Title Page

Tri-axial accelerometry differentiates lumbar and cervico-thoracic spine loading during cricket fast bowling

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Abstract

Context: Epidemiological studies highlight a prevalence of lumbar vertebrae injuries in cricket fast bowlers, with governing bodies implementing rules to reduce exposure. Analysis typically requires complex and laboratory-based biomechanical analyses, lacking ecological validity. Developments in GPS micro-technologies facilitate on-field measures of mechanical intensity, facilitating screening toward prevention and rehabilitation. ***Objective:*** To examine the efficacy of using GPS-mounted tri-axial accelerometers to quantify accumulated body 'load', and to investigate the effect of GPS unit placement in relation to epidemiological observations. ***Design:*** Repeated measures, field-based. ***Setting:*** Regulation cricket pitch. ***Participants:*** 10 male injury-free participants were recruited from a cricket academy (18.1 ± 0.6yrs). ***Intervention:*** Each participant was fitted with two GPS units placed at the cervico-thoracic and lumbar spine to measure tri-axial acceleration (100 Hz). The participants were instructed to deliver a 7 over 'spell' of Fast Bowling, as dictated by governing body guidelines. ***Main Outcome Measures:*** Tri-axial total accumulated body and the relative uni-axial contributions were calculated for each over. ***Results:*** There was no significant main effect for overs bowled, either in total load or the tri-axial contributions to total load. This finding suggests no cumulative fatigue effect across the 10-over spell. However there was a significant main effect for GPS unit location, with the lumbar unit exposed to significantly greater load than the cervico-thoracic unit in each of the tri-axial planes. ***Conclusions:*** There was no evidence to suggest that accumulated 'load' significantly increased as a result of 'spell' duration. In this respect the governing body guidelines for this age group can be considered safe, or potentially even conservative. However the observation of higher body 'load' at the lumbar spine compared with the cervico-thoracic spine supports epidemiological observations of injury incidence. GPS micro-technologies might therefore be considered in screening and monitoring of players toward injury prevention and/or during rehabilitation.

Introduction

It is evident from the epidemiological studies in cricket that fast bowlers are the players at greatest risk of injury.[1,2] Of particular concern is the high prevalence of lumbar vertebrae injuries.[3,4] The high physical demand from repeated impacts with the ground,[5] duration of bowling spells, and repetition of movement have been identified as risk factors for back injuries in fast bowlers, particularly in younger athletes.[6] The spine is vulnerable to damage from repetitive lumbar flexion, rotation and hyperextension.[7] The characteristic counter-rotation of the shoulder axis relative to the hip axis in the transverse plane[8,9] and contralateral lumbar side-flexion motion[5] increase the risk of lumbar stress injuries. Whilst clinicians advocate a minimum rest period of two-three months following a lumbar vertebrae injury,[4] six-twelve months is common for fast bowlers.[10] Time away from sport is therefore a primary concern for fast bowlers.[7]

The training and competition demands of fast bowlers are often characterised by multiple and prolonged spells on consecutive days, increasing the mechanical strain. The aetiological risk attributed to overuse has been considered,[11] and governing bodies have implemented guidelines restricting a player's exposure to the Fast Bowling action. Currently, fast bowlers are restricted to the amount bowling permitted in a 'spell' during competitive match play up to the age of 19. Despite research suggesting bowlers are at a risk of injury, very limited research has been conducted on the changes in mechanical 'load' over the completion of a spell. Research has extensively studied ground reaction forces in relation to injury risk,[12-14] but the laboratory design decreases ecological validity and is typically restricted to analysis of the delivery phase.[15] Quantifying 'load' using force plate analysis discounts the approach phase of the fast bowling action, and the potentially high loading of the follow-through strides after ball release. The laboratory requirements of most biomechanical analyses also limits ecological validity in relation to both prevention of and rehabilitation from injury.

