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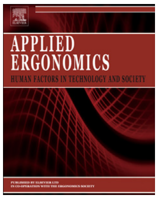

Evaluation of four sensor locations for physical activity assessment

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ABSTRACT

Direct measurements of physical activity (PA) obtained with inertial measurement units (IMUs) secured to the upper arms and trunk of 36 registered nurses working a full shift were compared to measurements obtained with a commercially-available PA monitor (ActiGraph wGT3X-BT) worn at the waist. Raw accelerations from each device were summarized into PA counts/min and metabolic equivalent (METs) categories using standard definitions. Differences between measurements were examined using repeated measures one-way analyses of variance (ANOVA) and agreement was assessed using Bland-Altman plots. Statistically significant differences were observed between all sensor locations for all PA summary metrics except for between the left and right arm for percentages of work time in the light and moderate counts/min categories. Bland-Altman plots suggested limited agreement between measurements obtained with the IMUs and measurements obtained with the wGT3X-BT waist-worn PA monitor. Results indicate that PA measurements vary substantially based on sensor location.

1. Introduction

Musculoskeletal health outcomes of the low back and neck/shoulder are among the most prevalent and burdensome of all occupational injuries. Estimates from the Global Burden of Disease 2010 study suggest that low back pain causes more global disability than any other condition, accounting for 83 million disability-adjusted life years (DALYs) in 2010 alone (Hoy et al., 2012, 2014a). Low back pain arising from occupational exposure to physical risk factors caused 21.7 million DALYs; an increase of 22% between 1990 and 2010 (Driscoll et al., 2014; Murray et al., 2013). Neck/shoulder pain was estimated to account for 33.6 million DALYs in 2010, ranking it the 4th highest in terms of disability and 21st in terms of overall burden (Hoy et al., 2014b).

Occupational exposure to non-neutral postures has been associated with musculoskeletal health outcomes of the low back and neck/shoulder (da Costa and Vieira, 2010; van Rijn et al., 2010; Vieira and Kumar, 2004). Methods for assessing exposure to non-neutral working postures in a field setting include self-report, observational, and direct measurement (Burdorf and Van Der Beek, 1999; David, 2005). The standard approach for directly measuring occupational exposure to non-neutral postures of the low back and shoulder is with piezoresistive accelerometers or, more recently, inertial measurement units (IMUs) secured to the trunk and/or upper arms (David, 2005; Li and Buckle, 1999; Teschke et al., 2009).

An IMU is a solid-state device that measures and reports an object's spatial orientation and motion characteristics using multiple electromechanical sensors (i.e., accelerometers, gyroscopes, and/or magnetometers). They are considered advantageous to accelerometers for posture assessment as fusion of the components of an IMU may address limitations of each individual sensor component (Luinge and Veltink, 2005; Roetenberg et al., 2007). For example, gyroscope measurements can be used to compensate for accelerometer-based measurements that are known to be negatively affected by dynamic and complex motions (Amasay et al., 2009; Godwin et al., 2009). Several recent studies have indicated that IMUs are reasonably stable and accurate when estimating trunk and upper arm postures in comparison to "gold-standard" optoelectric motion capture systems (Cuesta-Vargas et al., 2010; El-Gohary and McNames, 2012; Kim and Nussbaum, 2013; Schall et al., 2015a) and a field-capable reference device (Schall et al., 2015b).

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Additionally, the small size and increasing affordability of IMUs make them practical instruments for measuring posture in field-based research.

In addition to posture, an IMU's accelerometer may be used to measure other aspects of worker health that are typically difficult to observe, such as intensity of physical activity (PA). Although leisure-time PA is widely considered beneficial to overall health (Haskell et al., 2007; Warburton et al., 2006), and some studies have observed favorable effects of PA on musculoskeletal pain among worker populations (Hildebrandt et al., 2000), high intensity occupational PA has been associated with increased risk of several chronic health conditions and may be deleterious to health (Harari et al., 2015; Heneweer et al., 2011; Holtermann et al., 2012a, 2012b, 2010; Sitthipornvorakul et al., 2011). Moreover, some investigators have suggested a U-shaped relationship between intensity of PA and undesirable health outcomes (i.e. both inactivity and excessive activity may increase risk; Heneweer et al., 2009; Sesso et al., 2000). Recent work has thus emphasized the need for more accurate ascertainment of exposure to occupational and leisure-time PA using objective and validated field measurement instruments to better establish future public and occupational health recommendations (Holtermann, 2015; Prince et al., 2008).

Modern PA monitors are portable, electronic devices used to measure and track fitness-related metrics such as energy expenditure, caloric consumption, sleep patterns, and total activity. PA monitors are commonly used in epidemiological research because of their small size, freedom from biases associated with self-report, and accuracy and precision in estimating intensity of activity (Freedson et al., 2012; Matthews et al., 2012). Most PA monitors are worn at the waist or wrist and use single or multi-axis accelerometers to provide summary metrics of the quantity and intensity of movements during set time intervals (Taraldsen et al., 2012; Troiano et al., 2008; Van Remoortel et al., 2012). PA monitors have been used extensively to promote workplace health, with promising results (Bravata et al., 2007; Freak-Poli et al., 2011; Pal et al., 2009; van Sluijs et al., 2006).

