THE USE OF INERTIAL MEASUREMENT UNITS TO IDENTIFY BIOMECHANICAL FACTORS OF PERFORMANCE IN CRICKET FAST BOWLERS

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The role of a cricket bowler is to deliver the ball in such a way as to minimise batsmen scoring runs or get them out. Fast bowlers utilise the pace of delivery as a key tool to achieve this. The purpose of this study was to use inertial measurement units (IMUs) to investigate the relationship between IMU derived spinal kinematics, lower limb accelerations and ball release speed in cricket fast bowlers. Sacral vertical loading rate at back-foot impact and thoracic lateral flexion at front-foot impact displayed significant positive relationships with ball release speed (r=.521 and .629 respectively). Consequently, this study highlights IMUs are able to effectively identify trends in fast bowling performance and hence, larger accelerations at back-foot impact with increased lateral flexion at front-foot impact were effective strategies to increase ball release speed for the bowlers measured in this study.

KEYWORDS: inertial measurement units, fast bowling, cricket, performance.

INTRODUCTION: Biomechanical determinants of fast bowling performance have been well reported within the literature (Bartlett et al. 1996). Studies have generally defined fast bowling performance with ball release speed (Crewe et al. 2013). Higher approach speed, an extended front-knee at front-foot impact, greater trunk flexion through ball release and delayed spinal rotation in the direction of delivery have all been highlighted as key factors affecting ball release speed (Glazier et al. 2000; Worthington et al. 2013). Studies have generally used optoelectronic motion analysis systems. These systems provide a wealth of information, but there are typically limitations such as, portability, cost and restrictions to laboratory environments.

The development of inertial measurement units (IMUs) in recent years have provided valid and reliable alternatives to optoelectronic systems that may address some of these limitations, such as portability and cost (Robert-Lachaine et al. 2017). Previous studies using IMUs in fast bowling have highlighted novel metrics relating to lower limb accelerations and spinal kinematics and how they affect risk of lower back pain (Senington et al. 2018). However, whether inertial sensors are able to provide useful information relating to fast bowling performance has not been reported to the authors' knowledge. In addition, the conclusions from previous work looking at lower back pain risk with IMUs, may be useful to practitioners when looking at technique interventions or coaching. However, uptake is likely to be limited without the knowledge of the effects of these recommendations on fast bowling performance. Therefore, this study aimed to use inertial sensors to assess the correlation between lower limb accelerations and spinal kinematics and fast bowling ball release speed.

METHODS:

Participants

An a priori sample size calculation used senior lumbar flexion at BFI from Senington et al. (2020) (n=14). This yielded an effect size of *d*=1.92, thus a sample of 12 bowlers were needed to achieve an expected power of 0.8 with an alpha value set at $p<0.05$. 13 trained male club level fast bowlers, mean (±SD) age was 23 (5) years, height 1.81 (0.06) m and mass 79 (11) kg were used in this study. All participants were right-handed and classified as fast bowlers by their club coach.

Instrumentation
Three inertial sensors (THETAmetrix) were attached to the skin over the T1, L1 and S1 spinous processes with double-sided tape and re-enforced with elastic adhesive bandage. Sensors contained accelerometers, gyroscopes and magnetometers sampling at 100 Hz. An additional accelerometer (±200 g) sampling at 750 Hz was also attached to the medial aspect of the mid-tibia on the bowlers front and back leg with double-sided tape, vertically aligned to the tibia and secured further with a compressive bandage. One high-speed video camera (Sony FX1000) sampling at 200Hz was used to record ball release speed.

Procedure
Each bowler completed a ‘self-prescribed’ warm up until they felt ready to bowl. Bowlers were then instrumented with sensors as previously described. Instructions to bowl six balls (one over) with maximal effort were given to enable the participants to familiarise themselves with bowling whilst instrumented. Following this, participants bowled with maximal effort for one over. All bowlers bowled at a right-handed batsman in a standard ‘nets’ setup as part of a typical training session on grass wickets.

Data Processing and Statistics
All data were collected in Sensor Suite (Version 504) and transferred to Matlab (Ed. R2012a). Acceleration data were filtered using a bidirectional second-order, zero lag low-pass Butterworth filter with a cut-off frequency of 50 Hz. Resultant acceleration was defined as the square root of the sum of squared accelerations along all three axes. Time-to-peak acceleration was defined as the time taken for acceleration to reach its peak from the point of initial increase manually identified on the impact peak. Average loading rate was calculated by dividing peak tibial acceleration by time-to-peak acceleration.
Absolute orientations were filtered using a bidirectional second-order, zero-lag low-pass Butterworth filter with a cut off frequency of 5Hz (Burnett et al. 1998). Filtered orientations were then used to derive relative angles between two sensors from their direction cosine matrices (Burnett et al. 1998). This enabled the spine to be divided into lumbar, thoracic and thoracolumbar regions. The natural standing posture at the back of the bowler’s run-up facing the direction of delivery (towards the wickets) was taken as the initial frame of reference from which all movements were determined. Flexion, left lateral flexion and left rotation were defined as positive (with all bowlers being right-handed).
Peak accelerations were taken at back and front-foot impact and spinal kinematics between these time points (Senington et al. 2021). Resultant ball velocity was derived from the 5 frames following ball release. Following checks for normal distribution and collinearity, a stepwise multiple regression ($p>0.1$ removal criteria) was performed to explore the relationship between mean tibial and sacral accelerations, spinal kinematics and ball release speed for each bowler. An alpha of $p<0.05$ was set.

