throw it at a target set 9.45m from their starting position – to simulate an attempted run-out. Participants threw ten attempts from three different starting positions marked on the floor (straight towards the target, 45º to the target from their non-dominant side, and 45º to the target from their dominant side), totalling 30 throws. Throws were executed in a randomised order and approaches were representative of those likely to be used in a match. The target was an image of a set of stumps scaled to replicate the size of a physical set of stumps as it would be viewed from the edge of the 30 yard (27m) inner-ring in a limited-overs match.
Labelled marker trajectories were exported for processing in Visual 3D v6 Professional software (C-Motion, Maryland, USA) and smoothed using a fourth-order zero-lag Butterworth filter, with a cut-off frequency of 6Hz. Joint angles were determined using a XYZ Cardan rotation sequence for all segments, except the shoulder which followed a YXZ rotation sequence (Sěnk et al., 2006). Ball trajectories and velocities were calculated from the first five frames of Vicon data after ball release. Linear velocities were calculated as the first derivative of a linear trendline fitted to raw displacements in the horizontal axes and a 2^{nd} order polynomial trendline in the vertical axis. Throw accuracy was defined as absolute lateral displacement from the middle stump. The five most accurate and fastest throws (by rank order) were averaged and statistically analysed. Stepwise regression analyses were performed on kinematic parameters, one for each performance variable in each of the three approach conditions [n = 6]. Kinematic variables significantly ($p < 0.05$) contributing were included in the final regression models. Finally, a one-way repeated measures ANOVA analysis with Bonferroni post-hoc tests was performed on each performance variable from the three different approach conditions (significance set to $p < 0.05$).

Results: Regression models for ball velocity and throw accuracy are summarised in Table 1. For attempts made in the straight approach, vertical release angle and stride length predicted 82% of the variance in ball velocity. For the non-dominant approach, 85% of the variance in ball velocity was predicted by stride length and trunk flexion velocity. Finally, for players approaching from their dominant side, 62% of the variance in ball velocity was predicted by forward trunk tilt at release. Horizontal release angle was the sole significant predictor of throw accuracy in all three approaches, predicting 86% of the variance in lateral displacement at the stumps in the straight condition, 80% in the non-dominant condition, and 78% in the dominant condition. Mean ball velocities and lateral displacement for each approach are shown in Figure 1 and Figure 2. There was a significant main effect of approach on ball velocity (F = 8.816, $p < 0.05$) and throw accuracy (F = 23.224, $p < 0.001$). Throws were significantly quicker from the straight approach compared to the dominant and non-dominant approaches ($p < 0.05$),

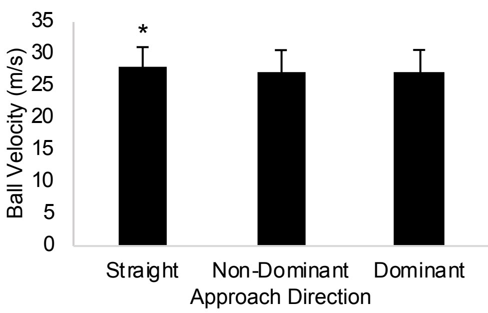

Figure 1: Mean ball velocities across the three approach conditions. *significant difference between straight compared to non-dominant and dominant approaches

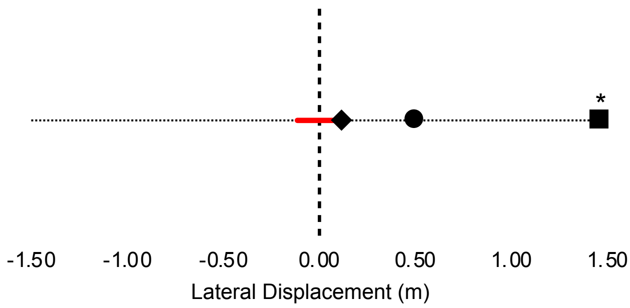

Figure 2: Mean lateral displacement of the ball as it intersects the plane of the stumps [dotted line] from three approach angles [straight ●; non-dominant ■; dominant ◆]. *significant difference between straight and dominant compared to non-dominant approach

Table 1: Model summaries and coefficients for regression and ANOVA analysis of ball velocity and throw accuracy in the straight, non-dominant and dominant approach conditions

