

CAN INERTIAL MEASUREMENT UNITS BE USED TO VALIDLY MEASURE PELVIS AND THORAX MOTION DURING CRICKET BOWLING?

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Identifying lumbar injury risk amongst cricket bowlers is a challenge to those involved in the sport. Bowling technique injury risk factors concerning thoracic and pelvic motion have been identified by previous research that used three-dimensional (3D) retro-reflective (RR) motion analysis. Inertial measurement units (IMUs) are considered a feasible and more portable means of 3D motion analysis. However, the validity of IMU measurement of thorax and pelvis movement during bowling has not yet been fully determined. This study aimed to achieve this by comparing concurrent IMU and RR angle outputs. Results suggest that when RR coordinate systems are aligned with the IMUs' there are no significant differences in cricket bowling relevant angle outputs. However, some differences arise when IMUs are compared to the anatomically derived RR angle outputs typically used in 3D analysis.

KEY WORDS: Inertial sensors, lumbar injury, injury screening

INTRODUCTION: Cricket fast bowlers are significantly more likely to suffer debilitating lumbar injuries than the general population (Johnson, Ferreira, & Hush, 2012). Bowling technique factors have been previously related to injury incidence (Bayne, Elliott, Campbell, & Alderson, 2016; Olivier et al., 2016). Many of these factors involve thorax and pelvis kinematics. Excessive rotation of the shoulders away from the bowling direction (shoulder counter-rotation) and shoulder-pelvis separation (SPS) at the start of the delivery stride, were linked to injury incidence in early prospective studies on bowling (Foster, John, Elliott, Ackland, & Fitch, 1989). More recent prospective studies have associated thorax lateral flexion (TLF) contralateral to the bowling arm, excessive pelvis rotation, and reduced front-leg hip flexion with increased injury risk (Bayne et al., 2016). Injury risk thresholds for the majority of these variables were identified by studies that used retro-reflective (RR) three-dimensional (3D) motion analysis (Bayne et al., 2016). Though reported to have sub-millimetre accuracy (Windolf, Gotzen, & Morlock, 2008), RR motion capture is unavailable to most bowlers and has poor ecological validity. Consequently, alternative analysis technologies are an attractive proposition to cricket coaches for lumbar injury risk screening purposes. Inertial measurement units (IMUs) combine accelerometers, gyroscopes and magnetometers to measure 3D motion. Unlike RR systems, they are relatively affordable, portable and easy to use, making them ideal for field use. Unfortunately, IMU literature has typically focused on validating IMU angle measurement for simple motions such as uniplanar movement or gait (Lopez-Nava & Angelica, 2016). IMU measurement validity for thorax and pelvis kinematics is unknown for cricket bowling. Therefore, this research aimed to assess whether IMUs are able to validly measure the high-speed, multi-planar thoracic and pelvic movements exhibited during cricket bowling. Concurrent IMU and RR angle measures were compared during the bowling action. RR coordinate systems aligned to the IMU coordinate systems, as well as anatomically defined segment coordinate systems were created to allow dual comparison. It was hypothesised that when the 3D coordinate systems of the IMUs and RR systems were aligned there would be no significant differences in angle outputs. However, some differences were expected when IMU angles were compared to anatomically defined angles that are typical of RR 3D modelling.

METHODS: Seven asymptomatic male (Mean \pm SD: 183.2 \pm 7.7 cm, 75.3 \pm 8.3 kg, age 26.1 \pm 8.6 years) and three asymptomatic female (Mean \pm SD: 173.8 \pm 6.2 cm, 66.7 \pm 4.9 kg, age 18.3 \pm 4.2 years) state or club level fast/medium bowlers agreed to participate in the study. Informed consent was obtained before data collection commenced. Data collection was completed in an indoor biomechanics laboratory. Ethical approval was granted prior to the commencement of the study.

Three XSens Mtw Awinda model IMUs (Enschede, Netherlands) (75 Hz sample, \pm 2000 deg/s gyroscope, \pm 160 m/s² accelerometer, \pm 1.9 Gauss magnetometer) were each placed on the thorax, pelvis, and shank. The thorax sensor was placed with its superior edge between the spinous processes of the 7th cervical (C7) and 1st thoracic (T1) vertebrae. The pelvis IMU had its inferior edge on the spinous process of the second sacral vertebrae, and the shank sensor was approximately 5 cm superior to the lateral malleolus, ipsilateral to the bowling arm. IMU data was captured by the manufacturer's software (MT Manager 4.2.1, Xsens Technologies).

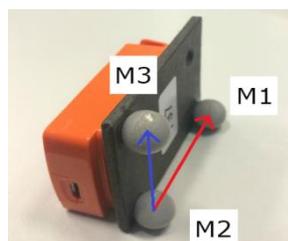


Figure 1: IMU and rigid marker plate.

