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Falls classification using tri-axial accelerometers during the five-times-sit-to-stand test

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ABSTRACT

The five-times-sit-to-stand test (FTSS) is an established assessment of lower limb strength, balance dysfunction and falls risk. Clinically, the time taken to complete the task is recorded with longer times indicating increased falls risk. Quantifying the movement using tri-axial accelerometers may provide a more objective and potentially more accurate falls risk estimate. 39 older adults, 19 with a history of falls, performed four repetitions of the FTSS in their homes. A tri-axial accelerometer was attached to the lateral thigh and used to identify each sit–stand–sit phase and sit–stand and stand–sit transitions. A second tri-axial accelerometer, attached to the sternum, captured torso acceleration. The mean and variation of the root-mean-squared amplitude, jerk and spectral edge frequency of the acceleration during each section of the assessment were examined. The test–retest reliability of each feature was examined using intra-class correlation analysis, ICC(2,k). A model was developed to classify participants according to falls status. Only features with ICC $>$ 0.7 were considered during feature selection. Sequential forward feature selection within leave-one-out cross-validation resulted in a model including four reliable accelerometer-derived features, providing 74.4% classification accuracy, 80.0% specificity and 68.7% sensitivity. An alternative model using FTSS time alone resulted in significantly reduced classification performance. Results suggest that the described methodology could provide a robust and accurate falls risk assessment.

1. Introduction

The five-times-sit-to-stand test (FTSS) was introduced in 1985 as a standardised measure of lower extremity strength [1]. It has since been associated with postural balance disorders [2–5] and cognitive function [6]. Additionally, it has been established that the time taken to complete the FTSS is an independent predictor of falls risk [7,8]. During the FTSS, participants must stand up from a chair, and sit down again, five times as quickly as possible. Typically, a clinician records the time taken to complete the task, with longer times indicating poorer performance.

Recent studies have examined the use of FTSS to identify balance disorders and those at higher risk of falling. Discriminant analysis using the FTSS time has been reported to identify 60% of participants over 60 years with balance dysfunction from those without, with an optimal cut-off of 14.2 s [3]. Additionally, FTSS times greater than 15 s were reported to indicate a 74% greater risk of recurrent falls [7]. The FTSS was also reported to provide more added value to a falls assessment than the "Timed Up and Go" (TUG) test, and the "One-Leg-Balance" test, particularly when examining those at moderate risk of falls [9]. Consistently, FTSS time was reported to significantly discriminate subjects who experienced multiple falls during the 12 months following assessment from non-recurrent fallers, with excellent test–retest reliability [10]. However, there is a lack of consensus on the cut-off time for high falls risk. Additionally, this single measure of performance does not quantify postural sway or steadiness of movement and is susceptible to human error. Due to the complex nature of falls, a more objective and comprehensive method to assess falls risk using the FTSS is required.

Accelerometry has been shown to be a valid tool to examine a single sit-to-stand movement in studies comparing it to a

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video-based system [11–13] and a force platform [14]. Recently, a falls risk estimation model based on accelerometer data obtained during an unsupervised protocol which included a TUG test, an 'alternative step test', and an FTSS was presented [15]. Therein, a linear least squares approach was used to develop models based on accelerometer-derived features of each assessment. 16 FTSS features were presented, of which the dissimilarity between sit-to-stand cycles was selected for inclusion in the reported falls risk model [15]. However, a method to quantify falls risk based on acceleration data captured during the FTSS alone has yet to be reported. Such a method would require little clinical time and space, and be particularly suitable for early detection of those at moderate risk of falls.

Accelerometry may provide an appropriate and useful method to assess falls risk using the FTSS, potentially with significant improvement in falls classification accuracy compared to FTSS time alone. In this study, logistic regression was used to develop a model to robustly classify falls status based on reliable accelerometer-derived FTSS features.

2. Methods

This study was performed as part of a larger research project which examined diurnal variations in the outcome of various clinical assessments and their association with falls history [16,17].

2.1. Participants

39 community-dwelling older adults provided informed consent and participated in this study. Approval was obtained from the local Ethics Committee. All participants had a detailed clinical assessment and falls history consistent with the AGS guidelines [18].

A fall was defined as an event which resulted in a person coming to rest on the lower level regardless of whether an injury was sustained, and not as a result of a major intrinsic event or overwhelming hazard [19]. 19 participants (7 male; age 74.89 ± 7.00 years, range 66–88 years; BMI: 26.62 ± 4.25, range 20.11–37.85) were categorised 'fallers'. Participants were considered 'fallers' if they experienced multiple falls, or one fall requiring medical attention, during the twelve months prior to assessment. Two participants were additionally categorised as fallers due to an unexplained fall which caused a bone fracture or coincided with a blackout during the 5 years prior to assessment. 20 participants (9 male; age 68.35 ± 6.22 years, range 61–87 years; BMI: 27.74 ± 2.79, range 22.01–32.34) were considered 'non-fallers', as they did not fit these criteria. Univariate analysis of variance (ANOVA) was used to examine the difference between the age and BMI of fallers and non-fallers.

The FTSS was conducted in the home under supervision at four fixed times during a 10 h period – between 9.00 and 9.30 am, 1.00 and 1.30 pm, 3.30 and 4.00 pm and 6.00 and 6.30 pm [16]. Participants were asked to refrain from vigorous exercise the day before and the day of the experiment. Participants were advised to eat a light breakfast between 8.30 and 9.00 am, light lunch at 12.30 pm and light snack at 2.30 pm, and to refrain from consuming caffeinated drinks.