The assessment of body 'load' has been conducted more recently using GPS-mounted tri-axial accelerometry,[16] enabling data collection in the field. GPS accelerometers have been used extensively in team invasion sports such as the Football codes.[17-20] In cricket it has been shown that fast bowlers cover the greatest distance at higher intensities,[21] with highly intermittent activities of variable intensities with varied work-rest ratios.[22]

Our aim was to quantify accumulated body 'load' using GPS tri-axial accelerometry during a bowling 'spell' in young fast bowlers. Typically, the GPS unit is positioned in a vest and worn between the scapulae, with the unit cited at the cervico-thoracic junction (T1). However, the position of the unit will influence the magnitude of response.[23] Given the prevalence of lumbar spine injuries in fast bowlers, a GPS unit was located at both the lumbar (L4) and cervico-thoracic (T1) spine, to examine the efficacy of this technique for monitoring injury risk and/or quantifying load during rehabilitation.

Methods

Design

The study was a repeated measures design. To increase the ecological validity of our study, all analyses were conducted on a regulation cricket pitch with participants tested in a single session. The duration of the bowling spell, which had 7 levels, and the location of the GPS unit were the independent variables. Accumulated body load in each of the tri-axial planes were the dependent variables.

Participants

Fast bowlers were recruited from an elite cricket academy. Inclusion criteria required that participants had a minimum two years bowling at a competitive level, had no previous injuries in the 6 months prior to testing, and no history of chronic low back pain (defined as that exceeding three months in duration). In total, 10 bowlers completed the study (18.1 ± 0.6 yrs). Written informed consent was obtained prior to data collection from the participants, and approval for the study obtained in accordance with Departmental and University ethical procedures in accord with the spirit of the Helsinki declaration.

Procedures

All bowling trials were completed using a regulation cricket crease (22 yards), with wicket at either end, and all bowlers used their full length competition approach. Prior to data collection bowlers completed a warm-up to replicate that performed before matches, incorporating dynamic exercise and practice deliveries. Bowlers were instructed to attempt to hit the stumps by bowling a good length each delivery. Participants bowled in pairs to further enhance ecological validity, with the rest period between overs standardised. Between overs, the subjects undertook passive recovery to simulate typical rest periods seen during competitive cricket. A ‘spell’ of bowling amounts to a number of overs bowled consecutively before a prolonged rest period. An ‘Over’ is classified as a bowler delivering 6 legitimate balls. The number of overs differs between players and is dependent on certain restrictions. The cohort in this study, as U19 players, completed 7 overs in accordance with the fast bowling guidelines prescribed by the ECB.

Participants were fitted with two GPS-mounted tri-axial accelerometer units (Catapult MinimaxX S4, Catapult Innovations, Scoresby, Victoria, Australia). The first unit was placed in a vest and worn by the participants as per manufacturer’s guidelines, positioned on the cervico-thoracic junction at approximately T1. The second unit was fixed (using under-wrap tape (Mueller Sports Medicine Incorporated, Wisconsin, USA)) to the lumbar spine at approximately L4. Data was collected using Catapult MinimaxX GPS-mounted tri-axial accelerometers. Uni-axial acceleration was collected at 100Hz in the medio-lateral (ML), anterio-posterior (AP) and vertical (V) planes. Tri-Axial accelerometry was used to calculate total player ‘Load’using the following formula.[17,24]

$$\text{Player load} = \sqrt{(a_{y1} - a_{y-1})^2 + (a_{x1} - a_{x-1})^2 + (a_{z1} - a_{z-1})^2} \,/\, 100$$

where: a_y = AP acceleration, a_x = ML acceleration, a_z = V acceleration

Accumulated load was calculated in each plane for each over, at the lumbar and cervico-thoracic placements. The relative contributions of each planar vector to total load was subsequently calculated.

Statistical Analyses

Data are presented as mean ± standard deviation across each over, and for each anatomical placement. Load is expressed in arbitrary units (au), consistent with the calculation described previously. To enable an investigation of a main effect for both anatomical placement and bowling duration, a general linear model repeated measures ANOVA was conducted. Statistical significance accepted at $P \leq 0.05$.

