TECHNIQUE CHANGES ACROSS MAXIMAL AND SUBMAXIMAL INTENSITIES IN FAST BOWLERS: IMPLICATIONS FOR ESTIMATING WORKLOAD

Corey Perrett [1,2], Melanie Bussey [2] and Peter Lamb [2]

[1] Chichester Institute of Sport, Chichester, West Sussex, UK
[2] School of Physical Education, Sport and Exercise Sciences, University of Otago, NZ

The purpose of this study was to determine which technique characteristics were associated with release speed when bowlers prescribed to maximal and submaximal intensities and compare these to the characteristics associated with the fastest bowlers. Elite and sub-elite, male fast bowlers (n=8) bowled one over each at 60%, 80% and 100% intensity in a randomised order and repeated this across two sessions. When bowling faster, bowlers tended to decrease BFC-FFC duration (R=0.63) and had a higher resultant angular velocity (R=0.59) and acceleration (R=0.55) of the non-bowling arm. Meanwhile, the fastest bowlers tended to have the shortest FFC-BR durations (R=0.66). Both inter- and intra-individual variation in technique should be considered when trying to improve performance or monitoring fast bowling workload across a range of intensities.

KEYWORDS: fast bowling, technique, workload, cricket.

INTRODUCTION: The movement of fast bowling involves large external forces and high rotational speeds that cause large amounts of stress to be experienced by many different parts of the body. The large stresses can lead to microtraumas, which in turn can lead to pain and eventual injury if mismanaged (Hamill et al., 2012). Controlling the number of microtraumas, or workload management, is important in fast bowlers due to the commonly recognised association between workload and injury (e.g., Alway et al., 2019; Orchard et al., 2015; Warren et al., 2018). While many methods can be used to characterise 'workload', it is important that any method is able to capture the reduced load placed on the body during submaximal intensity deliveries (Greig & Child, 2019), most likely bowled in trainings and warm-ups.
Previous studies have identified specific characteristics of the fast bowling technique that are critical to performance outcome. For example, a faster run-up velocity (Kiely et al., 2021; Worthington et al., 2013), higher angular velocity of the bowling arm and vertical velocity of the non-bowling arm (Salter et al., 2007) have all been associated with faster bowlers. Consequently, these variables could be measured in the field (e.g., using IMUs) and used as a proxy for release speed to assist in the estimation of workload and workload monitoring. However, if the aforementioned technique characteristics are not associated with release speed when bowlers work across maximal and submaximal intensities, then their potential as a workload variable is greatly reduced.
The aim of this study was therefore to determine which technique characteristics were associated with release speed when elite and sub-elite male fast bowlers responded to a change in performance criterion, i.e., what individuals changed about their technique to bowl faster/slower when prescribing to different intensities. These factors were then compared to the characteristics associated with the fastest bowlers. Specifically, two technique factors were focused upon, the timing of key events in the bowling action, and the kinematics of the non-bowling arm. The findings from this study will be applicable to coaches from a performance perspective (i.e., how to increase maximum release speed) and to sports scientists by improving the understanding of workload monitoring across a range of intensities.

METHODS: A sample of convenience comprised eight right-handed, male fast bowlers (age: 21 ± 3 years; height: 1.82 ± 0.06 m; weight: 82 ± 9 kg) including first-class (n = 2), provincial A (n = 2) and provincial U19 players (n = 4). All participants were free of lumbar stress fractures and disc herniations in the previous 12 months, considered themselves to be match-fit during both sessions and provided written consent prior to data collection. All procedures were approved by the University Ethics Committee (H19/138).

Each bowler was fitted with three Noraxon Ultium multi-modal sensors (Noraxon, Scottsdale, AZ) sampling at 400 Hz and activated to measure IMU data, consisting of a tri-axial accelerometer (± 16 g) and gyroscope (± 2000 $°s^{-1}$). Sensors were placed on the upper-back at the level of ~C7 (*x* and *y* aligned with vertical and mediolateral axes of the upper trunk respectively), non-bowling wrist and bowling wrist (aligned with the anatomical axis of the forearm; *x* vertical, *y* mediolateral). Data from the bowling wrist exceeded the limits of the IMU, so was excluded from the analysis. Video of each ball was captured using a GoPro Hero 5 (GoPro, San Mateo, CA) (frame rate, 100 FPS; ISO, 800; shutter speed, 1/400).

Two repeated testing sessions, one week apart, were used for this cross-sectional study. In each session, participants bowled one over each at 60%, 80% and 100% intensity, in a randomised order and were instructed to bowl a seam-up delivery to try and hit the top of off-stump to a right-handed batter from over the wicket. Release speed was measured using a calibrated Stalker ATSII radar gun (Applied Concepts Inc., Richardson, TX); no feedback on release speed was provided to participants.

