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A multi-resolution investigation for postural transition detection and quantification using a single wearable

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ABSTRACT

Background: Multi-resolution analyses involving wavelets are commonly applied to data derived from accelerometer-based wearable technologies (wearables) to identify and quantify postural transitions (PTs). Previous studies fail to provide rationale to inform their choice of wavelet and scale approximation when utilising discrete wavelet transforms. This study examines varying combinations of those parameters to identify best practice recommendations for detecting and quantifying sit-to-stand (SiSt) and stand-to-sit (StSi) PTs.
Methods: 39 young and 37 older participants completed three SiSt and StSi PTs on supported and unsupported chair types while wearing a single tri-axial accelerometer-based wearable on the lower back. Transition detection and duration were calculated through peak detection within the signal vector magnitude for a range of wavelets and scale approximations. A laboratory reference measure (2D video) was used for comparative analysis.
Results: Detection accuracy of wavelet and scale combinations for the transitions was excellent for both SiSt (87–97%) and StSi (82–86%) PT-types. The duration of PTs derived from the wearable showed considerable bias and poor agreement compared with the reference videos. No differences were observed between chair types and age groups respectively.
Conclusions: Improved detection of PTs could be achieved through the incorporation of different wavelet and scale combinations for the assessment of specific PT types in clinical and free-living settings. An upper threshold of 5th scale approximations is advocated for improved detection of multiple PT-types. However, care should be taken estimating the duration of PTs using wearables.

1. Introduction

Physical capability tests have been shown to be predictive of all-cause mortality in older adults [1,2]. One test is a timed sit-to-stand (SiSt) postural transition (PT) which has been identified as important for inclusion in the assessment of lifestyle-based interventions [3]. The high mechanical output needed for successful completion makes it a suitable surrogate marker of lower limb functional strength [4]. Traditionally, PTs are assessed by an observer with the use of a stop watch. Recent advances in accelerometer-based wearable technology (wearables) algorithms/methodologies have facilitated more objective measures through instrumentation in both controlled and free-living settings [5]. Wearables afford the researcher high precision temporal data as well as numerous novel accelerometer derived outcomes leading to more refined analysis [6,7]. However, further 'fine-tuning' of the former has been advocated to classify and assess this activity type [8].

Detecting PT-type and duration can be achieved using sensor integration (accelerometer and air pressure) [9]. In contrast, a single sensor configuration has been utilised from a chest worn wearable using scalar product and vertical velocity estimates [10]. Alternatively, algorithms have included multi-resolution approaches where wavelets are used to detect and quantify PT performance descriptors [11,12]. This methodology has also been applied to the signal vector magnitude (SVM) from a wearable worn on the lower back [13], proving useful when examining only PTs in composite measures of physical capability (e.g. timed-up-

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and-go) by supressing other signal dependant activities such as gait [14].

Wavelet-based approaches use a discrete wavelet transform (DWT), which can be interpreted as a filter bank where the signal is decomposed into several components, each representing a single frequency (scale) sub-band of the original signal [15]. Scaling of the wavelet enables frequency resolution and the shifting provides the time information [16]. This is important when considering the signal characteristics exhibited by the PT of interest, as the frequency banding must be of sufficient range to capture the desired output. As such, choice of wavelet and its associated parameters can influence the accuracy of PT detection/quantification.

Selection of wavelet methodologies (wavelet, order, and scale) often seems arbitrary with little rationale provided for the approaches taken with respect to PT analysis. To the authors knowledge no previous study has justified wavelet (and associated parameter) selection, i.e. a 'one size fits all' approach is usually adopted whereby a single wavelet is used for analysis of multiple PT types rather than considering different wavelets for different PTs (e.g. SiSt/StSi) [11–13]. Considering that different PT strategies are employed for different transitions [17], and the inherent effect sitting posture has on strategy selection [18], we hypothesise that a more optimal combination of wavelet and scale approximation could exist.

Therefore, the aim of this study is to examine the effect of wavelet methodology on detecting and quantifying the duration of PTs undertaken with two chair types in a large cohort of younger and older adults using a wearable on the lower back. The effect of age and chair type was also examined to investigate algorithm robustness. Manipulation of these parameters should reveal valuable information regarding best practice recommendations for analysis of PTs using wavelets. This research will serve to inform the design of wearable algorithms and direct future PT examination in clinical and free-living settings.

