SURFACE MEASURED ACCELERATIONS DURING CRICKET FAST-BOWLING

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The aim of this research was to quantify the magnitude and timing of surface measured accelerations during the fast-bowling action. Eleven males performed 6 maximum velocity deliveries with accelerometers positioned over: both ankles; knees; hips; L5; L1; and the C7 vertebrae. Accelerometer signals exhibited decreased peak and increased time to peak acceleration from the ankle to the C7 sensor. Even when distal accelerations were largest at front foot contact, the body was still able to dissipate more than 90% of the acceleration. Active and passive mechanisms such as joint compliance and spinal compression within the body therefore likely contribute to the progressive attenuation of accelerations. The effects of such compliance on investigations of the intersegmental forces and moments during cricket fast-bowling via inverse dynamics warrants further investigation.

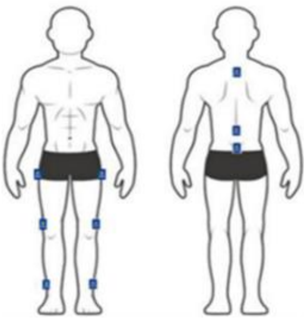
KEYWORDS: accelerometer, attenuation, inertial measurement unit, ground reaction force.

INTRODUCTION: It is well known that lower back injuries - in particular lumbar stress fractures - are the most damaging injury in professional cricket (Johnson et al., 2012). The nature of the fast-bowling action causes repeated mechanical loading of the vertebra, creating microdamage in the bone which can eventually lead to injury (Alway et al., 2019). The aetiology of lumbar stress fractures in fast bowlers remains unclear but is likely to be a combined effect of both intrinsic and extrinsic factors. Muscle strength, flexibility, ground reaction force (GRF), and bowling biomechanics are all factors that have been explored in literature and related to stress fracture injury risk**.** In many high impact activities, the GRF causes accelerations to be transmitted through the tissues of the musculoskeletal system (Zhang et al., 2008), and these accelerations are attenuated through internal body structures. Compliance in the form of joint rotations and tissue deformation extends the impact and reduces accelerations in a distal-to-proximal manner, preventing excessive accelerations from reaching vital organs such as the brain (McErlain-Naylor et al., 2021).
Previous studies which have investigated acceleration transmission have utilised surface mounted accelerometers, with most investigations attaching sensors to the tibia and head of the participants. In activities such as walking, running (Derrick, 1998) and landing (Zhang et al., 2008) the researchers consistently reported lower peak accelerations at the head compared with the tibia. To date there has only been one previous study that has quantified the progressive transfer of accelerations between neighbouring body segments (i.e., foot – shank – thigh – lower back – upper back) during drop jump landings (McErlain-Naylor et al., 2021). Impacts with the ground during the fast-bowling action have been reported to produce significantly greater GRFs than when compared to drop jump landing (Bates et al., 2013). Therefore, previous findings may not share the same conclusions when investigating accelerations during the fast-bowling action. The aim of this study was to quantify the magnitude and timing of surface-measured accelerations at each major human body segment during the fast-bowling action. It was hypothesised that: 1) peak acceleration would decrease

for acceleration signals at progressively more superior body segments: 2) peak accelerations would occur temporally later at more superior body segments. This will be the first investigation using such measures to evaluate the progressive transfer of accelerations between neighbouring body segments during the cricket fast-bowling action.

METHODS: Eleven healthy male, medium – fast bowlers' (19.3 ± 2.3 years, 80.5 ± 9.8 kg, 1.86 ± 0.06 m) who were a mixture of elite level county cricketers and members of Loughborough University 1st team took part in this study. They had no injuries in the 2 months prior to the testing date and the study was approved by Loughborough University's ethics committee. They each conducted an adequate warm-up prior to commencing the dynamic trials. Four Vicon Bonita cameras (OMG Plc, Oxford, UK) capturing at 250 Hz were used to identify the key instances of the action. In addition, nine inertial measurement units (IMUs) (Vicon Blue Trident, Oxford, UK) recording at 1600Hz were placed on the body at specific sites to measure acceleration following the 3 impact phases – back foot contact (BFC), front foot contact (FFC) and follow through (FT). Sensors were placed on both ankles (approximately 5 cm superior to the lateral malleolus), both knees (approximately 5 cm superior to the lateral femoral condyle), both hips (greater trochanter), L5, L1 and C7 vertebrae (Figure 1). The IMU's were secured using a highly adhesive, waterproof tape, not hindering normal physical movement, and reducing movement artefact.