2.2. Data acquisition

Two tri-axial accelerometers (Shimmer Research, Dublin, Ireland) were used to quantify movement during the FTSS. One accelerometer was positioned over the participant's clothing on the lateral aspect of the right thigh, with one axis aligned with the femur, recording the femoral acceleration, Fig. 1. Another accelerometer was positioned above the sternum and secured using elasticated bandages, such that its axes measured the superior–inferior (SI), anterior–posterior (AP) and medial–lateral (ML) acceleration of the sternum during the assessments. A 46 cm high chair was used, and participants were asked to keep their arms folded across their chest, Fig. 1. Participants were then asked to fully stand up and sit back down five times as quickly as possible.

Tri-axial accelerometer data were synchronously acquired at 102.4 Hz in real-time using BioMOBIUS (http://www.biomobius.org). Data were exported to text format. Post-processing and analysis were conducted using Matlab. Accelerometer data were calibrated using a published procedure [20] and low-pass filtered at 5 Hz using a 4th order Butterworth filter.

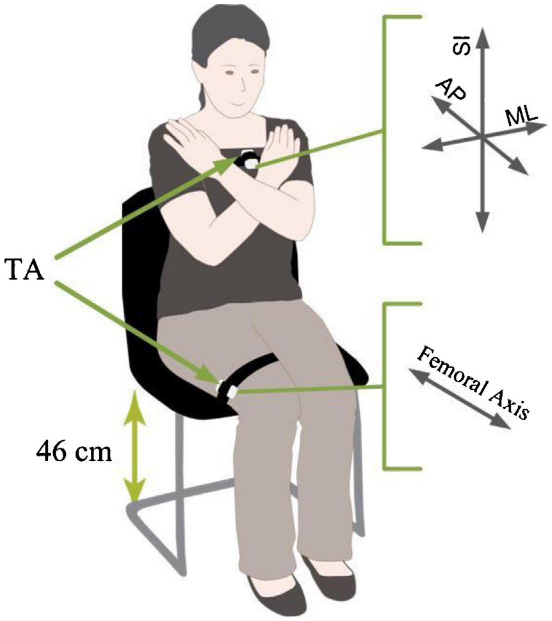

Fig. 1. Illustration of experimental set-up of the FTSS, tri-axial accelerometers (TA) worn on sternum and right thigh. Sensor axes are indicated.

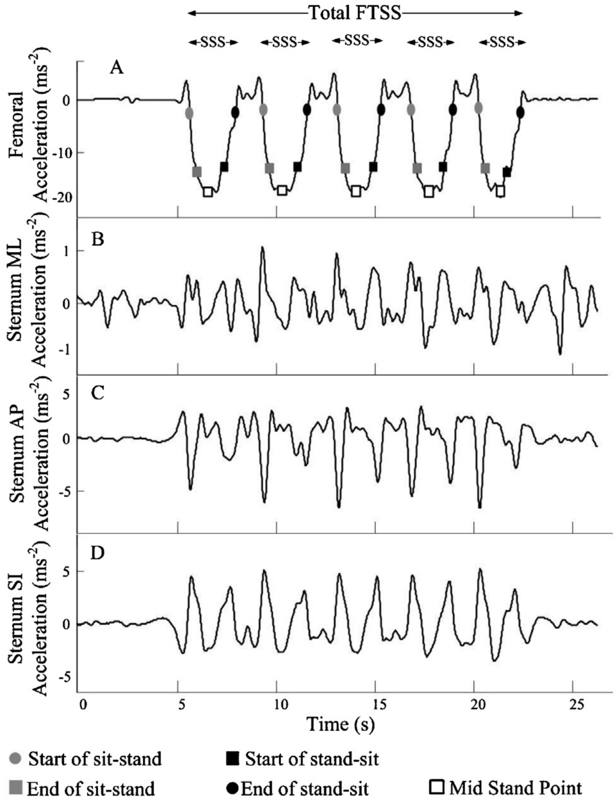

Fig. 2. Typical processed tri-axial accelerometer signals recording from the thigh (A) and from the sternum (B–D) during the FTSS test. Mid-stand points, and the start and end of each sit–stand and stand–sit transition are indicated using the femoral acceleration (A).

2.3. Feature extraction

The femoral acceleration was used to isolate each sit–stand–sit (SSS) phase of the FTSS. The minimum femoral acceleration over the total FTSS, $A_{\min}$, was used to detect the minimum acceleration during each SSS phase, referred to as mid-stand points, Fig. 2. Only mid-stand points with accelerations, A_{MS}, less than $0.8A_{\min}$ were deemed successful SSS attempts, ensuring that all successful SSS phases were detected. Recordings capturing exactly five mid-stand points were included in this analysis, 23 trials (14.4%) were thus excluded.

The start and end of each sit–stand transition, stand–sit transition and SSS phase were established using the empirically tuned thresholds $0.2A_{\mathrm{MS}}$ and $0.8A_{\mathrm{MS}}$. When the signal amplitude decreased past $0.2A_{\mathrm{MS}}$, this marked the start of a sit–stand transition. When the signal amplitude fell below $0.8A_{\mathrm{MS}}$, this marked the end of a