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WIRELESS VERTICAL DISPLACEMENT MEASURMENT DURING RUNNING USING AN ACCELEROMETER AND A MOBILE PHONE

Martin Eriksson[1], Dennis Sturm[1], Kjartan A. Halvorsen[1,2] and Lennart Gullstrand[3]

Department for Medical Engineering, KTH Royal Institute of Technology, Stockholm, Sweden[1]
Department of Information Technology, Uppsala University, Uppsala, Sweden[2]
Elite Sports Centre, Bosön Swedish Sports Confederation, Lidingö, Sweden[3]

The purpose of this study was to investigate in the usability of a wireless accelerometer linked to a mobile phone via Bluetooth radio for measuring vertical displacement in running athletes. Five experienced runners were monitored during lactate threshold testing at three to five different velocities. Accelerometer data was received, processed and stored on the phone to be compared to simultaneous position transducer (ground truth) recordings after data collection. A paired t-test and statistical analysis show no significant differences in the reliability of the recordings. While further investigations are encouraged, the accelerometer and algorithm (running in J2ME on the mobile phone) proof as a flexible, easy-to-use tool for out-of-the-lab monitoring and to provide real-time feedback for running technique experiments.

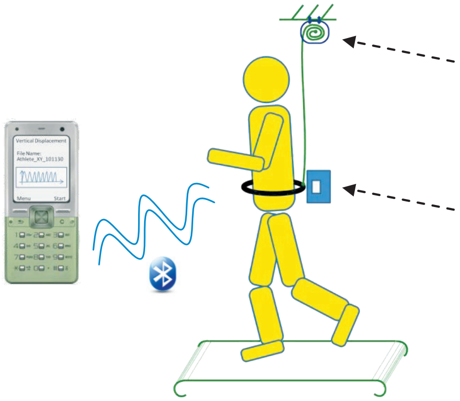
KEY WORDS: vertical displacement, running economy, accelerometer, Bluetooth.

INTRODUCTION: Running economy (RE) is generally defined as total oxygen consumption in $ml\cdot kg^{-1}\cdot min^{-1}$ during running at a given submaximal steady state velocity. There are a number of possible factors affecting running economy (Saunders et al., 2004). Biomechanical factors affecting RE as discussed by Berg (2003) are not as commonly reported as physiological factors.

From a mechanical standpoint, the vertical displacement (VD) of the runner's centre of mass at each step should be one indicator of the efficiency of the technique. The correlation between VD and RE has not been studied enough to draw any final conclusion. However, in a study by Williams and Cavanagh (1983), a weak correlation (non-significant) was shown. It has also been shown that an exaggerated VD does affect RE negatively (Tseh et al., 2008). Furthermore, a strong vertical force impulse has shown to affect RE negatively (Heise & Martin, 2001). As VD is proportional to the energy required at each step, a good measure of the power that the runner exerts is proportional to VD multiplied by the step-frequency (SF), even in the presence of elastic components that are not modelled in this work.

It has been shown that VD of the body's centre of mass can be approximated accurately by only considering the oscillations of the sacrum (Gullstrand et al., 2009). The same study also showed that VD can be estimated by using a two-axis accelerometer. However, all data processing in that study was performed off-line. In this study we demonstrate that it is possible to accurately compute VD in real-time with a wireless accelerometer unit and a standard mobile phone. The purpose of such a simple setup is to provide an accessible, non-obtrusive tool that can be used in the everyday training. The aim of this study is to demonstrate that the system provides accurate information to the athlete.

METHOD: The scenario is depicted in Figure 1. Motion data was recorded by two means: (a) a spring loaded position transducer (ground truth) and (b) a wireless accelerometer linked to a Bluetooth enabled mobile phone. The three-axial accelerometer was part of a battery driven six degree of freedom inertial measurement unit (6-DOF IMU Version 4, Sparkfun, Boulder (CO) USA). The accelerometer data was transmitted wirelessly using the Bluetooth SPP protocol to the mobile phone. Dedicated software written in Java (J2ME) on this phone (Sony Ericsson i650, Sweden) received the data, computed VD and stored the data on the phone's internal memory in real-time.



Position transducer, mounted to ceiling

Accelerometer and position transducer line connected to waist belt

Figure 1: Placement of the position transducer and the accelerometer. Dimensions not to scale.

Data was recorded from 5 experienced runners during lactate threshold testing. Each athlete ran for four minutes at three to five different running velocities. At each velocity, data was collected and divided into four one minute intervals.

VD of one step is defined as the distance between the highest and the lowest position of the sacrum. This measure has shown to be a reliable estimate for the vertical displacement of the runner's centre of mass (Gullstrand, 2009). However, this does not mean that the sacrum always follows the runner's centre of mass. It merely means that the difference between the extreme values over one step are similar.

Computing the vertical position of the sensor is done by double-integration of the vertical acceleration. There are two main sources of errors in such computations:

1. Integrating accelerations yields a drift due to integration of systematic errors.
2. The orientation of the sensor is not known, as it rotates slightly during one stride.

The first issue is dealt with by high-pass filtering incoming data in real-time. This removes the DC component of the signal. Since we are not interested in the absolute height of the sensor, no relevant information is lost. It is still possible to recover the oscillations of the sensor around its mean. In this implementation a Butterworth filter of order five with a cut-off frequency of 1.5 Hz was applied.

The second issue is handled by computing the average orientation over a longer period of time. This was implemented with a low-pass Butterworth filter of order five with a cut-off frequency of 0.5 Hz on the original signal. This means that the average orientation during approximately six consecutive steps was used. For each incoming data value, the vertical component was computed as the inner product between the average orientation and the current reading. The position (distance from mean) is then computed by double integration, as mentioned earlier.