2. Methods

2.1. Participant recruitment

Participants were recruited from staff and students at Newcastle University and VOICENorth,[1] an older adult volunteer group who participate in research. Participants were included only if they were healthy i.e. had no physical or neurological disabilities that might impede their movement or balance. Eighty healthy adults aged 20–40 years (40 young participants, YP) and 50–70 years (40 older participants, OP) were recruited. Ethical consent for the project was granted by the National Research Ethics Service (County Durham and Tees Valley) and the Newcastle-upon-Tyne Hospitals NHS Foundation Trust (11/NE/0383). All participants gave informed written consent before completing the study.

2.2. Equipment

Each participant wore a single tri-axial accelerometer-based wearable (Axivity AX3, York, UK) located on the lower back (5th lumbar vertebra-L5). The wearable was held in place by double sided tape and Hypafix (BSN Medical Limited, Hull, UK) and programmed to capture at 100 Hz (16-bit resolution, range of ±8 g). Data were stored locally on the wearable's internal memory as a raw binary file that was downloaded upon completion of the testing session. Video recordings (Sony HandyCam DCR-SR77, Sony Europe Ltd, Surrey, England; 25 Hz) were used as a reference measure to validate the PT type (SiSt or StSi) and duration.

2.3. Experimental protocol

Wearable data were transformed to a horizontal-vertical coordinate system [19]. For both chair types participants completed three SiSt and three StSi transitions with short (<3s) intermittent breaks between trials as part of a scripted laboratory protocol. Prior to performance, participants were instructed to sit in a comfortable upright position. In order to preserve parity between testing measures, SiSt and StSi transitions were defined as follows for video analysis [20]:

- SiSt transition: time interval between initial vertical movement of the waist (lateral aspect of the iliac-crest) to maximal hip extension.
- StSi transition: time interval between initial downward movement of the waist to touch-down on the chair surface.

The rationale being that this definition of a PT best equated to the functionality of the wearables instrumentation, i.e. wearable location and algorithm functionality. PTs were performed from two chairs of similar height:

- Supported Chair (Chair-S): Height 0.41 m with arm-rests. Participants were instructed to use the arm-rests if they wished.
- Unsupported Chair (Chair-US): Height 0.43 m, no arm-rests.

Two-dimensional motion analysis was completed using Kinovea motion analysis software (Version 0.8.15, Kinovea, France; temporal resolution 0.04s). To avoid inter-rater error, a single researcher examined transition kinematics and derived transition durations for all individual PT performances.

2.4. Algorithms

After testing, data were downloaded and analysed using a bespoke Matlab® program using the wavelet toolbox. A DWT was applied to the SVM of the accelerometer to extract single PTs. The DWT is given in Eq. (1) in terms of its recovery transform, where *d (k, l)* is a sampling of the wavelet coefficients at discrete points *k* and *l* with the wavelet ψ [10].

$$x(t) = \sum_{k=-\infty}^{\infty}\sum_{l=-\infty}^{\infty} d(k,l)2^{-\frac{k}{2}}\psi\left(2^{-k}t - l\right)\gamma \qquad (1)$$

The transition duration and type were estimated from twice the time and order between the negative/positive peaks, respectively [13].

2.5. Wavelets and scale approximation

A range of wavelets and orders were implemented to examine their suitability. Preliminary analysis revealed particular wavelets, orders and scales had insufficient compatibility to define the characteristics required for PT detection and duration (Fig. 1). Therefore only five wavelets and scales one-to-six were compared within this study (denoted by * Table 1.). Data were generated for the previously described PT and chair types (SiSt-S, StSi-S, SiSt-US, and StSi-US) for each participant.

2.6. Statistical analysis

2.6.1. Detection agreement

Detection accuracy of the wavelet and scale approximation combinations compared to video were calculated for SiSt and StSi PTs. Detection accuracy of each wavelet was defined as the number

[1] www.ncl.ac.uk/changingage/engagement/VOICENorth