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INERTIAL MOVEMENT ANALYSIS
WHITE PAPER

INTRODUCTION

Athlete tracking has evolved since the first application of Global Positioning Technology (GPS) to quantify athlete movement. PlayerLoad™ has been used as a key load monitoring variable across multiple elite sports[1,2]. Being an accelerometer derived variable, PlayerLoad™ remains favourable due to its ability to capture all movement of the athlete, not limited to running events.

The ability to objectively quantify athletes external load has enabled great insight into athlete load management and performance[5,6,7]. As a result, sport training has evolved whereby elite sporting teams around the world prescribe training protocols during and out of season based on reliable and accurate information[1,2]. While PlayerLoad™ is a valid load monitoring tool[1,2] one limitation is the inability to filter out high intensity acceleration, deceleration and change of direction (COD) micro movements. These short, frequent bursts of high intensity movements are an important component of many team sports such as: American Football, Basketball[3], Rugby League, Australian Football and Soccer. To identify these high frequency acceleration, deceleration and COD movements Catapult Sports created a non-gravity resultant vector of the X, Y and Z planes known as the inertial measurement unit (IMU). Recent literature supports the validity of the IMU acceleration stream during walking, jogging and running in comparison to motion capture as the criterion measure[8].

Using a combination of this accelerometer and gyroscope information through Kalman filtering techniques it is possible to identify specific micro movements referred to as the Inertial Movement Analysis (IMA). In order to register as an IMA event there are two criteria that must be met; magnitude and direction.

CALCULATION OF MAGNITUDE

To qualify as an IMA event a polynomial least squares fit is applied to the X,Y,Z resultant acceleration data and smoothed at a known frequency. This smoothed trace is then overlayed with the original acceleration trace and from here the start and end point of each event is identified. Once identified the sum of the X,Y area is calculated and expressed as the event magnitude in m/s.

CALCULATION OF DIRECTION

The direction of force applied throughout each IMA event dictates whether an event is registered as an acceleration, deceleration or change of direction. Broken up into 12, 30-degree segments whereby acceleration, deceleration and left/right change of direction consistent of a range across three, 30 degree segments.

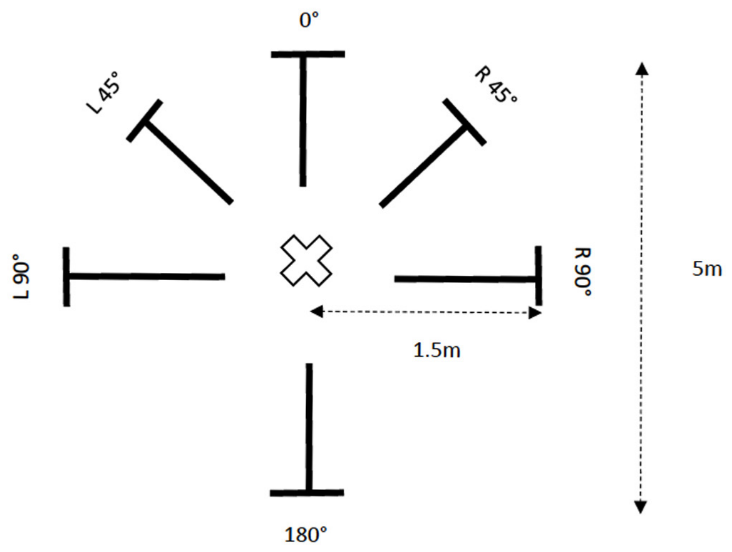
There is limited research investigating the reliability of the Catapult IMA algorithm to correctly identify the direction registered when an athlete performs a cut to change left or right[9,10,11]. Therefore, the aim of this investigation was to isolate the IMA event at the initial cut and report what the IMA output is at that time. Secondly, we aim to compare the IMA resultant acceleration to the motion analysis gold standard at the time of the cut, both filtered at the same frequency.

METHODS

Fifteen physically active participants were recruited for this study, mean age was 18 ± 1 year. Ethical approval from the Nebraska University Institutional Review Board was obtained and informed written consent from each participant prior to the commencement of the study. Familiarization of all courses and equipment were performed prior to data collection. Participants wore a single, athlete tracking device (Optimeye S5, Catapult Sports, Australia) positioned between the shoulder blades and worn in a tightly fitted manufacturer supplied garment. The device weighs 67g with a dimension of 96 x 52 x 14 mm. Each device contains multiple sensors including a tri-axial accelerometer and 3D gyroscope both sampling at 100Hz. A reflective marker was placed on the device to obtain the criterion measure of acceleration, determining its position using a calibrated 24 camera motion analysis system (Qualisys Oqus 7+, Goteborg Sweden), operating at 200Hz. Motion capture data was then downloaded to 100Hz to match that of Catapult accelerometery data. Video footage was captured at 25Hz to obtain the criterion measure of effort count and allow detection of time of cut.

DATA COLLECTION

Participants completed three countermovement jumps both pre and post each trial. Following the countermovement jumps, each participant was instructed to complete a series of acceleration, deceleration and change of direction cuts (see Figure 1). In total, there were six direction cuts and the course was completed three times with 2 minutes rest between trials. To avoid any learning affect all trials were randomized prior to commencing the study. Participants were instructed to complete each course with a clear, explosive movement at maximal intensity.



