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Validity of an inertial system to measure sprint time and sport task time: a proposal for the integration of photocells in an inertial system

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ABSTRACT
This study presents a proposal for the integration of photocell data (time) into an inertial system. We divert the signal emitted by the infrared cell (ChronoJump, Spain) towards the inertial device (WIMU PRO, RealTrack System, Almeria, Spain) by an ANT + transmitter to make a mark that is later visualised in S PRO software (RealTrack System, Almeria, Spain). The objective of this study is to show the validity of an inertial system to measure sprint and sport task time by integrating photocells into an inertial system. For this purpose, we compared the time of 108 runs (at 20, 150 and 400 m) between inertial software and photocell software (gold standard). The results of the validity in this study were satisfactory and had a bias .0006 ± .0018 s. To conclude, the time measurements between photocells and an inertial system using ANT + are accurate and the proposal presented in this manuscript could make this sport activity monitoring more efficient.

1. Introduction
Sprint performance is mainly dependent upon genetic predispositions (Eynon et al., 2013) and it is quite resistant to training enhancement (Tønnessen, Svendsen, Olsen, Guttormsen, & Haugen, 2015). Beyond a certain level, athletes can spend a lot of time trying to improve a few hundredths of a second over short distances (Sander, Keiner, Wirth, & Schmidtbleicher, 2013). Thus, an accurate and reliable measurement of sprint speed is necessary to detect the true changes in performance. Several instruments have been used to measure sprint time, such as manual timing (Mayhew et al., 2010), photocell timing (Yeadon, Kato, & Kerwin, 1999), floor pods (Duthie, Pyne, Ross, Livingstone, & Hooper, 2006), audio and visual start sensors (Impellizzeri et al., 2008), video timing (Harrison, Jensen, & Donoghue, 2005), laser and radar devices (Arsac & Locatelli, 2002), and positioning measurement such as radio-frequency positioning systems (e.g. global positioning system, GPS; ultra wave band, UWB; and local positioning system, LPS) (Barbero-Álvarez, Coutts, Granda, Barbero-Álvarez, & Castagna, 2010) and video analysis (Ogris et al., 2012; Valter, Adam, Barry, & Marco, 2006).
Although the fully automatic timing systems that are used in international athletics events have been considered to be the “gold standard” for this objective (Haugen, Tønnessen, & Seiler, 2012), these instruments are expensive and time consuming, and are not feasible for use by all professionals (Haugen & Buchheit, 2016). Consequently, photocell devices are commonly used due to their lower cost and ease of use, but with high accuracy and reliability (Haugen & Buchheit, 2016).

On the other hand, wireless inertial measurement units (IMU) have been extensively applied in a variety of team sports during the last decade to quantify external load and to measure running velocity in players during training sessions and games (Boyd, Ball, & Aughey, 2013; Bradley, Di Mascio, Peart, Olsen, & Sheldon, 2010; Montgomery, Pyne, & Minahan, 2010). These devices can incorporate several positioning systems, such as GPS and UWB, and they allow the simultaneous assessment of many players (Haugen & Buchheit, 2016). A few studies have aimed to investigate GPS validity and reliability for speed assessment, using photocells as the “gold standard” criterion in most of the cases (Barbero-Álvarez et al., 2010; Schutz & Herren, 2000; Townshend, Worthingham, & Stewart, 2008). The validity and reliability of GPS is affected by the sample rate, running velocity, running distance and movement pattern, so that lower sampling frequency (Varley, Fairweather, & Aughey, 2012), higher running speed (Duffield, Reid, Baker, & Spratford, 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010; Portas, Harley, Barnes, & Rush, 2010), shorter distance (Barbero-Álvarez et al., 2010; Duffield et al., 2010) and a greater number of changes of direction (Duffield et al., 2010; Jennings et al., 2010; Portas et al., 2010) will result in the lower validity and reliability of GPS. In addition, the GPS system uses earth-orbiting satellites and needs at least three of these satellites to obtain an accurate measurement (Larsson, 2003). Several authors have concluded that GPS has shown acceptable accuracy for sprint velocity assessment when compared with timing light (Barbero-Álvarez et al., 2010; Portas et al., 2010; Varley et al., 2012). On the other hand, several other types of systems are available for position tracking in sports, such as LPS-based and UWB-based devices, which are based on the frequency-modulated continuous wave principle (Leser, Baca, & Ogris, 2011; Leser, Schleindlhuber, Lyons, & Baca, 2014). This technology has been established as an accurate and valid tool to record the players’ positions in outdoor and indoor fields (Frencken, Lemmink, & Delleman, 2010; Leser et al., 2014; Ogris et al., 2012), as well as to provide accurate data in static and dynamic conditions at various speeds (Frencken et al., 2010; Ogris et al., 2012). The accuracy of this tracking system is limited by the strength of the radio signal and by the number of players tracked (Mandeljc, Kovačič, Kristan, & Perš, 2012); however, this system is also expensive and time consuming to set up.