RR marker trajectories were recorded using a 300 Hz, 20 camera Vicon system (Oxford, UK). The IMUs were overlaid by three-marker rigid plates (Figure 1), allowing creation of a RR technical coordinate system (RRtech). The RRtech orientation and the IMUs' coordinate system (IMUtech) orientations were aligned. The RRtech origin was the mean position of the three markers, with the first and second defining lines being M2 to M1 and M2 to M3 respectively (Figure 1). The first defining line was the y-axis, with the x-axis the cross-product of the first and second defining lines, and the z-axis perpendicular to the y and x axes.

A customised marker set and model was used to anatomically model the shoulders, thorax and pelvis (Campbell, Lloyd, Alderson, & Elliott, 2009; Dempsey et al., 2007). An upper thorax segment was created for measurement of shoulder counter-rotation (SCR) and SPS (Middleton, Foster, & Alderson, 2016). Anatomically defined segment coordinate systems are henceforth referred to as RRanat. Participants performed five bowling trials at match intensity, with the two trials of best data quality selected for analysis (determined by visual inspection). Two AMTI (Advanced Mechanical Technology Inc., Watertown, MA) force plates (1800 Hz) captured back foot contact (BFC) and front foot contact (FFC) of the bowling stride. A 300 Hz Vicon Bonita camera (Oxford, UK) synchronised with the RR system, was placed sagittal to a bowling crease marked on the second force plate. It was used to identify ball release (BR) post-data collection. Participants performed a calf-raise at the start of each trial to facilitate post processing temporal synchronisation. IMU data was processed using in-built Kalman filters to calculate IMU orientations from accelerations and angular velocities. Relative and absolute IMU angles were output as quaternions using the Xsens MT Manager software (Enschede, Netherlands). Prior to modelling, RR trajectories were filtered by a 4th order, low-pass Butterworth filter, with a 15 Hz cut-off determined by residual analysis (Winter, 1990). BFC to FFC was termed the delivery step, with delivery stride from BFC to BR.

IMU and RR data was processed further and output by a customised program developed in LabVIEW 2017 (National Instruments Corp. Austin, Texas). Relative and global IMU angles were produced from the quaternion outputs from each individual IMU. Phases were time normalised to 101 data-points using cubic spline interpolation. RR and IMU joint angles were output as Euler angles by following the Grood and Suntay method (Grood & Suntay, 1983).

One-dimensional statistical parametric mapping (1DSPM) incorporating a paired t-test ($p < 0.05$) (Pataky, Robinson, & Vanrenterghem, 2013) was used to test angular differences between IMUtech and RRtech, and IMUtech and RRanat for the variables of interest. SCR (global upper thorax rotation angle) and SPS (relative rotation angle between the upper thorax and pelvis) were assessed during the delivery step. Pelvis rotation (global pelvis angle), TLF (global TLF angle), thorax-to-pelvis flexion-extension (relative angle between the thorax and pelvis), and thorax-to-pelvis lateral flexion (relative angle between the thorax and pelvis) were all assessed during the delivery stride.

RESULTS AND DISCUSSION: The 1DSPM measurement comparison between IMUtech and RRtech showed no significant angle differences for any of the variables assessed. This suggests, that when coordinate systems are comparable, IMUs have good 3D measurement validity compared with RR systems for dynamic, multi-planar movements. The 1DSPM analysis of IMUtech vs RRanat did show significant differences for some variables. Shoulder rotation measurements were significantly different from 0-4% ($p=0.045$) and 92-100% ($p=0.048$) of the delivery step (Figure 2a), however SPS measures were not different during the same phase. Pelvis rotation measures were not significant different, however the other three delivery stride variables all displayed discrepancies. IMUs underestimated global TLF

