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Short communication

Automated approach for quantifying the repeated sit-to-stand using one body fixed sensor in young and older adults

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ABSTRACT

Much is known about the sit-to-stand (STS) and its biomechanics. Currently, however, there is little opportunity for instrumented quantification of the STS as part of screening or diagnosis in clinical practice. The objectives of the present study were to describe the feasibility of using an automated approach for quantifying the STS using one sensor location and to start testing the discriminative validity of this approach by comparing older and younger adults. 15 older subjects recruited from a residential care home and 16 young adults performed 5 repeated sit-to-stand and stand-to-sit movements. They were instrumented with a small and lightweight measurement system (DynaPort®) containing 1 triaxial seismic accelerometer and 3 uniaxial gyroscopes fixed in a belt around the waist. Durations of the (sub-)phases of the STS were analyzed and maximum angular velocities were determined. All successful STS cycles were automatically detected without any errors. The STS duration in the older adults was significantly longer and more variable in all phases (i.e., sit-to-stand, standing, stand-to-sit and sitting) compared to the young adults. Older adults also exhibited lower trunk flexion angular velocity. The results of this first fully automated analysis of instrumented repeated STS movements demonstrate that several STS parameters can be identified that provide a basis for a more precise, quantitative study of STS performance in clinical practice.

1. Introduction

Previous work using camera-based systems and force plates in laboratory settings has quantified sit-to-stand (STS) movements to better understand their biomechanical dynamics [1,2]. Body fixed sensors (BFS) were introduced to movement analysis research in the early 1990s [3] and offer an alternative approach to quantifying the STS. Studies using BFS demonstrated the ability to identify the beginning and end of STS transitions with one gyroscope fixed to the chest [4]. Accelerometers fixed to the sternum and to the upper leg were used to detect the start and end of a STS transition in healthy subjects and stroke subjects [5]. Using accelerometers and gyroscopes, the kinematics of rising from a chair were calculated [6]. Power during STS movements has been recently analyzed by adding magnetic-field sensors [7]. Nonetheless, to date, automated algorithms for quantifying repeated sit-to-stand and stand-to-sit movements using BFS have not been described. This method is expected to be usable for collecting quantitative STS data on a routine basis in clinical practice. Since this is currently not possible, the objective of the present study was to investigate the feasibility of using an automated approach for quantifying the STS using one sensor location and to start testing the discriminative validity of this approach by comparing older and younger adults.

2. Methods

2.1. Subjects

In this experimental cross-sectional study, 15 older adults (OA), living in a residential care home (11 female, median age 88 (73–99) years; median height 162 (156–192) cm; median weight 66 (44–91) kg) and 16 healthy young adults (YA) were recruited (9 female, median age 20 (18–23) years; median height 167 (162–184) cm; median weight 62 (53–78) kg). Height and weight were not significantly different in the two groups. All participants provided informed written consent. The protocol was approved by the Ethics committee of the Free University Amsterdam.

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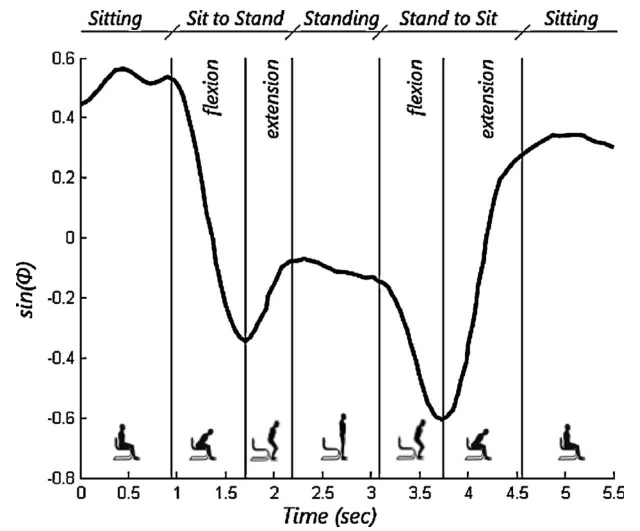

Fig. 1. The wavelet transform of the sine of the trunk angle, dw_sin(ϕ), is shown during the main sub-phases of a complete STS cycle, preceded and followed by a sitting epoch.

2.2. Instrumentation and data acquisition

A BFS system (DynaPort® Hybrid, McRoberts; 87 mm × 45 mm × 14 mm, 74 g) was inserted in an elastic belt on the lower back positioned at the lumbar vertebra. These included 3 pre-calibrated accelerometers (STM-LIS3LV02DQ), 3 gyroscopes (EPSON-XV-3500CB), sampling rate 100 Hz. The accelerometer signals have been shown to be highly reproducible [8]. Raw data were stored on a Micro-SD card (SanDisk).

2.3. Procedure

Subjects performed 5 STS cycles at a self-selected speed (start and end in a sitting position), while free to swing their arms. A standard chair without arm rests was used. Subjects were video taped from the side to enable post hoc visual inspection by a single observer of successful and failed attempts. A failed STS attempt was defined as the subject not being able to end in a standing position.