Some authors consider that GPS technology is not a valid method to measure sprint speed and is only accurate when the distance measured is greater than 30–40 m (Haugen & Buchheit, 2016; Jennings et al., 2010), and even with LPS technology they still report absolute errors of measurement of 23.4 ± 20.7 cm (Ogris et al., 2012). Although this type of technology is continuously improving and it now provides better measurement quality, it still has some handicaps. For example, if accurate sprint measurement is required, photocells are needed, and this involves the use of another system, which makes data collection and data extraction more complex and less practical. This study evaluates a proposal to integrate both systems (i.e. IMU and photocells) in order to improve data management. Therefore, it is necessary to verify that the manipulation made for this adaptation does not imply measurement bias (e.g. the signal’s travelling time, interferences, or minimum time
required for the signal to be sent). The aim of this study is to analyse the accuracy of the communication protocol between these two instruments, and to assess the validity of an inertial system to measure sprint and sport task time using photocells integrated into the IMU system.

2. Material and methods

Three well-trained athletes volunteered and provided written consent to participate in this study. In addition, this study was accepted by the Ethics Committee of the University of Murcia.

The equipment that we assembled for this study is essentially used to divert the signal emitted by the infrared cell (ChronoJump, Spain) towards the inertial device (WIMU PRO, RealTrack System, Almeria, Spain) to make a mark that can later be visualised in S PRO software (RealTrack System, Almeria, Spain). The sampling frequency can be configured from 10 to 1000 Hz. For data recording, sampling frequencies of 100 and 1000 Hz were used and were recorded on a microSD card that is incorporated into the device. The devices were calibrated prior to their placement. This was done with a self-calibration system that incorporates each device in the internal configuration of the boot. During self-calibration, three aspects were taken into account: (i) leaving the device immobile for 30 s; (ii) placing it in a flat area; and (iii) no magnetic devices around it. This process enables the accelerometers to eliminate the four sources of error that they present, which are: displacement error, scaling error, orthogonal errors and random error (Wang, Liu, & Fan, 2006). Infrared cells include two connections, which are: a power connection and a female connection that carries a communication signal to the software (ChronoJump, Spain) to start a timer when the light beam is interrupted. In this experiment, an ANT + transmitter was connected to the output of the communication signal via a RCA cable (standard communication cable). This emits a wireless signal for several seconds (see Figure 1). The inertial devices include ANT + receivers that register a mark when they receive a signal.

S PRO analysis software was used to measure time using an atomic clock and it makes automatic selections from mark to mark (see Figure 2). This indicates the time taken between them, as well as the speed, when the distance travelled is provided. To analyse the construct validity of the inertial system to measure sprint time from the integration of the photocells in the system, we make a comparison with the gold standard – which in this case is the data reported from the photocell software.

