Gait & Posture 41 (2015) 935–940

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Sensor-based monitoring of sit-to-stand performance is indicative of objective and self-reported aspects of functional status in older adults

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ARTICLE INFO

Article history:
Received 23 September 2014
Received in revised form 26 February 2015
Accepted 30 March 2015

Keywords:
Accelerometry
Kinematics
Balance
Clinical assessment
Aged

ABSTRACT

Studies show that body-fixed motion sensors can be used for long-term monitoring of sit-to-stand (STS) performance in older persons. However, it is unclear how sensor-based measures of STS performance relate to functional status in older adults. Therefore, this study investigated the associations between sensor-based STS measures and standard clinical measures of functional status in older adults. Participants (24 females, 12 males; 72–94 years) performed five normal STS movements while wearing motion sensors on the hip and chest. Objective measures were used to assess mobility (Timed-Up-and-Go Test, Five-Times-Sit-to-Stand Test, Stair Walk Test) and quadriceps strength. Self-reported questionnaires were used to assess limitations in activities of daily living (Groningen Activity Restriction Scale) and frailty (Groningen Frailty Indicator). In general, chest STS measures showed a larger number of significant associations and stronger associations with clinical measures than hip STS measures. Chest maximal velocity, chest peak power, chest scaled peak power and chest stabilization phase SD demonstrated significant associations (weak to strong) with all six clinical measures. Noteworthy is that hip stabilization phase SD showed significant associations (weak to moderate) with five clinical measures. In particular chest peak power and chest scaled peak power demonstrated a moderate ability to discriminate between higher and lower functioning individuals (area under the receiver–operating characteristic curve: 0.75–0.90). This study shows that in particular chest STS measures are indicative of objective and self-reported aspects of functional status in older adults. These findings support the clinical relevance of sensor-based monitoring of STS performance in older persons.

1. Introduction

With aging functional status may decline, therefore it is important to monitor functioning in older adults and to timely initiate interventions to prevent loss of functional abilities. Methods for the monitoring of motor functioning have been developed using body-fixed motion sensors [1]. Sensor-based measurement of leg power may be a relevant addition to existing sensor-based methods. Leg power is a determinant of mobility (changing basic body position, i.e. getting into and out of a body position and moving from one location to another [2]) and an important parameter for measuring intervention effects [3–6]. Motion sensors can be used to estimate vertical peak power during the STS transfer [7] with adequate reliability and sensitivity to change [8–10].

However, it is unclear how sensor-based STS peak power and other STS measures (e.g. maximal velocity) relate to the functional status of older adults. Therefore, the aim of this study was to investigate the associations between sensor-based STS measures and standard clinical measures of functional status in older adults. STS measures were calculated from an individual sensor, because from a practical perspective a single sensor is preferred over multiple sensors. Studies show that leg power is associated with mobility, leg strength, self-reported measures of activities and mobility [3–6]. Therefore, we hypothesized that sensor-based STS peak power is associated with mobility, leg strength, self-reported

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http://dx.doi.org/10.1016/j.gaitpost.2015.03.350
0966-6362/

measures of limitations in activities and frailty. In addition, we hypothesized that STS peak power is more strongly associated with the aforementioned aspects of functional status than other STS measures. As part of the study aim, we also investigated the ability of STS peak power to discriminate between higher and lower functioning individuals.

2. Methods

2.1. Participants

Participants were 36 older adults (24 females, 12 males; age: 72–94 years (mean ± SD: 82.2 ± 5.4 years); mass: 48.0–104.4 kg (79.3 ± 14.1 kg); height: 1.46–1.89 m (1.66 ± 0.10 m)). Inclusion criteria were: Age≥70 years, being able to perform STS movements and walk ≥10 m (with or without a wheeled walker or cane). Recruitment took place in a health care center, residential care home and sheltered houses. Exclusion criteria were: lower extremity orthopedic surgery or a stroke within the six months before the study, cognitive, neurological, cardiovascular or respiratory disorders, severe comorbidity, significantly reduced vision.

A statistical analysis was performed to determine the sample size [11]. Previous studies found a correlation of approximately 0.5 between leg power and functional status [4,5]. The analysis indicated that at least 28 participants were needed to find a significant correlation of 0.50 with an alpha of 0.05 and a power of 0.90.

The study received approval from the Medical Ethical Committee of University Medical Center Groningen, the Netherlands (METc2011.054). The study protocol conforms to the Helsinki declaration. All participants signed an informed consent.

