VALIDATION OF INERTIAL MEASUREMENT UNITS FOR TRACKING 100M SPRINT DATA

Lucy Parrington[1], Elissa Phillips[2], Andrew Wong[3], Mark Finch[3], Elizabeth Wain[4] and Clare MacMahon[1]

1. School of Health Sciences, Faculty of Health, Arts and Design, Swinburne University, Hawthorn, Victoria, Australia
2. Australia Institute of Sport, Canberra, Australia
3. iMeasureU, Auckland, New Zealand
4. School of Engineering, Faculty of Science, Engineering and Technology, Swinburne University, Hawthorn, Victoria, Australia

Wearable micro sensor measurement devices are a promising development in sports technology. This paper presents preliminary data evaluating the accuracy of an inertial measurement unit during 100m sprints against a criterion measure from a tripod-mounted Laveg laser. The inertial measurement units were found to be a valid tool for the analysis of peak velocity (r = 0.92) and average split velocities for splits after the first 10m (r = 0.85 - 0.95). Validation data suggests some caution should be taken in interpretation of the first 10m split (r = 0.32). Whilst data from the two devices for this split were correlated, the inertial measurement unit showed an overestimation for this parameter in comparison to the athlete velocity as measured by the laser. Further in-depth analysis should investigate this period.

KEYWORDS: IMU, wearable, accelerometer, gyroscope, running

INTRODUCTION: The ability to measure an athlete's performance within his or her natural environment is central to the methods of applied sports science sub-disciplines, such as biomechanics. The development of valid and reliable tools that a) do not impede an athlete's movement, b) can be used for technical analysis, and c) can provide real-time and in-situ performance information to coaches and rapid feedback to athletes, is of interest to applied scientists and researchers in the sports industry.

The portability and cost effectiveness of wearable devices paired with user-friendly tablet-based applications is highly desired by coaches to provide timely feedback to athletes in the training environment. Inertial measurement units (IMUs) provide a solution that minimises the constraints placed on an athlete, coach and/ or sports scientist when undertaking field-based testing. Inertial measurement units capture multi-dimensional accelerometer and gyroscope data to measure the kinematic parameters of a system, and have been shown to provide accurate in-field performance data, based on reference systems (Lee, Burkett, Thiel, & James, 2011; Wixted, Billing, & James, 2010). The purpose of this study was to evaluate the accuracy of an IMU device against corresponding time continuous data derived from a Laveg laser (Jenoptik, Germany), during a straight-line acceleration task. This paper presents preliminary analysis of the validity of the IMU against criterion data from the Laveg laser for peak velocity and average split velocity.

METHOD: Five male sub-elite Australian sprinters participated in this study. Participants were recruited from a high performance training centre in Melbourne, Australia. All participants were in training at the time of testing and were free from injury. Research methods were approved by the Swinburne University Human Research Ethics Committee.

Protocol: Each participant was fitted with an IMU on the sacral area at the mid-point between the left and right posterior superior iliac spine, which was securely fixed using double sided tape and sports tape. The Laveg laser was located behind the starting line and required the operator to track the pelvis of the participant throughout the 100m sprint. Participants performed their own training warm-up prior to the start of the trials. Participants were asked to perform eight maximal effort 100m sprints and were given a self-selected break period in between each trial to help reduce the effects of fatigue. This break period ranged approximately between five and ten minutes.

Data Collection and Processing: Data were collected simultaneously using the IMeasureU Blue Thunder IMU sensor and Research Application for iPhone (IMeasureU, Auckland, New Zealand) and a Laveg laser speed gun (LAVEG Sport, Jenoptik, Germany). The IMeasureU sensors contain accelerometer, rate gyroscope, and magnetometer microelectromechanical system technology (MEMS, ±16 g; ±2000.s^{-1}; and ±1200μT, respectively) mounted in a triaxial arrangement on a small circuit board. The sensors logged acceleration, angular velocities, and magnetic flux data in the three orthogonal planes at 500hz. The IMeasureU Research Application was used to set the sensors to log data to an on-board micro SD card (4 GB) as well as enter the start and end times for each sprint for use in post processing.

Raw data from the IMU were imported into Matlab, incorporated with a sensor fusion algorithm and processed with proprietary algorithms developed by IMeasureU. Data collected by the IMUs were passed through the Madgwick filter (Madgwick, Harrison & Vaidyanathan, 2011) to calculate the global orientation of the sensors. Known constraints were applied in the IMeasureU mathematical model to adjust for any drift in the orientation produced from the Madgwick filter process. Once stabilised, rotation matrices were built and applied to raw data in order to isolate the accelerations in the forward direction. Once the forward accelerations were isolated, integration was used to calculate velocity, and further integration used to calculate displacement. Further constraints were then applied to the model to account for any error (drift) introduced in the system. The data were then broken down into piecewise functions and fitted to models characteristic of the appropriate sprinting phase. These data were then exported for comparison with the Laveg data.