Results

Figure 1 summarises the change in total accumulated body load during the 7 over 'spell'. There was no significant main effect for the number of overs completed ($P = 0.31$), with cervico-thoracic load maintained at ~ 21 au and lumbar load maintained at ~ 34 au. Similarly there was no interaction effect between overs bowled and unit placement ($P = 0.20$). However there was a significant main effect for anatomical placement, with load at the lumbar spine significantly ($P = 0.04$) higher than the cervico-thoracic spine for each over.

*** Insert Figure 1 near here ***

There was no significant main effect for overs bowled in any movement plane (V: $P = 0.29$; AP: $P = 0.34$; ML: $P = 0.56$), and no interaction effect with unit placement. Load was higher at the lumbar spine than the cervico-thoracic spine in the V (L ~ 13.5 au, CT ~ 8.8 au, $P = 0.07$) and AP (L ~ 8.5 au, CT ~ 6.2 au, $P = 0.10$) planes. Lumbar load was significantly higher than cervico-thoracic load in the ML plane (L ~ 12.2 au, CT ~ 5.8 au, $P = 0.01$), as summarised in Figure 2.

** *Insert Figure 2 near here* **

There was no significant main effect for number of overs bowled in the relative uni-axial contributions to total load. The average percentile vector contributions of V:AP:ML were 42:30:28 for the cervico-thoracic spine, and 39:25:36 for the lumbar spine (Figure 3). The medio-lateral contribution to total load was significantly greater ($P = 0.03$) at the lumbar spine than the cervico-thoracic spine. The compensatory decreases in the relative contributions of AP ($P = 0.10$) and V loading ($P = 0.22$) at the lumbar spine were not statistically significant.

** *Insert Figure 3 near here* **

Discussion

Our aim was to assess the influence of 'spell' duration on mechanical 'load' during fast bowling using tri-axial accelerometry, and to consider the efficacy of this technique as a means of monitoring intensity as a marker of injury risk. The 7 over spell had no temporal effect on the total accumulated body load, or the uni-axial load in each movement plane. These findings suggest no acute effect of this bowling exposure on mechanical load as quantified using GPS-mounted tri-axial accelerometry. Although direct comparisons must be treated with caution, previous studies have similarly reported no performance decline over an 8 over spell,[25] and no increase in injury incidence rate in fast bowlers with a greater exposure.[26] These findings suggest that the ECB guidelines used in designing this study do protect the bowler from short-term injury risk. Indeed the guidelines might be overly conservative, restricting the (technical and tactical) development of young bowlers. The late stage rehabilitation of bowlers toward return-to-play can also be informed by such measures, facilitating graded increases in mechanical load.

The concept of overuse as an aetiological risk factor for lumbar injury might be age-dependant, with previous research identifying that bowlers with spinal abnormalities were significantly older than other asymptomatic cricketers.[13] Exposure must therefore be considered as a chronic issue, with no increase in subsequent injury risk for higher workloads in the medium term, but exceeding 100 overs (i.e., 600 match balls bowled) in 17 days or less has been associated with higher injury rates.[27] In line with current ECB guidelines for young fast bowlers, the maximum of 7 overs would exceed 100 overs only if the bowler performed almost every day.

The association between high bowling workloads during matches and lumbar injury potential might be attributable to modifications or compensations in bowling action to account for fatigue.[7] The combination of lumbar extension, contralateral side flexion, ipsilateral rotation and shoulder counter-rotation during the bowling delivery have been related to the aetiology of lower back injuries.[9,28,29] Whilst no decline in ball release speed was observed in an 8 over spell,[25] shoulder counter-rotation (a highly associated risk factor for lumbar injury) increased significantly.

