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Short communication

The development and validation of using inertial sensors to monitor postural change in resistance exercise ☆

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ABSTRACT

This research presented and validated a method of assessing postural changes during resistance exercise using inertial sensors. A simple lifting task was broken down to a series of well-defined tasks, which could be examined and measured in a controlled environment. The purpose of this research was to determine whether timing measures obtained from inertial sensor accelerometer outputs are able to provide accurate, quantifiable information of resistance exercise movement patterns. The aim was to complete a timing measure validation of inertial sensor outputs. Eleven participants completed five repetitions of 15 different deadlift variations. Participants were monitored with inertial sensors and an infrared three dimensional motion capture system. Validation was undertaken using a Will Hopkins Typical Error of the Estimate, with a Pearson's correlation and a Bland Altman Limits of Agreement analysis. Statistical validation measured the timing agreement during deadlifts, from inertial sensor outputs and the motion capture system. Timing validation results demonstrated a Pearson's correlation of 0.9997, with trivial standardised error (0.026) and standardised bias (0.002). Inertial sensors can now be used in practical settings with as much confidence as motion capture systems, for accelerometer timing measurements of resistance exercise. This research provides foundations for inertial sensors to be applied for qualitative activity recognition of resistance exercise and safe lifting practices.

1. Introduction

This research provides a foundation for inertial sensor technology to be applied for qualitative activity recognition of resistance exercise. The typical method of measuring movement and lifting patterns is infrared three dimensional motion capture (3D MoCap), which currently appears to be the most accepted method of monitoring kinematics (Mayagoitia et al., 2002). The need for new methods is due to the high cost of 3D MoCap systems, which are typically confined to laboratory environments (Luinge and Veltink, 2005). Therefore, 3D MoCap has limited use outside of laboratories, however offers an acceptable measure for comparisons of new or separate technology. The current generation of inertial sensor products are more affordable, light, small, unobtrusive and mass produced (Lee et al., 2012a, 2012b). Evaluating the agreement between inertial sensors and an accepted measure of kinematics would determine whether the method is valid for measuring movement during resistance exercise.

Inertial sensors typically include tri axial accelerometers and rate gyroscopes (Wong et al., 2007). Inertial sensors have been validated to measure human gait, trunk inclination, posture, dynamic angles between body segments and acceleration of movement (Faber et al., 2010; Kingma et al., 2001; Olsen et al., 2013). Furthermore, many studies have validated and monitored timing of human movements and the timing of key events during movement (Lee et al., 2011; Spratford et al., 2015). However, there is a resistance exercise gap in current literature for inertial sensor timing validations, with no known human movement validations specific to the movement of the spine during resistance exercises.

Timing during movement is important in many sporting contexts and timing differences between sensor outputs may provide insight into which body segments are moving at specific times throughout an exercise (Wixted et al., 2010). Numerous known studies have implemented inertial sensor designs and interventions, with no prior validation for qualitative lifting assessment tools using inertial sensors (Chang et al., 2007; Velloso et al., 2013).

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Acceleration and angular rate of change are typically the main criterion which provide information on movement patterns when using inertial sensors, and the timing of these outputs should ideally have high agreement with a gold standard measurement method to accurately portray movement as it occurs in real time (Lee et al., 2011; Spratford et al., 2015). Relevant to resistance exercise, the time that spine movement peaks or patterns occur could provide valuable information on the movement pattern for performance or safety parameters. However what is first needed before assessment, is validation that the timing of the inertial sensor output is accurate when compared to the gold standard of monitoring human movement. Therefore, the scope of this research was to fill a gap in current literature by determining the timing agreement between accelerometers and 3D MoCap to measure resistance exercise movement patterns of the spine.

The primary aim of this research was to investigate the validity of a new method using inertial sensors to measure the timing of postural trunk movements during different styles of a resistance exercise. The resistance exercise chosen for the purpose of this research was a conventional deadlift. Monitoring deadlift movement patterns during desired safe and unsafe techniques, with and without heavy loads allowed for timing comparisons between inertial sensors and 3D MoCap. Validating inertial sensors for this purpose provides evidence for the development of an accurate, quantitative and practical means of measuring resistance exercise technique, which is not dependant on subjective observational methods.

2. Materials and methods

Ethical clearance was granted by the Charles Darwin University Ethics Committee (reference H14046). One female and ten males volunteered, aged between 18 and 34 years. For the purpose of replicating desired deadlift technique and to minimise volunteer's injury risks, there was strict inclusion criterion. The criterion included a minimum of 12 months prior experience with weekly resistance exercise, completion of a recent one repetition maximum (1RM) attempt and an 18 year age minimum. Informed consent was obtained and a standardised and peer reviewed warm up procedure was implemented that has been safely utilised in gymnasiums (Brown and Weir, 2001). This protocol continues to a 1RM, however to ensure safety, participants only lifted to 80% of 1RM.