Using Kinovea (version 0.8.15), the frame number of back-foot contact (BFC), front-foot contact (FFC) and ball release (BR) was determined for each ball. Raw IMU data were filtered in MATLAB (R2017b; The MathWorks Inc., Natick, MA) using a low-pass, double second-order Butterworth filter with a cut-off at 10 Hz (Winter, 2009). The time between BFC and FFC (BFC-FFC duration), the time between FFC and BR (FFC-BR duration), maximum resultant acceleration and angular velocity of the non-bowling arm were calculated for each ball.

One-sample Kolmogorov Smirnov tests evaluated the normality of the release speed, temporal events and non-bowling arm kinematic data. The association between release speed and technique variables was examined using two separate approaches to determine: 1) The characteristics associated with the fastest bowlers when working maximally; calculated as the correlation between release speed and technique variables across the 100% deliveries, only. 2) The characteristics that were altered when bowlers prescribed to submaximal intensities; calculated as the correlation between release speed and technique variables, across all intensities, when all data was normalised to participant maximums. Results were reported as the Pearson's correlation coefficient (*R*) and corresponding 95% confidence interval (CI). Significance was supported if the 95% CI did not contain 0.

RESULTS: One-sample Kolmogorov Smirnov tests indicated that the residuals from linear regression models fit to prescribed intensity followed a normal distribution for release speed, timing of key events and non-bowling arm kinematics.

Table 1: Association between release speed and four technique variables. Results presented as Pearson's correlation coefficient (R) and the corresponding 95% confidence interval.

Par	Timing		Non-bowling arm	
	BFC-FFC duration	FFC-BR duration	Maximum resultant acceleration	Maximum resultant angular velocity
1	-0.81 [-0.90, -0.81] [1]	-0.10 [-0.42, 0.23]	0.81 [0.65, 0.90] [1]	0.84 [0.70, 0.91] [1]
2	-0.90 [-0.95, -0.81] [1]	0.34 [0.01, 0.59] [1]	0.67 [0.44, 0.82] [1]	0.68 [0.45, 0.82] [1]
3	-0.75 [-0.86, -0.55] [1]	-0.53 [-0.73, -0.24] [1]	0.38 [0.06, 0.63] [1]	0.74 [0.54, 0.86] [1]
4	-0.87 [-0.93, -0.76] [1]	-0.27 [-0.55, 0.06]	0.53 [0.25, 0.73] [1]	0.51 [0.21, 0.72] [1]
5	-0.81 [-0.90, -0.65] [1]	-0.23 [-0.51, 0.11]	0.46 [0.15, 0.68] [1]	0.22 [-0.12, 0.51]
6	-0.77 [-0.88, -0.60] [1]	-0.25 [-0.53, 0.09]	0.44 [0.13, 0.67] [1]	0.12 [-0.21, 0.43]
7	-0.41 [-0.66, -0.10] [1]	-0.13 [-0.44, 0.21]	0.18 [-0.16, 0.48]	0.55 [0.27, 0.75] [1]
8	-0.57 [-0.76, -0.30] [1]	-0.08 [-0.40, 0.25]	0.84 [0.70, 0.91] [1]	0.48 [0.18, 0.70] [1]
Group (100%) [2]	-0.08 [-0.28, 0.12] [1]	-0.66 [-0.76, -0.54] [1]	0.26 [0.06, 0.44] [1]	0.09 [-0.11, 0.29]
Group (all balls) [3]	-0.63 [-0.70, -0.56] [1]	0.10 [-0.02, 0.21]	0.55 [0.46, 0.62] [1]	0.59 [0.51, 0.66] [1]

[1] 95% confidence interval does not include 0
[2] Non-normalised data examined over 100% deliveries only

[3] Data normalised to participant maximum values examined across all intensities

Across all intensities, there was a strong association between normalised release speed and BFC-FFC duration (R = -0.63; 95% CI [-0.70, -0.56]), maximum resultant acceleration (R = 0.55; 95% CI [0.46, 0.62]) and maximum resultant angular velocity of the non-bowling arm (R = 0.59; 95% CI [0.51, 0.66]). All participants had a significant, negative correlation between release speed and BFC-FFC duration (Table) and a significant, positive correlation between release speed and at least one of the resultant kinematic variables from the non-bowling arm. Conversely, only two participants had a significant association between release speed and FFC-BR duration, with one of these associations (P2) being positive.
The fastest deliveries bowled at maximal intensities were associated with a reduced FFC-BR duration (R =-0.66; 95% CI [-0.76, -0.54]) and greater maximum resultant acceleration of the non-bowling arm (R = 0.26; 95% CI [0.06, 0.44]).