RESULTS:

Table 1: Mean (±SD) tibial and sacral accelerations during back and front foot impact and their relationship with ball release speed (n=13).

	Back Foot Impact	r	Front Foot Impact	r
Resultant Tibial Acc (g)	20.52 (5.02)	.186	40.15 (18.68)	.210
Time to Peak Tibial Acc X (ms)	47.32 (21.22)	.276	27.68 (14.94)	.145
Time to Peak Resultant Tibial Acc (ms)	29.23 (9.91)	.209	21.76 (13.23)	.013
Mean Tibial Loading Rate X ($g.s^{-1}$)	361.97 (203.43)	-.300	1156.16 (592.63)	.095
Mean Resultant Tibial Loading Rate ($g.s^{-1}$)	819.07 (234.75)	-.197	2271.40 (1365.37)	.216
Resultant Sacral Acc (g)	2.57 (0.39)	.099	3.23 (1.08)	-.285
Time to Peak Vertical Sacral Acc (ms)	85.03 (44.50)	.122	110.43 (55.23)	.290
Time to Peak Resultant Sacral Acc (ms)	84.65 (44.59)	.118	45.92 (13.27)	-.140
Mean Sacral Vertical Loading Rate ($g.s^{-1}$)	39.66 (24.10)	.521*	41.38 (22.98)	-.261
Mean Sacral Resultant Loading Rate ($g.s^{-1}$)	60.36 (31.29)	.433	79.67 (30.26)	-.204

*p<0.05

Table 2: Mean (±SD) spinal kinematics during back and front foot impact and their relationship with ball release speed (n=13).

Spinal Kinematics (°)	Back Foot Impact	r	Front Foot Impact	r
Shoulder counter-rotation	21.42 (8.17)	.135		
Hip-shoulder separation	33.41 (30.05)	.093		
T1 orientation	260.85 (10.07)	.467		
S1 orientation	259.59 (14.25)	.050		
Lumbar flexion	-15.01 (14.43)	-.025	22.78 (18.30)	-.160
Lumbar lateral flexion	-18.00 (19.47)	.390	11.08 (20.45)	-.195
Lumbar rotation	14.27 (15.41)	-.074	21.84 (29.28)	-.241
Thoracic flexion	-9.97 (14.48)	-.470	21.39 (20.66)	-.114
Thoracic lateral flexion	0.58 (22.84)	-.078	17.70 (21.68)	.629*
Thoracic rotation	-12.30 (10.26)	-.029	22.68 (24.85)	.029
Thoracolumbar flexion	-30.37 (13.95)	-.162	35.74 (14.61)	-.432
Thoracolumbar lateral flexion	-7.93 (26.51)	.034	18.06 (20.97)	-.076
Thoracolumbar rotation	-2.06 (12.44)	.332	22.14 (11.16)	-.266

*p<0.05

Of the thirteen participants analysed in this study, eight (62%) bowlers displayed ‘front-on’ techniques, three (23%) ‘side-on’ and two (15%) mixed. Mean (±SD) ball release speed was recorded at 27.4 (±2.7) m/s. Mean tibial and sacral accelerations and spinal kinematics are reported in Table 1 and 2. Sacral vertical loading rate at BFI displayed a significant positive, moderate correlation with ball release speed account for 27% of variance (r^2=.0.271, p=.041). Thoracic lateral flexion in the direction of delivery at FFI also displayed a significant positive, moderate correlation with ball release speed accounting for 40% of variance (r^2=.396, p=.014).

DISCUSSION:

This study aimed to use novel methods of analysis of tibial and sacral accelerations as well as three-dimensional spinal kinematics to investigate the relationship between ball release speed with fast bowling technique. Whilst previous studies have extensively investigated this relationship, the use of IMUs has highlighted previously unreported variables (Portus et al. 2004; Salter et al. 2007; Worthington et al. 2013). As such, the addition of this knowledge may provide coaches and practitioners with valuable data when using IMUs in practice.

No significant relationships were reported between tibial accelerations and ball release speed in this study. This supports the conclusions from Worthington and colleagues (2013) stating that higher ground reaction force does not necessarily elicit higher ball release speed.

The finding that vertical sacral loading rate at BFI displays a significant positive correlation with ball release speed is a novel one, with few studies reporting impact characteristics at BFI in relation to performance. Crewe et al. (2013) is the only study to report loading further up the body and this only highlights lumbar load between FFI and ball release. The fact that loading rate and not peak values showed a significant relationship, highlights it may not be magnitude of force, but rate at which force is loaded that may contribute to faster deliveries. The same trend was not seen in back foot tibial accelerations. Thus, while impacts may not differ at the tibia, faster bowlers are able to tolerate or produce higher loading rates at the sacrum and therefore transfer more momentum from the run-up into the delivery stride and further up the kinetic chain (Bartlett et al. 1996). Previous studies have outlined that increasing back tibial acceleration at BFI may decrease risk of lower back pain (Senington et al. 2018). Alongside findings from this study, it may be suggested that if an increase in tibial acceleration at BFI can be tolerated, further increasing loading at the sacrum, this intervention may be viable.