Prior to participant arrival, inertial sensors and 3D MoCap were calibrated. Sample rates were set at 100 Hz for both systems. Inertial sensors were placed directly onto the skin with 'Physio' tape on the spinal landmarks C7, T12, and S1 respectively. Three rigid bodies and reflective markers were fixed securely and directly to the inertial sensors at landmarks C7, T12, and S1. Participants completed five repetitions of 15 different lifting trials while being instructed by a certified strength and conditioning coach. The lifting trials completed included unweighted and weighted technique variations of a conventional deadlift, including common technique mistakes.

Raw data was collected via downloading directly from inertial sensor devices (SABEL Sense, SABEL Laboratory, Brisbane, Australia) (James et al., 2011). Motion capture data was collected with an OptiTrack system (NaturalPoint, Inc. Corvallis, Oregon, United States of America), and the trajectorise function was used in Arena™ (NaturalPoint, Inc. Corvallis, Oregon, United States of America) software, to track the movement of all included reflective markers, in three rigid bodies. The trajectorised data was collected, and signal processing of trajectorised data and inertial sensor data was completed in Matlab (R2013a, The MathWorks, Inc. Natick, Massachusetts, United States of America).

Data was synchronised for time in Matlab by utilising jumps that participants performed before and after the five repetitions of every lifting trial. The resulting acceleration spike in X axis acceleration data coincided with ground contact detected in the 3D MoCap system. This method has previously shown to be accurate for synchronisation (Lee et al., 2010). The timing points of identifiable corresponding acceleration peaks in accelerometer X axis and 3D MoCap raw data (vertical spine movement in the sagittal plane at landmarks C7, T12 and S1) during every lifting trial were manually identified and extracted using Matlab (Fig. 1). The reliability of this method may be considered subjective due to the manual process of picking timing data points, which may cause repeatability differences between researchers. However, reliability testing was outside the scope of the current research and automated detection may be an area for future research. Any agreement error between methods may be due only to errors in manual picking, and not relate to actual differences between the two systems. In theory, both methods should measure movement at the same time that accurately reflects movement in real time. Therefore, changing the person who manually picks the acceleration peaks should have minimal influence over results.

Gender data was grouped and one to five time points for each set of 3D MoCap and inertial sensor data (five repetitions per data set) were chosen for comparative analysis. The final sample size was 227 corresponding timing points in inertial sensor and 3D MoCap trials. The time (in seconds) that acceleration peaks in X axis inertial sensor data occurred (at C7, T12, and S1) were validated with the corresponding reflective markers. A Will Hopkins Typical Error of the Estimate validation, with a Pearson's correlation, and a Bland Altman Limits of Agreement were implemented, to determine the timing agreement between the two methods (Bland and Altman, 2010; Hopkins, 2000). Error and bias results were interpreted using the Will Hopkins modified Cohen scale: <0.20, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; >2.0, very large (Hopkins, 2000).

3. Results

The results demonstrate that the inertial sensors had high agreement for accurately detecting the timing of movement

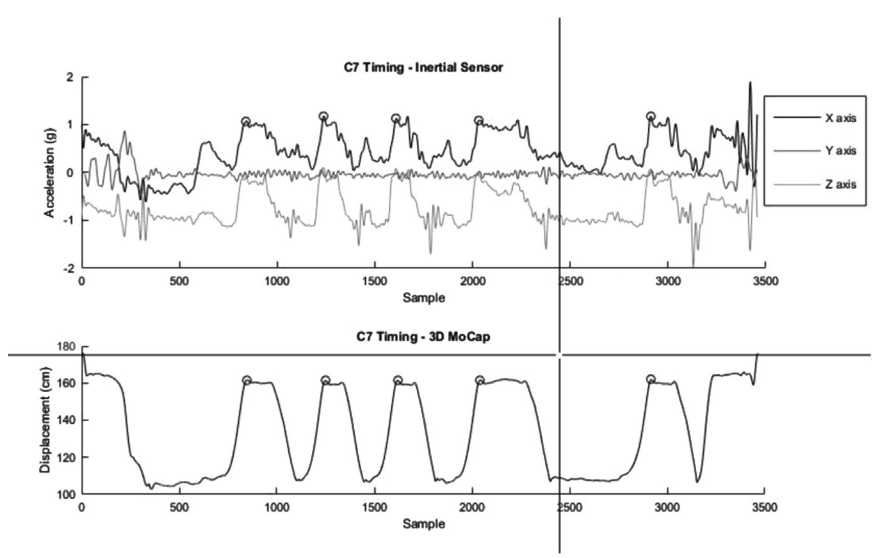

Fig. 1. Typical example of manual extraction of timing points of acceleration peaks from five lifting repetitions between methods. Circles depict the chosen acceleration peaks using cross hair targeting that was available within Matlab software.