Because IMUs and commercially available PA monitors incorporate fundamentally identical hardware (accelerometers), the use of small numbers of sensors in anatomic locations to capture both biomechanically meaningful posture information and PA information may be possible. Commercially available PA monitors positioned on the upper arms and on the upper back provide valid inclination data for direct long-term field measurements of upper arm and trunk inclinations in comparison to a magnetic tracking device (Korshøj et al., 2014) and a universal goniometer (Hirschhorn et al., 2015). However, the extent to which PA measurements obtained from sensors located on the upper arms or on the trunk agree with PA measurements obtained from PA monitor worn at the waist is not known. The objective of this study was, therefore, to estimate the agreement between measures of PA obtained with IMUs attached to the upper arms and to the trunk and measures of PA obtained with a commercially available PA monitor worn at the waist.

2. Methods

2.1. Participants and study design

A convenience sample of 36 healthy, female registered nurses (mean age = 30.8 years, SD = 10.1; mean body mass index [BMI] = 24.1, SD = 4.4) was recruited from two medical surgical inpatient units in the University of Iowa Hospitals and Clinics. Participants self-reported 1) no history of physician-diagnosed MSDs in the neck/shoulder or back regions, 2) no neck/shoulder or back pain two weeks prior to enrollment, and 3) no history of neurodegenerative disease (e.g., Parkinson's disease). All participants were right-hand dominant. Study procedures were approved by the University of Iowa Institutional Review Board and the University of Iowa Hospitals and Clinics Nursing Review Committee. Informed consent was obtained prior to participation.

2.2. Physical activity data processing

Direct measurements of PA from each participant were obtained using three IMUs and one wGT3X-BT PA monitor (ActiGraph, Pensacola, Florida, USA). Each IMU (ArduIMU v3, 3D Robotics Inc., Berkeley, CA) was a small wireless, battery-powered unit that was set to measure and store acceleration (triaxial, ±8 g) information. One IMU was secured to the posterior trunk at approximately the level of the 4th thoracic vertebral body and one IMU was secured to the lateral aspect of both upper arms approximately one-half the distance between the lateral epicondyle and the acromion (Fig. 1). The raw acceleration data streams of the wGT3X-BT (triaxial, ±8 g) and each IMU were sampled at 50 Hz for a continuous duration of 12 h. All devices stored the raw acceleration data to on-board flash memory. A combination of custom LabVIEW (version 2014, National Instruments Inc., Austin, TX) and Matlab (r2014a, The Mathworks, Natick, MA) programs were used to synchronize the data from each device (using time stamps recorded with the data) and process the raw acceleration information to PA summary metrics.

The raw acceleration information from each IMU and the wGT3X-BT were summarized using two approaches. For the first approach, the raw acceleration information was transformed from units of gravity (i.e., g) to a unitless metric describing the intensity of the acceleration (i.e., “counts”) (Chen and Bassett, 2005; John and Freedson, 2012). First, the raw acceleration values were converted into an omnidirectional measure of acceleration by calculating the vector magnitude of the three accelerometer axes. The resulting acceleration signal was then band-pass filtered (zero-phase, 6th order Butterworth) at a bandwidth of 0.25–2.5 Hz and full-wave rectified (John and Freedson, 2012). The filtered acceleration signal was then converted to activity counts, defined as any activity that was measured above a predefined threshold of 0.016317 m/s^2

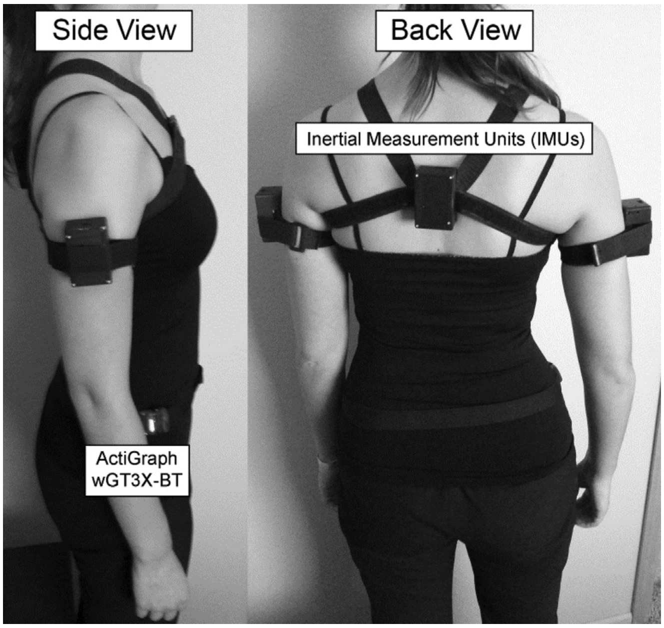

Fig. 1. The four sensor locations.