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An iPhone application for upper arm posture and movement measurements

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ABSTRACT

There is a need for objective methods for upper arm elevation measurements for accurate and convenient risk assessments. The aims of this study were (i) to compare a newly developed iOS application (iOS) for measuring upper arm elevation and angular velocity with a reference optical tracking system (OTS), and (ii) to compare the accuracy of the iOS incorporating a gyroscope and an accelerometer with using only an accelerometer, which is standard for inclinometry. The iOS–OTS limits of agreement for static postures (9 subjects) were −4.6° and 4.8°. All root mean square differences in arm swings and two simulated work tasks were <6.0°, and all mean correlation coefficients were >0.98. The mean absolute iOS–OTS difference of median angular velocity was <13.1°/s, which was significantly lower than only using an accelerometer (<43.5°/s). The accuracy of this iOS application compares well to that of today's research methods and it can be useful for practical upper arm measurements.

1. Introduction

Musculoskeletal disorders (MSDs) in the neck/shoulder regions are widespread in the working population (van Rijn et al., 2010). In the United States, shoulder disorders accounted for the sick leave of about 90,000 workers with a median of 26 sick days in 2014 (Bureau of Labor Statistics, 2015). Working with elevated arms has been shown to be a critical risk factor for shoulder disorders (Bernard, 1997; Svendsen et al., 2004; van Rijn et al., 2010) and neck pain (Petit et al., 2014; Viikari-Juntura et al., 2001), while there is limited knowledge about the quantitative exposure-response relationships (Dahlqvist et al., 2016).

To evaluate the exposure of risk factors for MSDs, three types of methods are available: self-reports, observational methods, and direct measurements (David, 2005). However, these methods have various limitations when applied for risk assessment. Self-reports are inexpensive and easy to use, but their validity is usually low (Hansson et al., 2001a; Prince et al., 2008). Observational methods are widely used; however, it is difficult to obtain quantitative information and usually has low inter-observer reliability using observational methods, especially for small and quick movements (Takala et al., 2010). Additionally, different observational methods often give differing assessment results (Chiasson et al., 2012). Direct measurements can provide valid results, but they have until now been considered expensive and require specialized staff for data analysis (David, 2005).

The recent development of electronics and small accelerometer devices with integrated memory has made it possible to develop uncomplicated whole-day measurements (Dahlqvist et al., 2016). Still, for these measurements, one needs to buy and initiate devices and run the analyses on a computer, which can be difficult for practitioners who have not used any direct methods before. However, this problem can be overcome by the rapid development of smartphones, which provides possibilities for convenient posture and movement assessments in scientific and clinical research (Mourcou et al., 2015). Firstly, smartphones are affordable, and are used daily by most people. Secondly, they have an embedded inertial motion unit (IMU), containing a 3D-accelerometer, gyroscope, and magnetometer as standard features. They are also equipped with a screen display and an audio system that enables direct result visualization and user feedback. Specific software, called "applications", for smartphones and other mobile devices can be developed and can take advantage of these functionalities. Thirdly, data on the smartphone can be sent wirelessly via

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Bluetooth or Internet connection, which provides convenient data transmission and possibilities for further assessment. Finally, data can be combined easily with other data from self-reports or observations to achieve a better risk assessment and improve interventions at workplaces.

There are various mobile device applications which have been found to be reliable tools in clinical or field research, using the embedded accelerometer or magnetometer, for e.g. body position measurements (Milani et al., 2014), gait and posture analyses (Kosse et al., 2014), and whole-body vibration assessments (Wolfgang et al., 2014). However, few exist that record and assess upper arm postures and movements. An iPhone or iPod Touch (Apple Inc., USA) has embedded factory-calibrated inertial sensors with which the maximum sampling frequency obtained by the iOS operating system is 100 Hz, thus making it capable to record human motion. The performance of the embedded inertial sensors of the iPhone 4 and 5s has been shown to be accurate and reliable for angular movements measurement in comparison to a robotic arm (Mourcou et al., 2015). These findings prompted the development and public release of a free iOS application – ErgoArmMeter (Yang and Forsman, 2015), which facilitates a convenient and inexpensive means of measuring upper arm elevation, suitable for workplace risk assessment. The iPhone 6, which was released later, is equipped with a new generation of inertial sensors and had not been evaluated in the scientific literature by the time this study was carried out. Thus, both the iPhone 6 and 5s were included and compared with each other in this study.

The first aim of this study was to establish the criterion validity of the ErgoArmMeter application using an iPhone 6 and 5s for measurements of upper arm postures and movements. The second aim was to compare the results from the application, of which signals from the embedded accelerometer and gyroscope in the iPhone are used, with the case of only using the accelerometer signal (as in standard inclinometry).

This paper describes first the functions of the iOS application and then an evaluation of its validity, which was carried out as a comparison of its data with data simultaneously obtained from an optical tracking system (OTS) under static and dynamic conditions.