The Laveg system measured positional information on the athlete at 100hz. This information was then used to calculate instantaneous speed of the sprinter as well as split times. Raw Laveg position data were imported into Excel and smoothed using a 51-point moving average. As the Laveg system requires the user to target and track the same position on the back of the athlete throughout the sprint, data can become noisy over the last 10 to 20m of the 100m sprints. Where noisy data existed over this period, data were cropped and extrapolated. As a consequence, greater caution is required for the interpretation of the 80-90m split and 90-100m where error in measurement may have been greater.

Data analysis: To evaluate the accuracy of the IMU sensor and algorithms, peak velocity and average split velocities were calculated for both Laveg and IMU datasets. For the IMU, peak average velocity (the average velocity from the time of peak velocity to the end of the 100m) was used as a proxy for peak velocity. For both the IMU and Laveg datasets, average split velocity was calculated as the velocity per 10m split. Validity of the IMUs was assessed through Pearson's correlation and standard error of the estimate (Varley, Fairweather, & Aughey, 2012), as well as per cent difference between the IMU and criterion value of the Laveg laser. Bland-Altman plots (Bland & Altman, 2007) were also examined.

RESULTS: Correlation, standard error of the estimate and per cent difference results for peak velocity and split velocities are presented in Table 1.

Table 1 Validity results expressed as % and confidence interval

		r	SE	% Difference ± *SD*		
Peak velocity		0.92	0.21	1.5%	±	2.4%
Average split velocity	0-10m	0.32	0.44	0.1%	±	10.1%
	10-20m	0.85	0.25	9.1%	±	2.9%
	20-30m	0.89	0.23	4.2%	±	2.5%
	30-40m	0.90	0.23	1.4%	±	2.5%
	40-50m	0.92	0.20	0.6%	±	2.4%
	50-60m	0.93	0.19	0.8%	±	2.6%
	60-70m	0.95	0.17	1.5%	±	2.4%
	70-80m	0.95	0.17	2.8%	±	2.4%
	80-90m	0.93	0.19	3.9%	±	2.7%
	90-100m	0.86	0.26	5.3%	±	3.4%

**SE = standard error of the estimate*

The IMU data were strongly correlated with the criterion data derived from the Laveg laser, excluding the first split (0-10m), where only a medium size correlation existed. The first split had the highest variance (of the per cent difference), whilst the second split had the highest per cent difference between the devices.
Representative data from participant one are displayed in Figure 1 (grey/solid = Laveg, black/dashed = IMU). A Bland-Altman plot for peak velocity group data is presented in Figure 2.

Figure 1 Representative data for velocity vs. distance

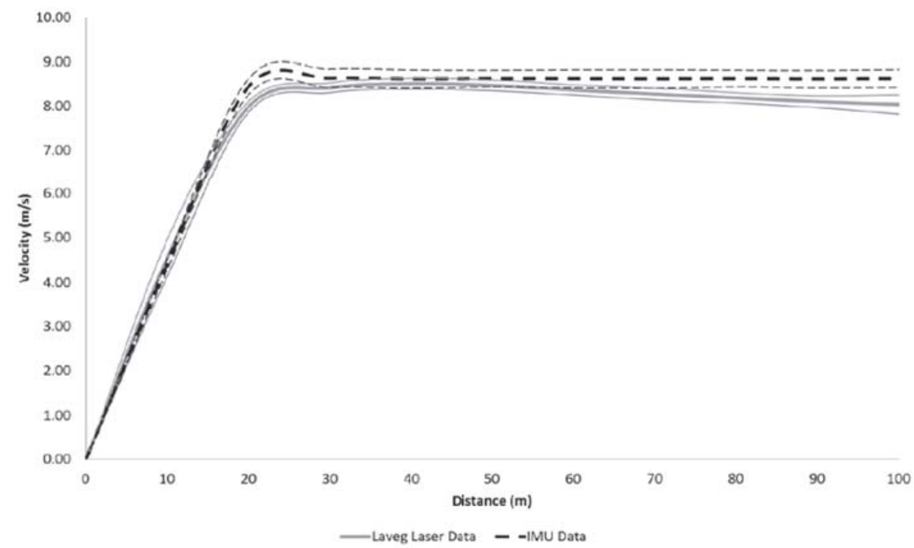
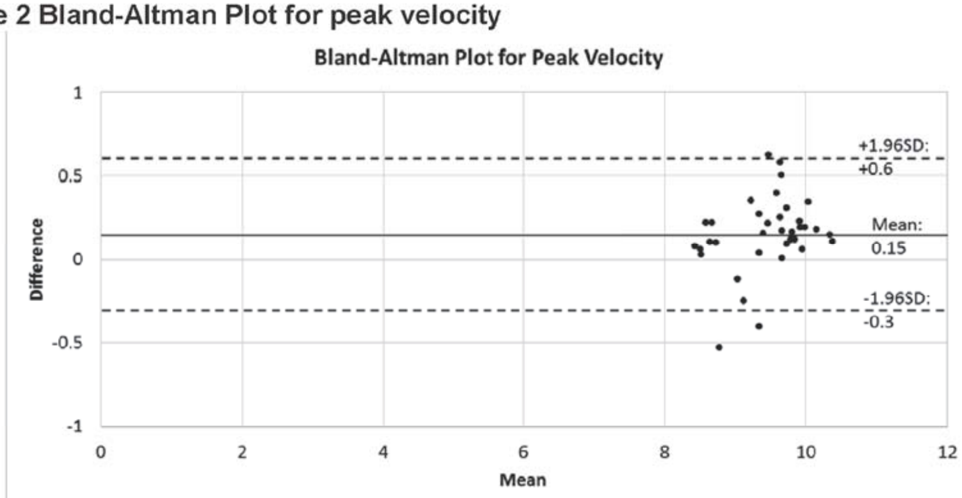