The anatomical specificity in injury epidemiology informed the design of our study, with an additional tri-axial accelerometer placed at the lumbar spine as a comparison with the more often used cervico-thoracic location. The positioning of the GPS unit in the vest worn at the cervico-thoracic junction is recommended by manufacturers to enhance positioning signal.[30] The 'load' is based on the movement of the GPS unit, and thus will be site-specific. The consideration of uni-axial contributions to total body 'load' has potential in understanding technique modifications.[17] Whilst the current study showed no fatigue effect in uni-axial load, the lumbar spine was exposed to significantly greater total accumulated body load throughout the bowling spell. This greater accumulation of load supports epidemiological observations of back injuries in fast bowlers.[3,4] This observation can be attributed to the functional role of the lumbar, cervical and thoracic spines during fast bowling. In the thoracic spine the arrangement of the superior and inferior articular processes restricts flexion and extension, and lateral flexion is limited by the thoracic cage. In the lumbar region the articular processes provide rotational stability and primarily enables flexion and extension between adjacent vertebrae. In comparison to the relatively fixed cervico-thoracic junction, the lumbar spine can become rotated, hyperextended, laterally flexed and axially loaded during bowling. The lumbar flexion, rotation and hyperextension,[7] transverse counter-rotation of the shoulders relative to the hips ,[8,9] and the contralateral side-flexion motion[5] of the lumbar spine are characteristic of fast bowling technique.

The increase in load at the lumbar spine was evident in all directions, but most notably in the medio-lateral plane. Subsequently the relative contribution of medio-lateral loading was significantly higher at the lumbar spine than the cervico-thoracic spine. The relative directional demands placed on the lumbar and cervico-thoracic spine have implications for the aetiological risk factors described previously. These findings support the mechanical efficacy in using tri-axial accelerometry to monitor training load, or in quantifying rehabilitation.

Few other studies have considered the anatomical placement of the GPS-mounted accelerometer for quantifying mechanical demands. In treadmill running body 'load' was measured at the scapulae and the centre of mass,[23] considered the criterion location for body 'load' assessment.[30] However the centre of mass must be considered as a hypothetical and fluid location, of no specific relevance to injury epidemiology. There is however opportunity for alternate (or multiple) placement of the GPS unit to fit the relevance of the sport, and the research question. In the present study the tri-axial evaluation of 'load' may facilitate in the identification of the causes most associated with lumbar spine abnormalities in fast bowling. This technique might be further developed to consider lower-limb loading using anatomically relevant sites for the GPS units, and utilised increasingly in injury prevention and rehabilitation.

The current study considered only one age group (U19), and did not sub-sample for bowling style, a commonly cited risk factor for lumbar vertebrae injury.[8,9,13,] Exposure (by age and/or playing level) and bowling action warrant further investigation. Furthermore, the findings of our study cannot be generalised beyond a single 'spell' of 7 overs duration, and the influence of bowling style and the potential speed-accuracy trade-off with fatigue warrant further investigation.

Conclusions

The 7 over 'spell' had no significant effects on accumulated body 'load', either total or in each orthogonal movement plane. This suggests that the governing body guidelines used to inform the research design are safe, at least in the short-term. If overly conservative, such guidelines might hamper technical development in young bowlers, and alternate means of injury prevention might be considered. In rehabilitation this technique provides a means of quantifying load, enabling a graded adaptation.

The significantly higher load measured at the lumbar spine in comparison to the cervico-thoracic spine supports epidemiological observations in young fast bowlers. Our results suggest that GPS-mounted tri-axial accelerometry has potential to differentiate the load at the lumbar and cervico-thoracic spine, with implications for use in training and match-play. Furthermore, the opportunity to collect biomechanical data in the field widens the sphere of research questions and increases ecological validity.

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Figure Legends

Figure 1. Temporal pattern of changes in total accumulated body load.

Figure 2. Temporal pattern of changes in Medio-Lateral body load.

Figure 3. Relative uni-axial contributions to total accumulated body load.

Figure 1. Temporal pattern of changes in total accumulated body load.