Performance variable & approach	Regression equation components		Variance	ANOVA
	Predictor 1 (unstandardised ß coefficient)	Predictor 2 (unstandardised ß coefficient)	(R^2, *p value*)	(*F value*, *p value*)
BV straight	Vertical release angle (-0.417)	Stride length (0.114)	0.823 $p < 0.001$	20.88 $p < 0.001$
BV non-dominant	Trunk flexion velocity (-0.026)	Stride length (0.153)	0.852 $p < 0.05$	28.75 $p < 0.001$
BV dominant	Forward trunk tilt @ release (0.171)	-	0.621 $p < 0.05$	*14.77* $p = 0.004$
TA straight	Horizontal release angle (0.331)	-	0.860 $p < 0.001$	61.57 $p < 0.001$
TA non-dominant	Horizontal release angle (0.342)	-	0.804 $p < 0.001$	45.18 $p < 0.001$
TA dominant	Horizontal release angle (0.260)	-	0.779 $p < 0.001$	31.66 $p < 0.001$

BV = ball velocity, TA = accuracy.

and significantly more accurate from the straight and dominant approaches compared to the non-dominant approach ($p < 0.001$).

Discussion: To the authors' knowledge, this is the first study to investigate the kinematic attributes associated with both aspects of cricket throwing performance, ball velocity and throw accuracy concurrently. Five kinematic variables significantly predicted throwing performance. Vertical release angle, stride length, trunk flexion velocity and forward trunk tilt were associated with ball velocity across three different approach conditions, and horizontal release angle was associated with accuracy. Throws were significantly faster from the straight approach, and significantly more accurate from the straight and dominant approaches compared to the non-dominant. These results indicate that throwing strategies are adapted as the approach direction changes, supporting similar findings of Cook et al. (2000).

Faster throws in the straight condition may be explained by more linear momentum being focussed in the direction of the target. Wagner et al. (2011) showed that throws in handball were quicker when a run-up towards the target was incorporated, thus, as throws in the current study were slower in both the non-dominant and dominant conditions, this idea appears to be further reinforced. The straight approach also produced some of the most accurate throws, as did the dominant approach. From the straight approach a more vertically inclined arm path may have been facilitated, allowing horizontal displacement to be limited. Conversely, from the dominant approach, the reduction in ball velocity may be responsible for increased accuracy. Freeston et al. (2007) showed that a trade-off exists between speed and accuracy for cricketers, thus, as ball velocity is reduces, accuracy improves.

Only stride length was identified as a significant predictor of throwing velocity in more than one condition (straight and non-dominant). Increasing stride length allows the lower-body to stabilise, facilitating a more efficient transfer of energy up the kinetic chain and faster ball speeds (Keeley et al., 2015). Vertical release angle was identified as a predictor of ball velocity from the straight approach. Lowering the release angle of a projectile means more force can be applied in the direction of the throw and less energy is spent trying to overcome gravity (Linthorne, 2014). Cricketers might exploit this benefit as they can bounce the ball before reaching the target. Trunk flexion velocity predicted ball velocity from the non-dominant approach, and may be explained by the limited rotational energy available from the trunk due

to the position adopted. Owing to a more open stance, energy transfer may have been inefficient and other kinematics – like trunk flexion velocity – may have had to compensate (Tocci et al., 2017). Finally, forward trunk tilt significantly predicted ball velocity from the dominant approach direction. Like the non-dominant condition, this may have been due to insufficient transfer of rotational energy, yet, instead of being a result of an open stance, it was due to a closed stance. Consequently, as the pelvis became blocked off and could not rotate optimally, more distal body segments may have compensated to maintain ball velocities.
Horizontal release angle was the only significant predictor of throw accuracy identified across all three conditions. More accurate throws were related to a smaller horizontal release angle, indicating that reducing the horizontal release angle appears to limit horizontal error. Horizontal error is more important to the throw in cricket than vertical error as a cricketer is permitted to bounce the ball before it reaches the target when throwing. Freeston et al. (2014) commented that limiting horizontal error was indicative of superior throwing, and results appear to support this notion. It must be noted, however, that only the lateral component of accuracy was calculated in the current study. This is a limitation as the ball's displacement does not have an explicitly horizontal component, but a vertical aspect too. This may mean that other kinematic parameters could also be linked to accuracy which were not identified here. Additionally, the confines of the laboratory may have resulted in participants' techniques not being fully representative of how they would be in an unconstrained environment, though further research is required to confirm this.

Conclusion: Five kinematic variables associated with throwing performance were identified in the current study. Parameters differed between conditions, with only stride length (ball velocity) and horizontal release angle (accuracy) being significant predictors of throwing performance from multiple approaches. Additionally, throws were significantly quicker from the straight approach and significantly more accurate from the dominant and straight approaches. This suggests that throwing strategy alters as approach changes, and may help inform future coaching practices in order to improve throwing performance. It is suggested that the throwing skill should be trained from different approach directions so a variety of strategies can be developed, instead of from exclusively straight-on.

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