2.4. Signal analysis

Data was corrected for tilt [9]. The acceleration and the angular velocity in the sagittal plane determined the trunk angle (ϕ) [10]. Subsequently, the sine of the trunk angle (sin(ϕ)) was calculated. Drift and noise were removed from the sin(ϕ) using the discrete wavelet transform dw_sin(ϕ) [4]. "True vertical acceleration" was estimated by removing the influence of ϕ from the vertical acceleration signal. Finally, vertical velocity was derived by integrating this signal.

The vertical velocity was used to differentiate between successful STS movements and failed STS attempts. The dips in dw_sin(ϕ) were used to detect a change in trunk rotation direction (Fig. 1). The start of the sit-to-stand was defined as the

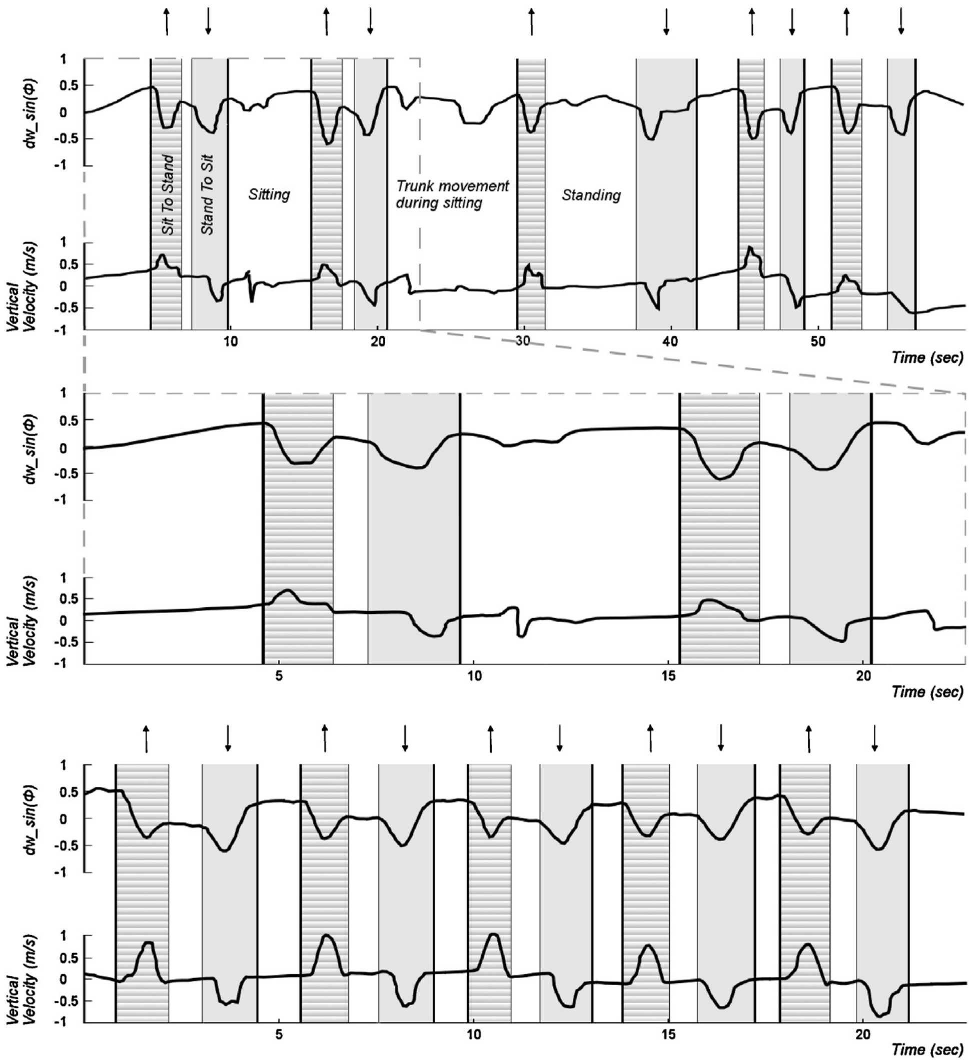

Fig. 2. Typical example of five repeated STS cycles of an older adult (top panel) and a young adult (bottom panel). In the middle panel the first 23 s of the older adult panel is stretched, indicated by a dotted line, for better comparibility to the young adult panel. In the panels dw_sin(ϕ) andvertical velocity are shown. Standing up is indicated by ↑, sitting down is indicated by ↓. Variability of the signals of the OA is highand of the YA is relatively low. Duration of standing and sitting of the OA is relatively long.

Table 1
Durations (s), maximum angular velocity ($\omega_{\max}$, in°/s), and coefficient of variation of durations (percentage) of the 5 repeated sit-to-stand cycles of the young and older adults.