2.1. Procedures

For the validity assessment, each participant completed six runs at 20, 150 and 400 m (18 runs × 3 participants × 2 devices). All of the runs were performed at maximum speed, except for the second task which contains runs of different speeds. The first run is a (1) 20 m sprint that continues with a (2) simulated circuit of typical sports tasks (which contains runs of different speed, changes of direction, agility, and accelerations and decelerations). The last run is a (3) 400 m square (see Figure 3). The assessment was performed during two days (9 at 100 Hz and 9 at 1000 Hz) with 48 h of rest between both sessions. Two different IMU devices, one for each session, were employed in order to verify that this non-systematic variation in the sprint was the same. The inertial units were placed inside specially designed garments and positioned so that they sat between the participants’ scapulae.
2.2. Data analysis

The data of the two measurements was presented as mean ± SD. A Pearson’s correlation coefficient \( r \) was performed to calculate the concurrent validity and Bland–Altman plots (Bland & Altman, 2010) were performed to complete the validity analysis of WIMU PRO with a representation of the degree of agreement between seconds obtained using this purpose and photocells. The intraclass correlation coefficient (ICC) was used to analyse the validity of the seconds measured between the two measurements with 95% confidence intervals. ICC was interpreted according to Bartko (1966), as follows: moderate (.50–.69), high (.70–.89), and excellent (.90 and above). The same criterion was used for Pearson’s correlation coefficient \( r \). All of the analyses were performed using SPSS 21.0 software for Windows (IBM Co., USA), except for the Bland–Altman plots, which were made using Graphpad Prism software (Graphpad, Inc., USA).

![Figure 1. Equipment assembled for the integration of photocells in an IMU system. A: Complete assembly of photocells; B: infrared light reflector; C: infrared cell; D: ANT + transmitter; E: RCA cable to connect the infrared cell and ANT + transmitter.](image-url)
3. Results

Table 1 shows the time elapsed for each distance by M ± SD for the two measurements (ChronoJump and S PRO). The differences, ICC (1.00), IC al 95% (1.000 to 1.00) and Pearson’s r (1.00) were also reported.

A Bland–Altman procedure was employed to establish measurement bias. The Bland–Altman plots (Figure 4) showed that bias was .0006 ± .0018 s, which is 95% of the limits agreement from −.0029 to .0041 s.

4. Discussion

This study was the first to determine the validity of an IMU system to measure time with high accuracy as a result of the integration of timing lights into the system. The results of the validity in this study were satisfactory with a bias of .0006222 ± .001802 s. A total of 95% of
the data measured is between -.002911 and .004155 s. In this study we use single-beamed photocells because they are commonly used in the practice of sports and also because this model is an open system (we can manipulate it for this purpose). Besides, inspections of reliability data with single-beamed photocells across short-sprint studies reveal .03 s of standard error of measurement (Wong, Chaouachi, Chamari, Dellal, & Wisloff, 2010). Therefore, we consider that they have enough measurement accuracy to be used as a reference standard in this validation. A perfect Pearson relationship (r = 1.00) and intraclass correlation coefficient between the two measurements (ICC = 1.00) are shown as complementary statistics. We suppose that the error shown is only due to the time that it takes for the signal to travel from the sender to the device.

Agreement between measurements was not affected by the distance travelled (20, 150 or 400 m) or by the time spent running. The measurement accuracy was the same in the different situations recorded. This is an important fact because GPS technology has shown questionable validity and reliability when used to measure sprint time for sprint races below 30 m (Haugen & Buchheit, 2016). GPS technology has several handicaps that cannot be solved because it feeds on U.S. satellites, which cannot be controlled (Schutz and Chambaz, 1997).

The sampling frequency is one of the factors that are being improved and it is described as one of the most important factors to obtain a precise measurement (Barbero-Álvarez et al., 2010; Jennings et al., 2010; Ogris et al., 2012; Varley et al., 2012). However, the lack of

### Table 1. Descriptive statistics, and validity analysis based on intraclass correlation coefficients (ICC) and Pearson’s r.

