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Early identification of declining balance in higher functioning older adults, an inertial sensor based method

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A B S T R A C T

Higher functioning older adults rarely have their balance assessed clinically and as such early decline in balance is not captured. Early identification of declining balance would facilitate earlier intervention and improved management of the ageing process. This study sought to determine if (a) a once off inertial sensor measurement and (b) changes in inertial sensor measurements one year apart can identify declining balance for higher functioning older adults. One hundred and nineteen community dwelling older adults (58 males; 72.5 ± 5.8 years) completed a timed up and go (TUG) instrumented with inertial sensors and the Berg balance scale (BBS) at two time points, one year apart. Temporal and spatio-temporal gait parameters as well as angular velocity and turn parameters were derived from the inertial sensor data. A change in balance from baseline to follow-up was determined by sub-components of the BBS. Changes in inertial sensor parameters from baseline to follow-up demonstrated strong association with balance decline in higher functioning older adults (e.g. mean medial-lateral angular velocity odds ratio = 0.2; 95% CI: 0.1–0.5). The area under the Receiver operating characteristic curve (AUC) ranged from 0.8 to 0.9, a marked improvement over change in TUG time alone (AUC 0.6–0.7). Baseline inertial sensor parameters had a similar association with declining balance as age and TUG time. For higher functioning older adults, the change in inertial sensor parameters over time may reflect declining balance. These measures may be useful clinically, to monitor the balance status of older adults and facilitate earlier identification of balance deficits.

Introduction

With declining fertility and increasing life expectancy for most regions of the world, the mean global age has increased [1]. This trend is expected to continue with projected figures for 2050 of 2 billion adults over the age of 60 [2]. In order to minimise the economic and health costs of these changing population demographic early identification of decline coupled with timely medical intervention is required.

Higher functioning older adults represent those who are community dwelling, independently mobile and have few morbidities [3]. Despite evidence that it is an essential component of the functional assessment of older adults, balance is often not assessed in these older adults [4]. Declining balance is associated with limited mobility and an increased risk of falls [5]. Early detection of decline in balance could facilitate earlier intervention and potentially reduce the risk of falls. Current clinical measures of balance are restricted by ceiling scores which higher functioning older adults are likely to obtain [6]. Inertial sensor based balance assessments may represent an appropriate substitute to current assessments for higher functioning groups.

The timed up and go (TUG) is used to assess functional mobility and requires both static and dynamic balance [7,8]. The TUG is quick, easy to administer and has been shown to have some predictive power for falls and mobility impairment [9,10]. Additionally, the application of wireless inertial sensors to the lower limbs during the TUG allows measurements such as cadence, stance phase duration and angular velocity to be recorded [11,12]. These objective measures have been combined statistically to improve the accuracy of falls risk assessment as compared to TUG time [11,12]. As altered balance is associated with falls risk these inertial sensor based measures may have utility in identifying early changes in balance for higher functioning groups [4].

This study had two objectives:

(1) To determine if baseline quantitative TUG parameters are associated with a decline in balance at follow-up for higher functioning older adults.

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(2) To determine if changes in quantitative TUG parameters (measured at two time points one year apart) reflect decline in balance for higher functioning older adults.

Methods

Participants were those from the Technology Research for Independent Living (TRIL) longitudinal study on ageing (www.trilcentre.org). Those who were community dwelling, greater than 60 years of age, able to walk independently, cognitively intact and able to provide informed consent were included in the TRIL cohort. Participants attended the TRIL Clinic, St. James's Hospital Dublin, Ireland in 2010–2011 for a comprehensive baseline assessment [13]. Follow-up assessments were completed on average 12.9 months later, over a period of 22 months after the initial baseline assessment. Institutional ethical approval was granted.

In a study of several clinical measures of balance, the BBS demonstrated the lowest rates of ceiling effect amongst a group of older adults with functional limitations [5]. The BBS has been shown to be highly correlated with TUG time [12] (also referred to as manual TUG). As such it was selected as the clinical reference standard of balance for comparison with the quantitative TUG. The BBS is progressive in nature with the final components (tandem stance and single leg stance) considered the most challenging [14]. It was anticipated that a change in these more complex tasks would be seen before a change in the simpler tasks for those older adults who were higher functioning. For the current study, the more complex BBS sub-components were targeted as indices of declining balance. Decline in each BBS sub-component was defined as a negative change in component score of 2 or more ($\geq$40% reduction). Participants were categorised as 'balance declined' or 'balance not-declined' for each individual sub-component as well as overall BBS, based on how each BBS sub-component and the overall BBS changed between baseline and follow-up. For the total BBS a decline in balance was defined as a decrease in total score of at least four [15].