DATA PROCESSING

Data from the Catapult tracking device and motion analysis (MA) system were downloaded and analysed through manufacturer supplied software (MA: Visual3D - C Motion, Germantown, Maryland, Accelerometer: OpenField 1.14, Catapult Sports, Australia). The combination of X,Y,Z axes were exported from both systems where the resultant data was calculated and used for further analysis.

Based on previous findings the MA and Catapult data was smoothed using a fourth order, dual pass, butterworth filter at a 6Hz cut-off frequency and accelerometer data also at a 6Hz cut-off frequency.

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The resultant accelerometer values without the effect of gravity were compared to the MA resultant values for each direction change.

To ensure a representative sample was selected for comparison 25Hz video footage was synced with Catapult accelerometery data to identify the time of the cut.

Once MA and Catapult accelerometery data was synced and the peak at the cut identified, 90 data points either side of the peak were selected per cut.

The data was tested for heteroscedasticity by plotting a figure of the residual error versus the predicted acceleration measure and computing the correlation.

Correlation coefficients (r) were calculated to examine the relationship between the MA criterion and acceleration measures.

Correlations are categorised as strong ($1.0 \geq r \geq 0.5$), moderation ($0.5 < r \geq 0.3$), and weak ($r < 0.3$), (Cohen, 1992).

A paired sample T-test was used to determine whether the criterion measure for each change of direction task were significantly different from each other.

Figure 2 shows an example of the synced Catapult and motion analysis accelerometer trace.

Video footage from each circuit was downsampled through analysis software to allow detection of each effort count.

To examine the relationship between the video criterion measure of effort count and IMU derived measure, Pearson's correlation coefficient was calculated.

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RESULTS

No significant (P > 0.05) differences were detected between the Catapult accelerometry and motion analysis derived acceleration. A strong correlation (r=0.980) was observed between Catapult accelerometry and motion analysis acceleration.

From the 15 participant's a total of 204 trials were recorded, of these 101 were used for comparison. Only trials that were synced with no offset were analysed and additionally only those with no dropouts in motion analysis acceleration were used. This was done to ensure only accurately synced data was used for comparison. The mean acceleration reported from the Catapult data was 0.925 G (95% CI, 0.90-0.95) and motion analysis acceleration data 0.964 G (95% CI,0.94-0.99) as seen in Table 1. From these 15 participant's all direction cuts regardless of angle were included. A strong correlation (r=0.98) was observed between the catapult and motion analysis acceleration (Figure 2).

Figure 2. Comparison of Catapult acceleration (meanCA) and motion analysis acceleration (meanMA). Data are recorded as means where each data point in the figure represents a single change of direction cut across 42 trials.

Data from the 45 and 90 degrees left and right change of direction movements were analysed to investigate the IMA algorithm accuracy at correctly identifying these events. Trials were only included if participants reached the threshold of a 'low' IMA event of 1.5 as only those events >1.5 are included in the IMA count within the software. Shown in Table 2 the total count of events included were; 43, 45, 40 and 44 for 45 left, 90 left, 45 right and 90 right, respectively. Error has been reported as percentage.

Table 1.
Comparison of Catapult and Motion Analysis Acceleration during each COD cut

	Catapult	Motion Analysis
Mean	0.925	0.964
Range	0.543 (0.90 - 0.95)	0.583 (0.94 - 0.99)
Total	101	101
Correlation, *r*	0.980	

Data are means, expressed in G and (95% confidence interval, CI).

Table 2
Count of left and right 45 degree and 90 degree change of direction cuts.

	45 L	90 L	45 R	90 R
Acceleration				
Deceleration			3	7
Right	1	2	35	36
Left	42	43	2	1
Total	43	45	40	44
Error	2%	4%	13%	18%

DISCUSSION

Results from this study suggest that Catapult accelerometery data offer a valid data stream when compared to the criterion measure of Motion Analysis.

Across the 42 analysed trials the average acceleration for the Catapult and Motion Analysis acceleration were 0.821 & 0.856, respectively. Additionally, the strong correlation of r=0.988 indicates a very strong relationship between these two variables. This is consistent with previous research8, although Wundersitz filtered the data at 8Hz and 10Hz cut off. In this study, it was decided to filter at 6Hz to match the motion capture. Gravity decoupled acceleration forms the basis in determining the 'IMA' or explosive movement events.

This study confirms Catapult accelerometery is an accurate measure, however this is not the metric that's reported on a daily basis by practitioners in the sports science field. It has been shown that IMA events are best reported as a total[10]. Contrary to these findings the current study confirms the IMA cut to be accurately categorized when performing 45 and 90 degree left change of direction with an error of 2% and 4%, respectively. The error on the right direction cuts were not as acceptable being 13% and 18% for 45 and 90 degrees, respectively. The population completing these trials was non-elite and therefore may explain their inability to change direction with the same level of skill execution on both sides.

Additionally, IMA will be affected most by the direction of the trunk as this is where the device is mounted. Therefore, the direction in which the force is applied at the time of the cut dictates the direction the IMA event is registered. In this population, it's possible they were not able to clearly execute the right direction cuts as proficiently as they could on the left. It does appear the misclassification of events as decelerations highlights this. Future research should focus on repeating the course with an elite population throughout multiple sports to understand whether these results remain consistent.

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