<table>
<thead>
<tr>
<th>Session</th>
<th>Hz</th>
<th>Distance (m)</th>
<th>ChronoJump</th>
<th>S PRO</th>
<th>D</th>
<th>ICC</th>
<th>IC 95%</th>
<th>Pearson’s r</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>1000</td>
<td>20</td>
<td>5.14 ± .25</td>
<td>5.14 ± .25</td>
<td>−.001</td>
<td>1.00</td>
<td>1.00–1.00</td>
<td>1.00*</td>
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<tr>
<td></td>
<td>150</td>
<td>20.04 ± .28</td>
<td>20.04 ± .28</td>
<td>.002</td>
<td>1.00</td>
<td>1.00–1.00</td>
<td>1.00*</td>
<td></td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>60.11 ± .13</td>
<td>60.10 ± .13</td>
<td>.006</td>
<td>1.00</td>
<td>1.00–1.00</td>
<td>1.00*</td>
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<tr>
<td>100</td>
<td>20</td>
<td>5.04 ± .2</td>
<td>5.04 ± .2</td>
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<td>1.00–1.00</td>
<td>1.00*</td>
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<td>150</td>
<td>20.00 ± .13</td>
<td>20.00 ± .13</td>
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<td>1.00*</td>
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<td>60.14 ± .2</td>
<td>.002</td>
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<tr>
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<td>20</td>
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<tr>
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<td>150</td>
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<td>1.00–1.00</td>
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<tr>
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<td>60.51 ± .29</td>
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<td>1.00</td>
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<td>2</td>
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<td>20</td>
<td>5.61 ± .23</td>
<td>5.61 ± .23</td>
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<td>150</td>
<td>20.96 ± .44</td>
<td>20.95 ± .44</td>
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<td>1.00</td>
<td>1.00–1.00</td>
<td>1.00*</td>
<td></td>
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</table>

Note: Values in seconds; D: differences. *p < .001.

### Figure 4. (A) Bland–Altman test of S PRO and ChronoJump time measure in seconds. (B) Histogram of the frequency distribution data of the differences.
accuracy in short sprints occurs from 1 Hz GPS localisation devices (Barbero-Álvarez et al., 2010) to more sophisticated radiofrequency systems at 45 Hz (Ogris et al., 2012).

In this study we also experimented with two different IMU devices, one for each session, in order to verify that this non-systematic variation in the sprint was the same. The same experience occurred at the pre-configured sampling frequency of the inertial device. Sometimes it can be reduced or increased as a strategy for increasing its energy autonomy or for greater accuracy of registration, respectively. None of these facts influenced the validation results.

The accuracy of the data reported by the different models of localisation devices in the literature are increasingly reducing their measurement error, especially in specific sport actions where there are tasks of high intensity, changes of direction, and constant accelerations and decelerations (Cummins, Orr, & O’Connor, 2013). Even so, it has not yet been possible to obtain an acceptable validity in this type of action at a high intensity (Aughey, 2011), even when increasing the sampling frequency. It seems that this is not the determining (although it is important) feature of this technology for better accuracy (Buchheit & Simpson, 2016). In this sense, Johnston et al. (2014) showed that a model with lower sampling frequency (10 Hz) obtained better precision than a model with a higher sampling frequency (15 Hz). According to Buchheit and Simpson (2016), the state of micro-technology is still under construction, and clubs and coaches should choose their monitoring variables and technologies according to two factors: (i) their usefulness within the training programme; and (ii) the cost and benefit balance (i.e. cost of technology, ease of use, ease of data analysis, portability, and capacity to impact in the training programme). The validation proposal that is presented here is intended to fit these demands and this could be applied with any other technology. In fact, other devices – such as NIRS technology – that show muscle oxygen saturation in real time have already been integrated (Bastida-Castillo, Gómez-Carmona, & Pino-Ortega, 2016). However, our proposal has several limitations, as follows: (i) timing gates are still needed in order to obtain a highly accurate sprint time measurement; (ii) concurrent measurements of several players could be complex because different signals could be received by all devices; and (iii) a new software application should be developed in order to obtain real time data.

5. Conclusion and practical applications

- Time measurements between photocells and an inertial system using ANT + are accurate.
- Sports clubs and coaches should look for a system that allows them to gather or integrate data collection as much as possible into a single system in order to make activity monitoring more practical.
- The proposal presented in this manuscript could make sport activity monitoring more efficient and promote the integration of different systems.

Disclosure statement

No potential conflict of interest was reported by the authors.
References