Each bowler was instructed to bowl six maximum velocity deliveries with their front foot hitting the popping crease. The three best trials (fastest deliveries striking the popping crease at FFC) were analysed and averaged for each participant. The time for first contact with the ground at each key instance of the action was determined by the Bonita cameras set up in the laboratory (Figure 2) and fastest delivery determined by a speed radar gun (Stalker II radar gun, Radar Sales, Minneapolis, US) which was positioned behind the bowler's arm. The raw acceleration data from the IMU's were exported and peak resultant acceleration and time to peak resultant acceleration calculated. Statistical analyses were conducted in IBM SPSS Statistics (Version 24, IBM SPSS Software), data presented as mean ± standard deviation. Two-way repeated measures ANOVA ($\alpha = 0.05$) were used to evaluate the effects of accelerometer position (within) and bowling phase (between) on each parameter describing acceleration. Post hoc tests were conducted using Bonferroni analysis.



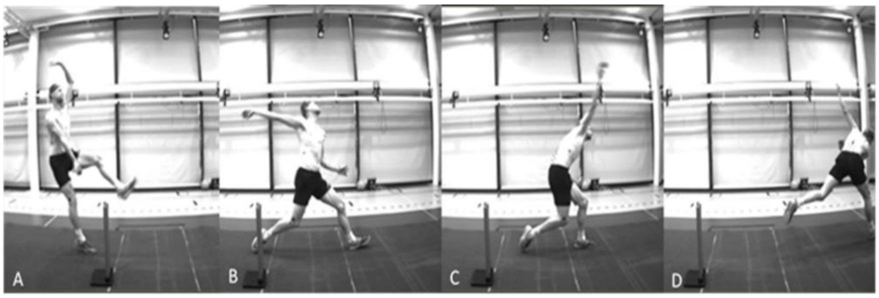
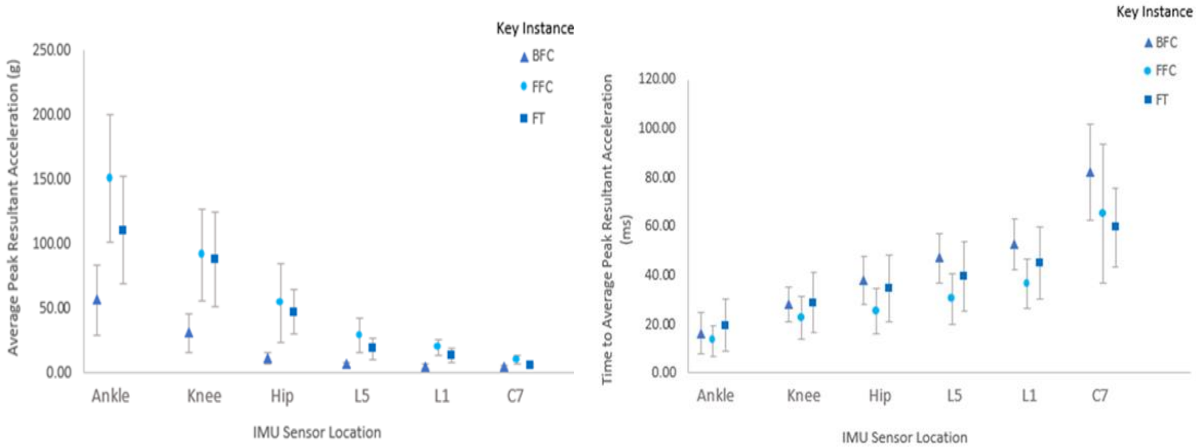


Figure 1&2: Accelerometer locations (left) and Key instance identified (right) (A) BFC (B) FFC (C) Ball Release (D) FT.

RESULTS: Accelerometer position had a significant effect on the magnitude of peak resultant acceleration (Figure 3; $p < 0.01$) and timing (Figure 4; $p < 0.01$) of peak resultant acceleration. Further post hoc comparisons using Bonferroni correction indicated there were significant differences at each accelerometer location for both peak and time to peak resultant accelerations ($p < 0.01$). With every advanced step up the body from ankle to C7, peak resultant accelerations reduced, and the acceleration signals were attenuated. On average, compared with the ankle sensor, peak resultant acceleration was reduced by 45 ± 17%, 77 ± 11%, 88 ± 3%, 91 ± 2% and 93 ± 2% at the knee, hip, L5, L1 and C7 sensor during BFC. Similarly, peak resultant acceleration was reduced by 38 ± 15%, 63 ± 14%, 80 ± 10%, 86 ±

5% and 93 ± 4% during FFC and by 18 ± 20%, 55 ± 11%, 82 ± 8%, 88 ± 4% and 95 ± 3% during the follow through phase (Figure 3). Peak accelerations were also temporally delayed with every progressive step up the body (Figure 4). Bowling phase had a significant effect on peak resultant acceleration, with significant differences between BFC and FT (p < 0.01) and FFC and FT (p < 0.01), however there were no significant differences observed between FFC and the FT phase of the action (Table 1). In addition, bowling phase had no overall effect on the temporal delay of accelerations at each accelerometer position (p = 0.38).