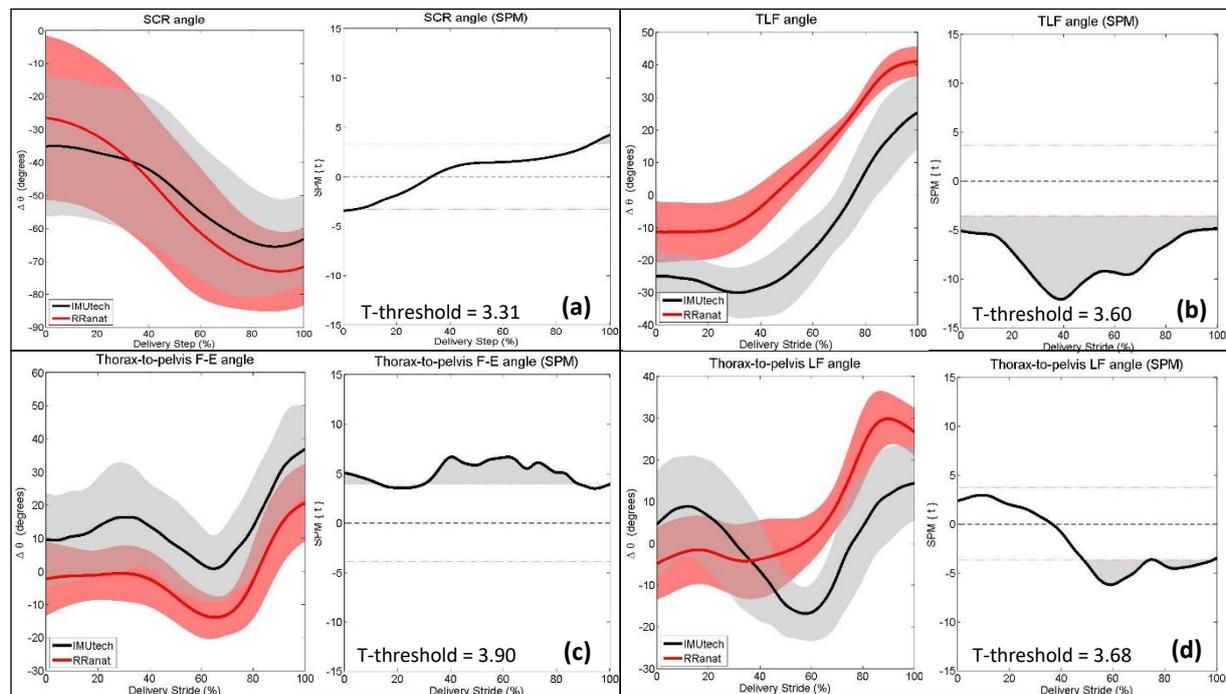


Figure 2: 1DSPM for IMUtech (black/grey) versus RRanat (red). Time-varying angles with standard deviation clouds plus SPM graphs are shown for factors with significant differences: (a) SCR, (b) TLF, (c) thorax-to-pelvis flexion-extension, (d) thorax-to-pelvis lateral flexion. Significance ($p<0.05$) was reached when the t-threshold was crossed on the SPM graph.

when compared with RRanat, with significant differences for 100% of the delivery stride ($p<0.01$) (Figure 2b). Significant differences were also seen for thorax-to-pelvis flexion-extension at 0-13% ($p<0.01$) and 30-88% ($p=0.048$) of the delivery stride (Figure 2c), and thorax-to-pelvis lateral flexion at 49-73% ($p<0.01$) and 76-98% ($p<0.01$) of the delivery stride (Figure 2d). Given no significant differences were found between IMUtech and RRtech measures, our findings suggest that pelvis and thorax angle measurement differences between IMUs and RR systems are likely due to segment coordinate system modelling differences. The findings suggest that IMUs are capable of validly measuring dynamic, multi-planar movements, but the IMU movement may not reflect movement of the whole body segment. The inherent errors associated with RR motion capture, and IMU motion capture to a lesser extent, may also contribute to discrepancies in measurement. Marker placement errors and movement artefacts can contribute to misrepresentations of joint centre positions and segment orientations during anatomical modelling (Reinschmidt, Van den Bogert, Nigg, Lundberg, & Murphy, 1997; Taylor et al., 2005). The employed assumption that body segments are rigid entities is also not always accurate. Significant differences were displayed for IMUtech to RRanat comparisons involving the thorax segment. The thoracic spine is comprised of 12 vertebrae that do not move as a single unit, therefore expecting an IMU to represent the movement of the entire thorax may be unrealistic. The SJs were also used to define the upper thorax segment. SJC estimation is known to become less reliable during humeral elevation (Campbell, Alderson, Lloyd, & Elliott, 2009); a movement exhibited at high

velocities during bowling. These examples may help to explain why significant differences were exhibited for IMUtech to RRanat comparisons relating to the thorax but not for pelvis rotation. The pelvis is an almost rigid segment and hence is likely to be less susceptible to some of the errors presented. The findings suggest that IMUs are capable of measuring high-speed, multi-planar movement with measurement differences between IMU and RR methods most likely attributable to coordinate system definition differences.

Future work will evaluate dynamic, multi-planar measurement validity of IMUs from other manufacturers. IMU measurement validity for movements of other body segments during bowling is also of interest. It may be prudent for cricket researchers to establish new IMU-derived thresholds for the injury risk factors discussed in this paper. This would enable cricket coaches to screen bowlers for 3D lumbar injury risk factors by using IMUs.

CONCLUSION: We provide evidence supporting the use of IMUs to validly measure high-speed, multi-planar movements, such as those displayed during cricket bowling. Modelling differences between the IMU coordinate systems and the anatomically defined body segment coordinate systems used in RR 3D motion capture appear to be the main cause of statistical differences for 3D angular measures of thorax and pelvis motion during bowling. Nonetheless, these findings suggest that valid field-based 3D kinematic screening for lumbar injury risk factors in cricket bowlers is a sensible and feasible aim.

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