DISCUSSION: This study examined ways in which fast bowlers altered their technique when prescribing to submaximal intensities and focused on two technique factors – the timing of key events and non-bowling arm kinematics. The intra-individual changes to technique when individuals worked at higher intensities (e.g., a reduced BFC-FFC duration) were mostly consistent across the group but did not match the characteristics that were associated with release speed at maximal intensities. The results of this study have implications for the estimation of workload in fast bowlers: Any potential workload variable should be sensitive to the intra-individual technique changes that occur during submaximal bowling and therefore able to estimate the stresses placed on the internal structures of the body when different bowlers, with different techniques work across a range of intensities.
The timing of key events in the bowling action has only recently been examined from a performance perspective (Kiely et al., 2021), it was reported that both BFC-FFC and FFC-BR duration were negatively associated with release speed. Our FFC-BR duration results agreed with those presented by Kiely et al. (2021), with the fastest bowlers tending to have the shortest FFC-BR duration (R = 0.66). However, the inverse was seen with our BFC-FFC duration results. While a reduced BFC-FFC duration was a characteristic shown by individuals when they bowled faster (R = 0.63), the fastest bowlers did not have the shortest time between back-foot and front-foot contact (R = 0.08), indicating that it may not be critical to performance in all bowlers who utilise a range of different techniques. Shortening the time between BFC and FFC will reduce the amount of time the body is decelerating in the anteroposterior direction, thereby increasing the amount of momentum a bowler has at front-foot contact and the capacity they have for a higher release speed. However, female bowlers that are more reliant on trunk rotation than run-up speed for ball velocity generation (Felton et al., 2019) would require a greater amount of time for the counter-rotation and rotation of the trunk to occur, therefore a shorter BFC-FFC duration may not be as beneficial. Future studies that examine bowling technique should specify the population(s) that their results are applicable to – if elite, male bowlers make up the entire sample population, then the applicability of any results to adolescent female bowlers may be severely limited. Where possible, individual analyses of fast bowling techniques should continue to be used (Salter et al., 2007).
The kinematics of the non-bowling arm has also been scarcely examined from a technique perspective, with the exception of Salter et al. (2007), who reported that faster bowlers had a higher vertical velocity of the non-bowling arm. Vertical velocity is difficult to determine from a single IMU on the wrist, due to varying amounts of elbow flexion, radioulnar supination, ulnar/radial deviation, and wrist flexion that would alter the orientation of the IMU as the arm is pulled down; instead, maximum resultant acceleration and angular velocity were examined in this study. While a greater resultant acceleration (R = 0.55) and angular velocity (R = 0.59) were characteristics shown by bowlers when bowling faster, it is again important to consider inter-individual variations in results. Two of the participants (P5 and P6) did not have a linear relationship between prescribed intensity and maximum resultant angular velocity of the non-bowling arm, meaning that it would not be an accurate workload variable across intensities for these individuals.

Finally, the limitations of this study must be noted. Firstly, the COVID-19 outbreak greatly shortened the data collection period. This led to a much reduced sample size and also necessitated the use of previously collected data, hence some sub-standard techniques were utilised to determine certain variables (e.g., 2D kinematics at 100 fps to determine temporal events). Secondly, in this paper, submaximal deliveries were considered to be when bowlers intentionally released the ball slower than they were capable of and were all aimed at the top of off-stump. In trainings and/or games, submaximal deliveries would also include slower balls bowled to try and deceive batters, be delivered from both over and around the wicket and have targets other than the top of off stump. Validating any potential workload variable in these aforementioned situations is an important consideration for future studies.

CONCLUSION: Ideally, workload variables would be accurate at estimating the stress that each delivery places on internal structures of the body, regardless of the technique utilised by individuals or the intensity at which they are working at. However, for a single workload variable to be equally accurate for all individuals across all intensities, every bowler would have to alter their technique in a similar way when working submaximally. The results of this study indicate that this is not the case. There is the potential that the fast bowling-research world has skipped an important step when looking to estimate workload. Before it can be hoped that workload can be estimated accurately across a range of intensities, it should first be understood how *each individual bowler* moves at different intensities. If changes to technique are consistent among certain groups of individuals, then different workload variables could be developed that are able to accurately quantify the stresses placed on the internal structures of the body (i.e., workload) during the fast bowling movement.

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