Figures 3&4: Peak resultant (left) and time to peak resultant acceleration (right) at each accelerometer position during key phases of the fast-bowling action. Bars show standard deviation.

Table 1: Comparison of peak resultant acceleration at each key phase during the fast-bowling action. Data presented as mean ± sd. (abc) denotes significance between groups (p<0.05).

Key Instance	IMU Sensor Location					
	Ankle	Knee	Hip	L5	L1	C7
BFC (a)	55.92 (27.57)^{bc}	30.44 (15.34)^{bc}	10.96 (4.58)^{bc}	5.82 (1.85)^{bc}	4.39 (1.63)^{bc}	3.70 (1.06)^{b}
FFC (b)	150.17 (49.67)^{a}	90.75 (36.03)^{a}	53.69 (30.49)^{a}	28.76 (13.32)^{a}	19.27 (5.93)^{a}	9.54 (3.26)^{ac}
FT (c)	110.21 (41.54)^{a}	87.70 (36.70)^{a}	46.84 (17.50)^{a}	18.20 (8.63)^{a}	12.77 (12.78)^{a}	5.21 (1.61)^{b}

DISCUSSION: This investigation explored the surface-mounted accelerations throughout the body following three key instances during the fast-bowling action. The peak accelerations experienced were dissipated in a distal-to-proximal pattern between every sensor location from the ankle to the C7 vertebra, and this dissipation was illustrated by a temporal delay in signals. This is the first investigation quantifying the gradual reduction of impact related accelerations between neighbouring body segments during the fast-bowling action. The gradual distal-to-proximal dissipation meant peak accelerations reduced significantly, so that less than 10% of the acceleration experienced at the ankle was experienced close to vital organs within the body. These results are generally in agreement with previous findings in alternate high impact activities (McErlain-Naylor et al., 2021). It can be argued that specific structures within the lower extremities and torso are affecting attenuation of acceleration. Mechanisms responsible for this attenuation, include but not limited to, lower limb joint rotations, joint compression, soft tissue displacement and intervertebral discs, with Castillo and Lieberman (2018) showing intervertebral discs are associated with increased shock attenuation during running. This may be the reason for the continuous reduction of acceleration seen after L5. This additional attenuation contradicts McErlain-Naylor et al., (2021) who reported no acceleration attenuation beyond the L5 vertebra following drop jump landings. The reasons for this are possibly due to the fast-bowling action producing greater peak accelerations at the ankle sensor and greater accelerations are reaching the L5, L1 and C7 accelerometers.

Measuring the relationship that each specific mechanism (e.g. tissue deformation, spinal compression) has on the dissipation of acceleration falls outside the reach of this investigation. Potential future research could determine what is contributing to the attenuation within the body, particularly considering the possible effects for the modelling of high impact activities such as the fast-bowling action in whole-body inverse and forward dynamics computer simulations (McErlain-Naylor et al., 2021). Previous methodologies that have tried to associate the aetiology of lumbar injuries in cricket fast bowlers may have misinterpreted spinal loading values, as they have not considered how the acceleration is attenuated between multiple body segments. Failure to consider compliance within joint structures could lead to errors in segment accelerations and therefore also in calculated kinetics. Bobbert et al., (1992) suggested intersegmental forces and moments evaluated via inverse dynamics may be misinterpreted if the peak segment accelerations are not correctly analysed. These mechanisms have so far been neglected in existing cricket whole-body simulation models, which have focused solely on performance (Felton et al., 2020) and have not yet explored the relationship between performance and injury. Allen et al., (2012) suggested compliance must be incorporated within a computer model to accurately estimate internal forces during high impact activities such as the triple jump and therefore, must also be included within future cricket fast-bowling simulations.

CONCLUSION: This is the first study to quantify the progressive transfer of acceleration between multiple body segments during the fast-bowling action. Mechanisms associated with the attenuation and delay of acceleration prevent excessive accelerations from reaching an individual's trunk and head. Distal accelerations are greater following FFC and the FT phase of the action, however, the body remains capable of attenuating these accelerations prior to reaching the vital organs. The findings of this study highlight the need to develop a more valid method to quantify accelerations present in the body during cricket fast-bowling and the implications it has on the associated kinetics. One way of achieving this would be to develop a whole-body computer simulation model which incorporates joint compliance between different body segments to accurately represent the transmission of acceleration.

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