VD of each one minute interval (computed by both methods) was then averaged, generating 4 values for each speed. Corresponding values, measured with the accelerometer and the transducer, were finally compared in order to establish the accuracy of the accelerometer-based calculation.

RESULTS: The data has been plotted for each athlete in Figure 2. Every bar represents a one minute average of VD. It should be mentioned that the accelerometer came slightly loose during data collection at velocity 3 with athlete 5. This may explain the overestimation of VD by the accelerometer visible in the results for athlete 5 in Figure 2. It is otherwise noteworthy that the accelerometer consistently underestimated VD for three runners, and consistently overestimated VD for two runners.

Figure 3 shows a Bland-Altman graph of the position transducer data and of the accelerometer for all athletes and all velocities.

A paired t-test at a 5% significance level shows no difference between the methods.

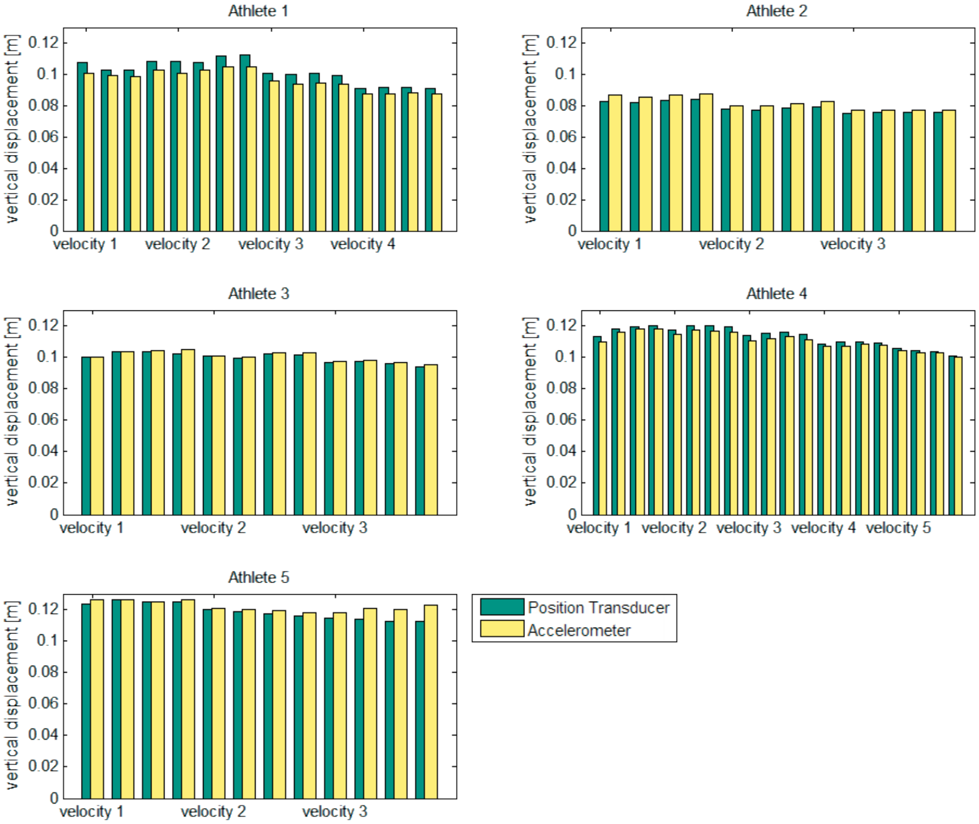


Figure 2: VD data for all athletes from both measurement methods.

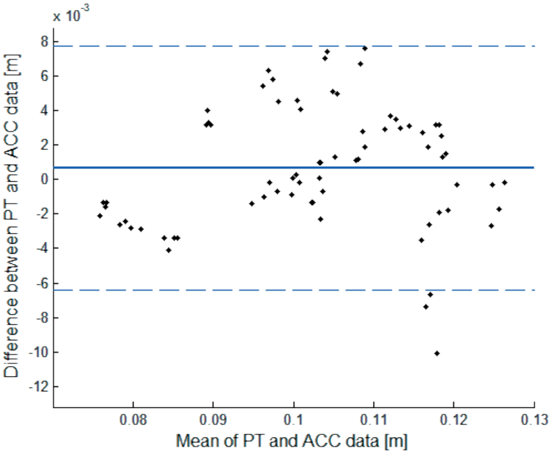


Figure 3: Bland-Altman graph showing the relationship of measured data by the position transducer (PT) and the accelerometer (ACC).

DISCUSSION: The results of this study indicate that it is possible to accurately measure a runner's vertical displacement with a small, light and off-the-shelf sensor. This in turns means that it is possible to use the system outside the lab in an everyday training setting. As all computations are performed on the phone, the runner can be given real-time feedback about his or her performance in terms of mechanical efficiency. Feedback is essential in motor learning, and normally the feedback is based on the result. However, feedback based on how the result was achieved can be more powerful under certain conditions (Schmidt & Lee, 2005). Also, it has been shown that it is possible to accurately alter a runner's vertical displacement with auditive feedback (Eriksson et al., 2011). Thus, this could lead to new, non-obtrusive equipment to improve running mechanics.

There seems to be a systematic error for each athlete but not across athletes, this should be examined in a larger population. Furthermore, accelerations in the forward-backward direction can also be measured by the described hardware – and the effect on RE may be analysed. Additional data collection is encouraged to investigate these issues.

CONCLUSION: This study presents a cost-effective, wireless feedback system that allows runners to experiment with different running mechanics outside the lab. The wireless measurement method used in this study can also be used to manipulate the running technique of test persons in order to evaluate the effect of a change in the technique.

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