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Reliability and validity of a smartphone-based application for the quantification of the sit-to-stand movement in healthy seniors

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ABSTRACT

Introduction: Recently, it has been demonstrated that biomechanical parameters measured with accelerometers during everyday activities might provide early information about mobility in seniors. The use of smartphones has been suggested for this purpose. The aim of this study was to develop and validate a smartphone-based application for the quantification of the sit-to-stand movement (STS) in healthy seniors.

Methods: Sixteen healthy seniors performed the STS with a smartphone first attached to the lower back and then to the sternum. The subjects' vertical ground reaction forces (VGRF) and vertical acceleration (VAcc) were recorded simultaneously using two force plates (reference standard) and the smartphone, respectively. VAcc data were converted to force; power was then calculated based on both force-time curves. Subsequently, the total movement duration (T_{total}), peak force (F_{max}), rate of force development (RFD) and peak power (P_{max}) were determined. Relative (intraclass correlation coefficient [ICC]) and absolute (standard error of measurement [SEM]) reliability were also calculated. For the variables showing strong reliability (ICC ≥ 0.75), Pearson correlation coefficients (r) between VGRF- and VAcc-derived data and one-sample T-tests for the mean differences were carried out.

Results: In the sternal configuration, all variables showed strong reliability (range: 0.86–0.93), except the smartphone-derived parameter RFD (ICC = 0.43). F_{max} and T_{total} were found to be highly valid (r = 0.86 and 0.98, respectively).

Conclusion: The results showed that the smartphone-based application can be used as a reliable and valid tool for the quantification of the STS in healthy seniors if the proposed protocol is followed.

1. Introduction

Population aging is a well-known phenomenon in industrialized countries [1,2]. It has been reported that in older adults a physiological decline often leads to difficulties in performing daily activities and to a decreased quality of life [3,4]. The sit-to-stand movement (STS) is of particular concern, because it is not only key to preserving functional autonomy [5], but also one of the most challenging daily exercises in terms of mechanics [5] and balance [6]. Because of this, several clinical tests such as the timed-up and go test (TUG) have been developed thus improving the evaluation of physical performance and mobility. It is also thought that the TUG is associated with fall risk because it replicates everyday mobility tasks [7]. Even though such tests may be useful, it has been consistently reported that stopwatch-based tests lack sensitivity in certain patient groups [8–11] and are prone to limitations such as assessment subjectivity [12]. These issues have led to a more refined approach to quantifying mobility and the risk of falling in biomechanical studies. It has been reported that elderly people with a history of falls show decreased vertical velocity of the center of mass (COM) [13] and generate less vertical force [14] during STS, compared to non-fallers. In order to measure such parameters in clinical practice, the use of triaxial accelerometers has been suggested [7,14]. This practice has evolved into an inexpensive and easy-to-use procedure, which is no longer tied to a biomechanical laboratory [12].

Smartphones are increasingly used in medical applications [16] and recent studies have suggested that assessments using accelerometers incorporated into smartphones may be reliable

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and accurate enough to substitute specific portable devices in gait assessment [15]. It would therefore seem logical that smartphones could also yield practicability and financial benefits when assessing functional tasks such as STS in seniors. Thus, the purpose of this study was to develop a smartphone-based application for the estimation of the ground reaction forces generated during STS movement and to evaluate its concurrent validity against force plate measurements in healthy seniors.

2. Methods

2.1. Smartphone application development

To enable the measurement of acceleration during STS sequences, an application on the basis of the mobile operating system (OS) Android (Google Inc., Mountain View, CA, USA) was developed, sampling data from the device's internal movement sensors. The sensors used were a triaxial accelerometer and a rotation vector sensor, measuring device acceleration (m/s^2) and rotation (axis-angle-representation) [17] respectively. While the accelerometer is an actual hardware sensor on all Android devices, the rotation vector sensor is, on most device models, a software-based (virtual) sensor, which itself uses acceleration and magnetic field measurements to calculate device orientation [18]. The rotation vector sensor data was used to transform raw acceleration data from device coordinates to world coordinates (Fig. 1), thus correcting inevitable device orientation changes during STS sequences. As rotation vector sensor data describes the device's momentary orientation in world coordinates in terms of a single rotation around a specific axis by a specific angle, raw acceleration data can be transformed to world coordinates by rotating the acceleration vector back around this very axis by this very angle. The calculation of this rotation was done by the application directly after each measurement, using Rodrigues' rotation formula [17]. Android applications cannot directly access hardware sensors, but they can register sensor events, which are produced and shared by the OS whenever new sensor data is available. The frequency with which these events occur is irregular [18] and with the device used for this study (see Section 2.3) the mean frequency was found to be 59 ± 13 Hz. This issue was resolved later in the analysis, by resampling all raw sensor data (see Section 2.5).