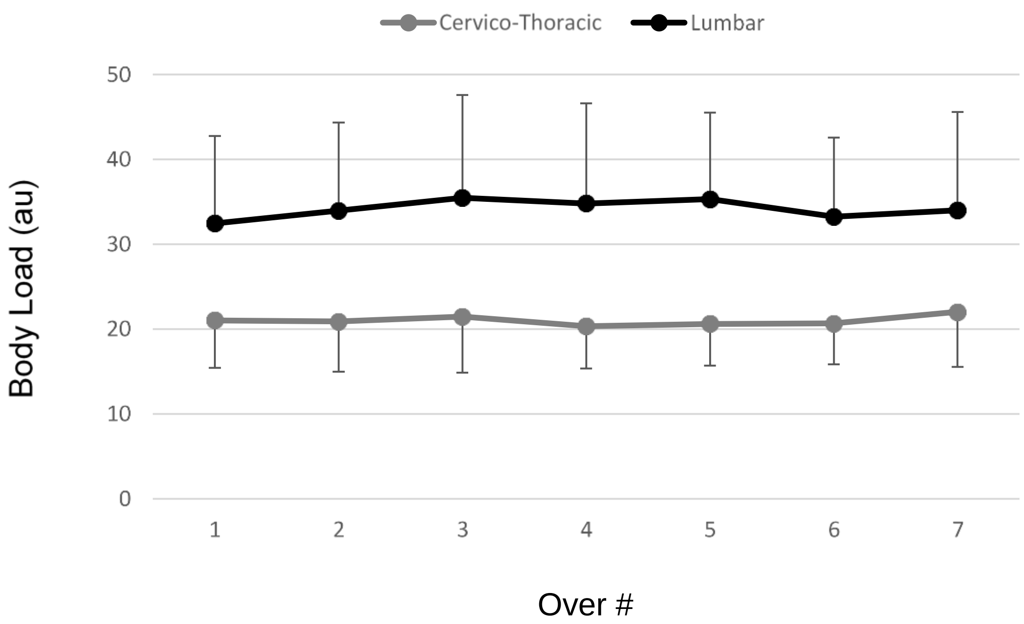
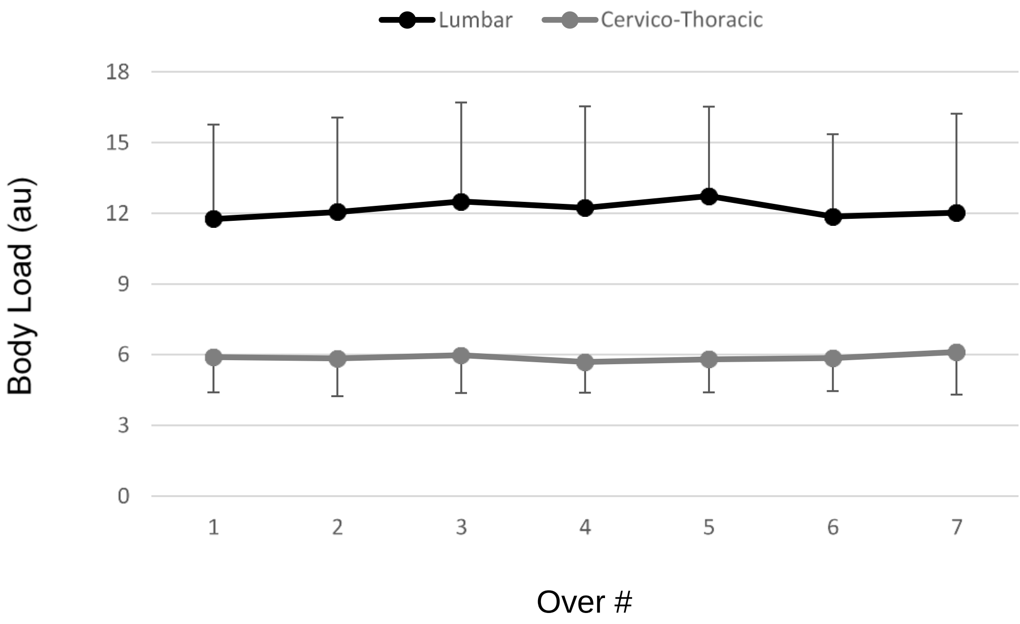


Figure 2. Temporal pattern of changes in Medio-Lateral body load.



357

Figure 3. Relative uni-axial contributions to total accumulated body load.