2. Materials and methods

2.1. The iOS application

The iOS application, which was named ErgoArmMeter, was written in Swift using the development tool Xcode (version 6.2, Apple Inc., USA). It collects three-dimensional data from the built-in accelerometer and gyroscope of the iPhone or iPod Touch with a sampling frequency of 20 Hz. When the application is started, the user enters trial information as project name, trial number, measured arm and notes (Fig. 1A). The measurement phase then includes a so-called calibration, and buttons to start, pause, redo and stop recordings (Fig. 1B). For the calibration, or reference posture identification, an average measurement of a 2-second period is used. This posture is then defined as 0° elevation. The 2-second period starts 0.5 s after the click on the calibration button, in order to avoid errors from shaking. When the reference posture is identified, the user may start a measurement, via the start button. Upon ending (via the stop button), the application calculates the 50th and 90th percentiles of the angular distribution, the percentage of time with the elevation greater than 30°, 60° and 90°, respectively, and the median of the generalized angular velocity distribution (Fig. 1C), which are commonly used summary metrics in field studies on occupational exposures (Hansson et al., 2010; Wahlstrom et al., 2010). The trial information, the measurement results, and the complete angular data can be shared via email in a comma-separated values file for further analysis. The raw data from the accelerometer and gyroscope are not written in the file, but it was recorded and saved during the validation experiment (see below).

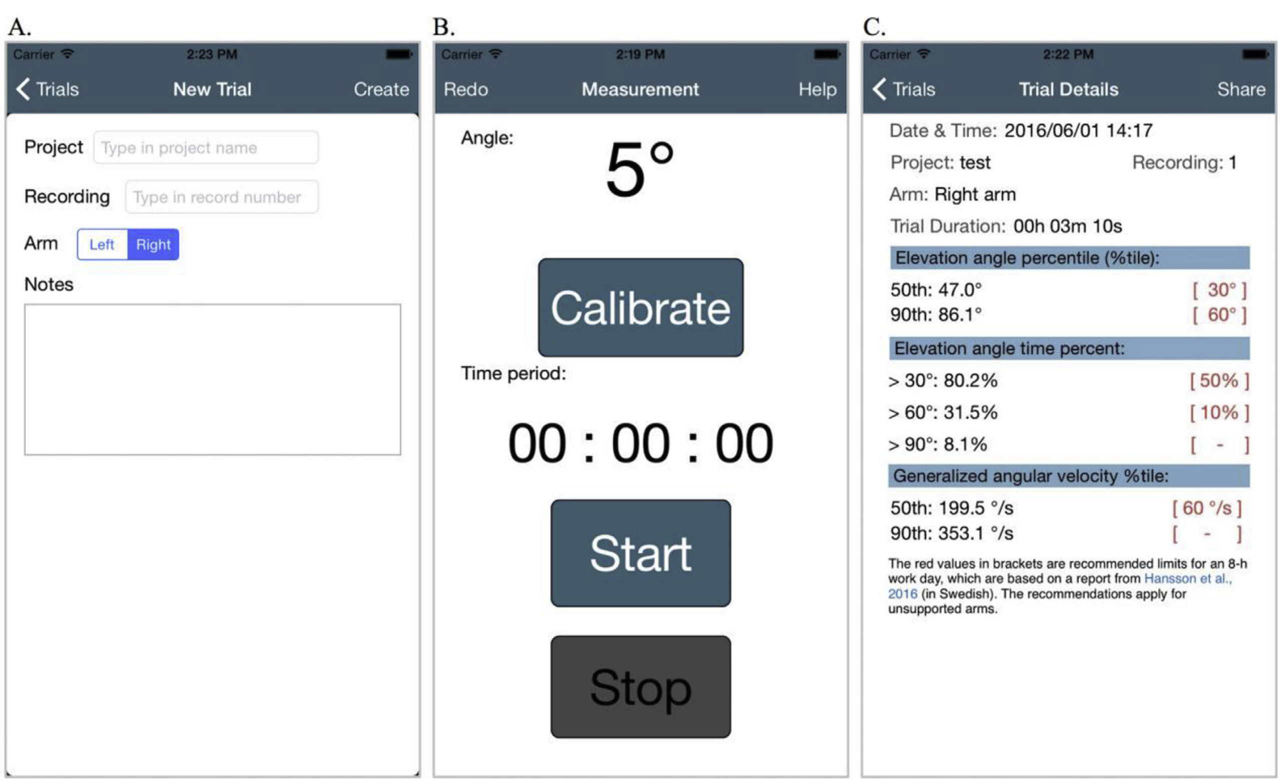

Fig. 1. User interfaces of the iOS application. A: Creating a trial; B: Calibrating and starting a measurement; C: Results of a measurement.