In addition, the application allowed a measurement timeout to be set, as well as remote control of start and stop of measurements from another smartphone or computer via a Bluetooth connection. A graphical preview of the data of each measurement was displayed immediately on the device, allowing the verification of the acquired data.

2.2. Subjects

Participants were recruited from two regional retirement homes and the author's entourage. Sixteen elderly subjects (age = 73.5 ($\pm$10.4) years, height = 171.9 ($\pm$5.9) cm, mass = 81.4 ($\pm$11.9) kg) were included based on the following inclusion criteria: (1) male sex, (2) $\geq$55 years old, (3) able to stand up from a chair without help (i.e. without the use of the arms or an assistant), (4) healthy, which was defined as "no acute ailment" (e.g. fever or inflammation) and no other illness that would restrain the subject in performing a STS task "properly" (i.e. without obvious compensatory movement) and (5) able to understand the provided information and task. Any violation of the inclusion criteria was considered an exclusion criterion. The study was approved by the local ethics board and written informed consent was obtained from all subjects.

2.3. Apparatus and data acquisition

Vertical ground reaction forces (VGRF) were measured using two separate force plates (FP) (Type 9286BA, Kistler, Winterthur, Switzerland), one placed under the subjects' feet and another one under a custom-built chair with a seat height of 50 cm (ISO 9241-5 standard) (Fig. 2). A universal measurement amplifier (UMVE, uk labs, Kempen, Germany) with a gain of 2$\times$ was used to amplify the signal. FP data was recorded at a sampling rate of 1 kHz using the software Nexus (version 1.7.1, Vicon, Oxford, UK). In parallel, the subject's vertical acceleration (VAcc) was measured using a HTC Desire HD smartphone (HTC Corp., Taoyuan City, Taiwan) with Android OS (version 2.3.5) that was attached to the subject's body with a custom-built non-elastic Velcro belt (Ortho-Team AG, Bern, Switzerland).

2.4. Procedure

Prior to any measurements, the subjects' body mass (kg) and height (m) were recorded. In order to find the best approximation of the COM, STS measurements were performed with the smartphone attached in one of two positions: position (1) the lower back (spinous process of the third lumbar vertebra [L3]) and

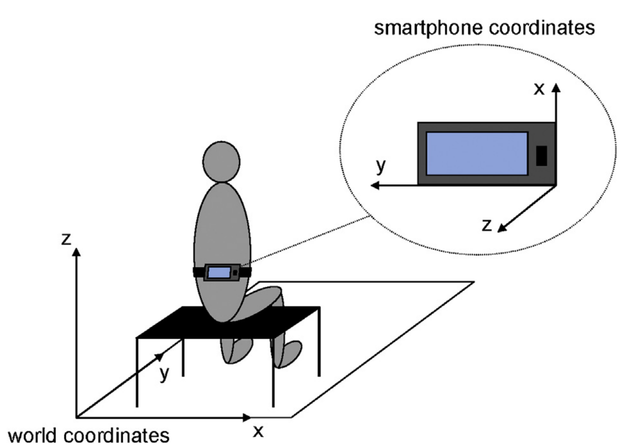

Fig. 1. Scheme presenting a subject with the smartphone attached to the lower back (L3). The smartphone coordinates are shown in enlarged viewing in the upper right corner (*x*-axis = vertical axis; *y*-axis = medio-lateral axis; *z*-axis = antero-posterior axis). The accelerations in these three directions were then converted into world coordinates (three arrows starting from the lower left corner of the area representing the laboratory's surface).

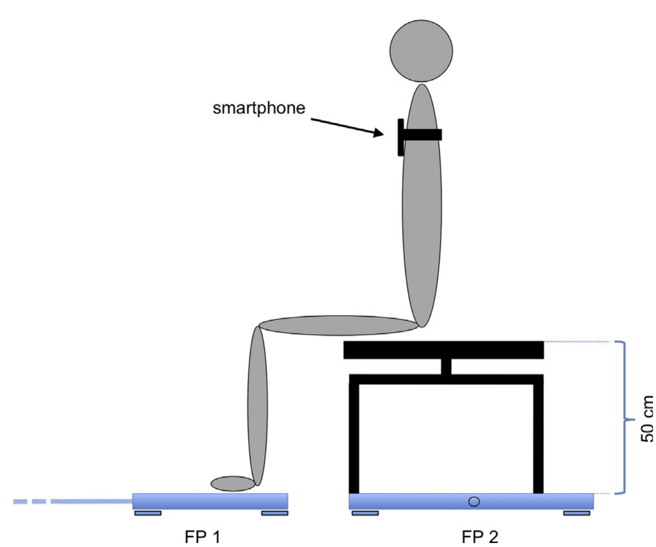

Fig. 2. Measurement set-up with the custom-made chair and both force plates (FP 1 and FP 2) as well as a subject with the smartphone attached to the sternum.