2.2. Sensor-based STS measurements

2.2.1. Procedures

Participants performed five normal STS movements from a standard chair (height: 0.47 m). Start position was sitting against the back of the chair. Participants were requested to cross their arms in front of the chest before standing up. Following each STS movement, participants were instructed to stand still for 5 s. Following each stand-to-sit movement, participants sat still on the chair for 10 s before conducting the next STS movement.

2.2.2. Data acquisition

Participants wore two sensors (π-Node, Philips). One sensor was worn on the right side of the hip (see figure 2 in Regterschot et al., 2014a [8]), because the sensor-based estimation of center of mass acceleration during STS is most accurate at this location [7]. Another sensor was worn on the chest (sternum), because this seems a practical location for mobility monitoring [12]. Each sensor contained a 3D accelerometer (±2 g), gyroscope (±300°/s) and magnetometer (±2G) [7–9,13]. Sampling frequency was 50 Hz. Data were wirelessly sent to a PC [13].

2.2.3. Data analysis

The analysis was applied to the data of each individual sensor using Matlab (The Mathworks; version 7.12). Quaternions were used to estimate accelerations of the sensor in the global coordinate system [13]. A low-pass Butterworth filter (cut-off = 3 Hz) was applied on the data. Thereafter, STS measures were calculated based on the vertical acceleration data in the global coordinate system:

1. *STS duration*: Time between the beginning of the forward trunk rotation prior to standing up and the first intersection of the vertical acceleration signal with the gravitational acceleration, after the deceleration period (see figure 3 in Regterschot et al., 2014a) [8].
2. *Maximal acceleration*: Highest vertical acceleration during STS.
3. *Maximal jerk*: Maximal positive jerk during the acceleration period of the STS movement. The formula $jerk_i = (a_{i+1} - a_i)/(1/f_s)$ was used, with i representing sample number, a vertical acceleration, and f_s sample frequency.
4. *Maximal velocity*: Highest vertical velocity during STS. We calculated velocity by numerical integration of vertical acceleration and assumed that velocity was 0 m/s at the beginning of the STS movement.
5. *Peak power*: Maximal vertical power generated during STS. Power was calculated by multiplying force and velocity: $P_i = F_i \cdot v_i$ [7]. Force was estimated as follows: $F_i = m \cdot a_i$. The m represents body mass.
6. *Scaled peak power*: Peak power scaled by body mass (m), height (l) and gravity (g): $P_{scaled} = P/(m \cdot g^{1.5} \cdot l^{0.5})$ [14].
7. *Stabilization phase SD*: the standard deviation (SD) of the vertical acceleration signal during the stabilization phase, which was defined as the interval of 0.8 s after STS. Previous research showed that this interval includes the stabilization phase durations of most elderly and that the time of the stabilization phase predicts STS duration [15].

2.3. Standard clinical measurements

2.3.1. Objective measures

2.3.1.1. Mobility. Mobility was assessed with the Timed-Up-and-Go Test (TUGT) [16], Five-Times-Sit-to-Stand Test (FTSST) [17], and Stair Walk Test (SWT).

The TUGT started when the investigator said "Go". Participants stood up from a chair, walked 3 m, turned around a cone, walked back, and the TUGT ended when the participant sat down again. The test was performed at a self-preferred speed. The use of chair armrests, wheeled walker or cane was allowed. The TUGT was practiced once. Duration was measured. As cut-off value 13.5 s was used to distinguish higher and lower functioning individuals [18].

During the FTSST participants performed five STS movements as quickly as possible. The FTSST started when the investigator said "Go" and time was measured. Participants stood up from the chair with their arms crossed in front of the chest. When sitting down, participants moved toward a vertical trunk position, without touching the back of the chair. The FTSST ended when the participant's buttocks reached the chair seat after the fifth STS transfer. Participants practiced the FTSST once. A cut-off value of 15 s was used [19].

For the SWT, participants were instructed to walk a stair consisting of three steps as fast as possible. Participants were not allowed to skip a step. Start position was standing 3 cm in front of the first step. The test started when the investigator said "Go" and ended when the participant was standing with both feet on the third step. Time was measured. Participants were allowed to use the right handrail and practiced the SWT once. The SWT is a novel test with excellent test–retest reliability in the present study sample (intraclass correlation (ICC) = 0.92).

2.3.1.2. Isometric quadriceps strength (IQS). Maximal isometric quadriceps strength was assessed with a quadriceps force measuring system [20]. Participants performed two maximal voluntary contractions with the right and left leg at 70° knee flexion. Final score was the average score of all trials.

2.3.2. Self-reported measures

2.3.2.1. Limitations in activities of daily living. Limitations in activities of daily living were measured with the self-reported