Figure 2 Bland-Altman Plot for peak velocity



DISCUSSION: This study provides a preliminary analysis of the validity of the innovative IMeasureU Blue Thunder sensor, which utilises accelerometer, gyroscope and magnetometer sensors in its algorithms to account for accelerometer drift. This study assessed the validity of the IMUs' velocity calculation against the criterion measure of the Laveg laser. The overall findings indicated that the IMU Blue Thunder sensor provided an accurate representation of an athlete's 100m sprint kinematics. The correlations paired with the small standard error of the estimate and per cent difference results found in this preliminary analysis fit within the range of values of other validity studies (e.g. Lee et al., 2011; Varley et al., 2012) and suggest that the IMUs were overall valid in the output of peak velocity and average split velocity. At this stage of analysis, however, caution should be made in the interpretation of some of the split data during acceleration and deceleration phases.

The reduced correlation and variance of the first split related to the IMU data fluctuating above or below the Laveg value, whilst the greater per cent difference in the second split reflected the IMUs bias towards slightly overestimating the velocity (average of 0.8m/s). Figure 1 provides a visual example of this. These differences seen in the first two splits may be attributed to the acceleration phase of the sprint, and the algorithm used to curve fit this phase not being fully representative of the individual sprint performance per athlete per sprint. Additionally, differences in the sampling frequency of the two systems and methods of treatment of the raw data may have led to some differences in the level of fidelity of athlete velocity presented.

Small wearable IMUs that are able to provide accurate and meaningful information could be a valuable tool for assessing athlete performance in high performance sport. In particular, the use of these IMUs can be beneficial to both athletes and coaches. Firstly, whilst further evaluation of the device is planned, this initial analysis suggests that the IMU may be a useful substitute for timing gates and laser analysis, alleviating the need to transport and set up this equipment at the training ground. Furthermore, use of the IMU and paired application can aid coaches by removing the need for additional on site sports science staff to assess velocity during training. Finally, the rapid delivery of feedback on linear velocity can be helpful to athletes during training.

Our preliminary analysis involved a small sample. Further analysis of these devices will be conducted on a greater number of participants, include timing gate data, and include a second Laveg laser to capture the last 20m with improved accuracy.

Future directions include the statistical assessment of data waveforms, assessment of different attachment locations for the IMU sensor (i.e., difference between attachment on pelvis versus upper trunk position), and assessment of this technology for other sprint-based sports where the profiling of velocity is important, such as short track speed skating or wheelchair racing.

CONCLUSION: Findings from this initial stage of the study demonstrated a high correlation and low standard error of the estimate for peak velocity and average split velocities (excluding the first split). These data suggested the IMU was able to provide a relatively close representation of velocity information for the 100m sprint. Nonetheless, further developments are required to strengthen the relationship between the datasets, especially for the first split. This finding provides rationale for further in-depth analysis of IMUs in sprint sports to provide quick on-site feedback to coaches and athletes. Waveform analysis of paired IMU and Laveg data provide an interesting phase for future research.

REFERENCES:

Bland, J. M., & Altman, D. G. (2007). Agreement between methods of measurement with multiple observations per individual. *Journal of biopharmaceutical statistics*, *17*(4), 571-582.

Lee, J. B., Burkett, B. J., Thiel, D. V., & James, D. A. (2011). Inertial sensor, 3D and 2D assessment of stroke phases in freestyle swimming. *Procedia Engineering, 13*, 148-153. doi: 10.1016/j.proeng.2011.05.065

Madgwick, S. O., Harrison, A. J. L., & Vaidyanathan, R. (2011). Estimation of IMU and MARG orientation using a gradient descent algorithm. Proceedings of the IEEE International Conference on Rehabilitation Robotics (pp. 1-7). Switzerland: Zurich. doi: 10.1109/ICORR.2011.5975346

Varley, M. C., Fairweather, I. H., & Aughey1, 2, R. J. (2012). Validity and reliability of GPS for measuring instantaneous velocity during acceleration, deceleration, and constant motion. *Journal of sports sciences*, *30*(2), 121-127.

Wixted, A. J., Billing, D. C., & James, D. A. (2010). Validation of trunk mounted inertial sensors for analysing running biomechanics under field conditions, using synchronously collected foot contact data. *Sports Engineering, 12*(4), 207-212. doi: 10.1007/s12283-010-0043-2