Participants completed the BBS and the quantitative TUG at both test sessions. The BBS was delivered and scored as per the protocol outlined by Berg et al. [16]. The TUG was conducted as per the protocol described by Greene et al. [11]. Wireless inertial sensors (SHIMMER Research, Dublin, Ireland) were used to capture kinematic data during the TUG (Fig. 1). Each sensor contained a tri-axial accelerometer and a tri-axial gyroscope and sampled at 102.4 Hz. Sensors were calibrated using a standard procedure [17] and attached to the anterior tibia of each leg. Sensor data were transmitted wirelessly via Bluetooth to a PC.

All sensor data analysis was performed using MATLAB version 7.11 (Mathworks, Natick, MA, USA). Quantitative TUG parameters were calculated from the raw sensor data, these are described in detail elsewhere [11,12]. In summary temporal, spatio-temporal, turn and tri-axial angular velocity parameters were extracted for further analyses. The sensor angular velocities were described as medio-lateral (ML), anterior-posterior (AP) and vertical (V) (Fig. 1). Quantitative TUG parameters were derived for baseline TUG sensor data and for the changes in sensor data between baseline and follow-up.

Additional measures were collected at the baseline assessment to further characterise the cohort. Cognitive status was assessed using the Mini-Mental State Examination (MMSE) [18]. Maximum grip strength was measured using a handheld dynamometer (Baseline® Hydraulic Hand Dynamometers, Nex-Gen Ergonomics Inc., Quebec, Canada). Polypharmacy was defined as the regular use of four or more prescription medications [19]. Finally, the age-adjusted Charlston co-morbidity index (AACCI) provided an indication of health status [20].

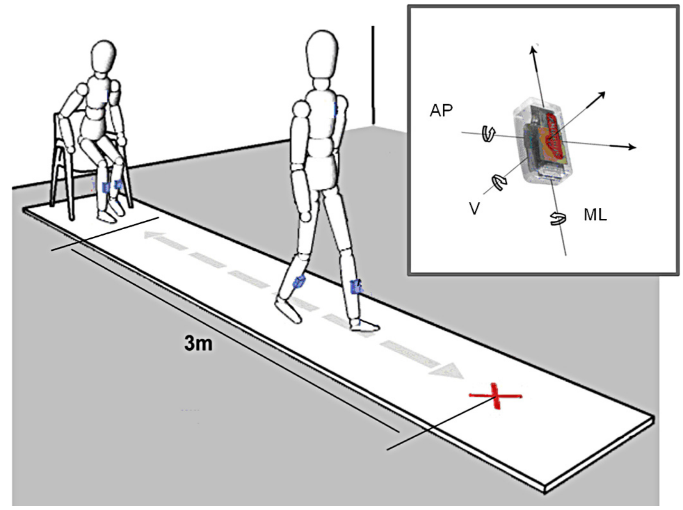

Fig. 1. Experimental setup for capture of inertial sensor data during the TUG test. Sensors were affixed to the anterior tibia of each lower limb during the TUG test.

Statistical analysis

Statistical analyses were performed using SPSS version 18.0 for Windows (SPSS Inc., Chicago, IL, USA). Baseline participant characteristics were generated for groups based on declined/not-declined status and described in terms of sample proportions, their means and standard deviations, or median, minimum and maximum. Independent *t*-tests and Mann–Whitney rank-sum tests were performed to investigate if between groups differences ($\alpha \leq 0.05$; 95% confidence interval (CI)) in baseline characteristics were evident. The coefficient of variation (CV) was calculated as the standard deviation of each quantitative TUG parameter divided by the mean of each quantitative TUG parameter taken across the entire TUG test.

To avoid multicollinearity the number of variables was reduced using logistic regression by block analysis. Fifty-two inertial sensor derived variables were grouped into five blocks (temporal ($n = 17$), spatio-temporal ($n = 6$), turn ($n = 6$), angular velocity ($n = 14$), angular velocity by height parameters ($n = 9$)). The balance dichotomization of declined/not-declined for single leg stance, tandem stance and total BBS was used as the dependent variable. Working with each block, a univariate logistic regression was performed on each independent variable on each balance outcome and only those which were significant ($\alpha \leq 0.05$) were retained in each block. Through this procedure all non-significant variables were excluded from the analyses for each final model.

Final logistic regression models were generated using the results of the sub-group analyses. Three models assessed the association of baseline quantitative TUG parameters with decline in single leg stance, tandem stance and total BBS, respectively. These models were adjusted for age as a potential confounder. An additional three models assessed whether the change in TUG parameters between baseline and follow-up assessments was associated with a decline in single leg stance, tandem stance and total BBS. Change in age over time is a constant and as such was not included in these models. An additional six univariate models assessed the association of TUG time and change in TUG time with declining balance. Odds ratios with 95% confidence intervals for the final models were described. The area under the receiver operating characteristic (ROC) curve and its associated confidence interval was used as an indicator of each model's predictive capability.