Spinal rotation is the only kinematic variable that this study was able to measure that has been correlated to ball release speed in previous literature. Consequently, the fact that this study reports a moderate, positive correlation between thoracic left lateral flexion at FFI and ball release speed is novel. This may be explained by differences in bowling technique and ability

between cohorts; 85% of bowlers in this study were 'front-on' or 'side-on' bowlers whereas previous literature commonly reports a greater percentage of 'mixed' bowling actions. Thus, similar hip and shoulder alignments (seen in front and side-on actions) may allow increased lateral flexion due to less concurrent rotation at these time points. In contrast, the difference in hip and shoulder alignment in the mixed action is likely to limit concurrent lateral flexion and as such is more reliant on shoulder rotation to generate pace on the ball (Glazier, 2010).
Whilst the variables reported in this study give an insight into fast bowling technique and the relationship with ball release speed, it must be acknowledged that thoracic lateral flexion and BFI sacral loading rate described in this study account for 40% and 27% of variance seen in ball release speed respectively (r^2= 0.396 and 0.271). Thus, a large proportion of variance is unaccounted for by this analysis. Biomechanically, this is likely to consist of approach speed, lower limb and shoulder kinematics as highlighted by previous work (Portus et al. 2004; Glazier et al. 2010; Worthington et al. 2013). Aside from biomechanical variables, physical factors will likely result in variance in ball release speed between bowlers. As this study was not able to physiologically profile bowlers, this information was unknown and was therefore not able to be factored into the analysis. Furthermore, care must be taken when interpreting these findings beyond this cohort. As more trained bowlers displaying different bowling actions are unlikely to employ the same strategies.

CONCLUSION:

The findings in this study highlighting positive correlations between BFI sacral loading rate and thoracic lateral flexion and ball release speed are novel findings. Whilst these findings are likely to be specific to the measured cohort, this study does highlight IMUs as a feasible method to monitor technique outside of a laboratory environment. Further investigation should focus on the implementation of IMUs for technique monitoring and whether they are an effective tool in practice.

REFERENCES

Bartlett, R., Stockill, N., Elliott, B. and Burnett, A., 1996. The biomechanics of fast bowling in men's cricket: a review. Journal of Sports Sciences, 14(5), 403-424.

Burnett, A., Barrett, C., Marshall, R., Elliott, B. and Day, R., 1998. Three-dimensional measurement of lumbar spine kinematics for fast bowlers in cricket. Clinical Biomechanics, 13, 574-583.

Crewe, H., Campbell, A., Elliott, B. and Alderson, J., 2013. Lumbo-pelvic loading during fast bowling in adolescent cricketers: The influence of bowling speed and technique. Journal of Sports Sciences, 31(10), 1082-1090.

Glazier, P., 2010. Is the 'crunch factor' an important consideration in the aetiology of lumbar spine pathology in cricket fast bowlers? Sports Medicine, 40(10), 809-815.

Glazier, P., Paradisis, G. and Cooper, S., 2000. Anthropometric and kinematic influences on release speed in men's fast-medium bowling. Journal of Sports Sciences, 18(12), 1013-1021.

Portus, M., Mason, B., Elliott, B., Pfitzner, M. and Done, R., 2004. Cricket: Technique factors related to ball release speed and trunk injuries in high performance cricket fast bowlers. Sports Biomechanics, 3(2), 263-284.

Robert-Lachaine, X., Mecheri, H., Larue, C. and Plamondon, A., 2017. Accuracy and repeatability of single-pose calibration of inertial measurement units for whole-body motion analysis. Gait & Posture, 54, pp.80-86.

Salter, C.W., Sinclair, P.J. and Portus, M.R., 2007. The associations between fast bowling technique and ball release speed: A pilot study of the within-bowler and between-bowler approaches. Journal of Sports Sciences, 25(11), pp.1279-1285.

Senington, B. 2018. An investigation into the spinal kinematics and lower limb impacts during cricket fast bowling and their association with lower back pain. PhD Thesis, Bournemouth University.

Senington, B., Lee, R.Y. and Williams, J.M., 2020. Biomechanical risk factors of lower back pain in cricket fast bowlers using inertial measurement units: a prospective and retrospective investigation. *BMJ Open Sport & Exercise Medicine*, *6*(1), p.e000818.

Senington, B., Lee, R.Y. and Williams, J.M., 2021. Validity and reliability of innovative field measurements of tibial accelerations and spinal kinematics during cricket fast bowling. Medical & Biological Engineering & Computing, 59(7), pp.1475-1484.

Worthington, P., King, M. and Ranson, C., 2013. The influence of cricket fast bowlers' front leg technique on peak ground reaction forces. Journal of Sports Sciences, 31(4), 434-441.