		Young adults			Older adults			p-Value*
		Median	Min	Max	Median	Min	Max	
Duration (s)								
Sit-to-stand	Duration	1.45	1.14	2.58	1.98	1.65	3.49	<0.001
	Flexion duration	0.73	0.63	0.88	1.06	0.74	1.64	<0.001
	Extension duration	0.72	0.49	1.74	1.1	0.82	1.94	<0.001
Standing	Duration	0.33	0	0.74	1.35	0.57	6.57	<0.001
Stand-to-sit	Duration	1.47	1.18	2.28	2.59	1.34	3.21	<0.001
	Flexion duration	0.69	0.46	0.91	1.31	0.65	1.87	<0.001
	Extension duration	0.79	0.71	1.37	1.06	0.69	1.68	0.024
Sitting	Duration	0.33	0.06	0.7	3.1	0.36	9.71	<0.001
Angular velocities (°/s)								
Sit-to-stand	$\omega_{\max_{\text{flexion}}}$	124.62	90.04	192.7	91.62	57.31	125.46	<0.001
	$\omega_{\max_{\text{extension}}}$	57.22	20.7	98.9	54.67	25.57	93.33	0.323
Stand-to-sit	$\omega_{\max_{\text{flexion}}}$	79.68	50.32	117.63	40.93	22.99	72.71	<0.001
	$\omega_{\max_{\text{extension}}}$	102.15	60.42	138.22	107.31	65.65	170.29	0.527
Coefficient of variation (%)								
Sit-to-stand	Duration	7	2	15	26	7	42	<0.001
	Flexion duration	8	5	16	19	9	41	<0.001
	Extension duration	11	3	33	40	7	85	0.003
Standing	Duration	40	5	96	55	26	121	0.08
Stand-to-sit	Duration	8	3	39	19	7	51	0.001
	Flexion duration	12	2	36	22	9	44	0.005
	Extension duration	10	3	61	18	11	79	<0.001
Sitting	Duration	36	8	69	57	38	140	0.002

* P-values compared the young and older adults are calculated using the Mann–Whitney U-test ($p < 0.05$).

end of the plateau before the first dip in dw_sin(ϕ). Similarly, the end of the sit-to-stand was defined as the start of the plateau after the first dip in dw_sin(ϕ). The start of the stand-to-sit was defined as the end of the plateau before the second dip in dw_sin(ϕ) and the end of the of the stand-to-sit was defined as the start of the plateau after the second dip in dw_sin(ϕ). Plateaus were identified where the slope of dw_sin(ϕ) was smaller than 0.1. After automated identification of all phases (sit-to-stand and stand-to-sit) and sub-phases (flexion and extension), durations, coefficients of variation of all durations (CV) and maximum angular velocity were calculated. Only subjects who completed all 5 repetitions were included in the analysis of the CV.

To evaluate the feasibility of the automated method, we documented the % of STS movements that correctly identified using the BFS and compared that to those identified by the observer.

2.5. Statistical analysis

Due to the small sample size and non-normal distribution of some measures, parameters are described using median, minimum and maximum values. Differences in outcomes between OA and YA were analyzed using the Mann–Whitney U-test ($p < 0.05$) (SPSS version 17.0).

3. Results

All 16 young controls were able to complete the 5 STS cycles. Twelve of the OA completed all 5 STS cycles, three completed at least 1 cycle. The data of all subjects were included in the analysis of duration and angular velocity.

From the 12 OA who completed the 5 repetitions, 3 had failed efforts to rise from the chair. All (100%) of the failed attempts were detected as such by the software and all successful transitions were correctly identified. Fig. 2 illustrates an example of the dw_sin(ϕ) of the trunk angle and the vertical velocity of five STS cycles of a typical OA and YA. The variability of the signal and the durations of the phases of the older adult are high. Nonetheless, all sit-to-stand and stand-to-sit transitions were correctly detected by the software without manual interference.

All durations were significantly longer for the OA (Table 1). The median of the summed time of standing and sitting was 4.45 s and 0.66 s for OA and YA, respectively, representing 49% and 18% of the total STS cycle time. The maximum angular velocity was lower for the OA during the flexion phases of sit-to-stand and stand-to-sit than for the YA ($p < 0.001$), but not during the extension phases. All but one (standing phase) of the CV scores were significantly higher for OA than for YA (Table 1).

4. Discussion and conclusions

The present findings demonstrate that automated analyses of repeated STS data captured using a single BFS is feasible. The software was able to correctly detect durations and maximum angular velocity of all successfully completed sit-to-stand and stand-to-sit cycles.

The automated detection also identified many features of the STS that were different in this small sample of older and young adults. Future work is needed to identify parameters that are most sensitive to aging and intervention. Duration parameters were chosen to differentiate between the duration of different phases. The angular velocity parameters were chosen because in other studies they relate to moments, which might be critical for successful STS transition. CV parameters were chosen because they might show loss of automation. The initial findings suggest that these three different sets of parameters may have clinical utility.

Further validation in a larger sample size and in patients who may have more disturbed STS patterns are needed to confirm the present findings and identify the most relevant parameters. Nonetheless, the results of this first fully automated analysis of instrumented repeated STS movements demonstrate that several STS parameters can be identified that provide a basis for a more precise, quantitative study of STS performance, in clinical practice.

Acknowledgements

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Conflict of interest

R.C.V.L. is the owner and E.A. is an employee of McRoberts B.V. This company is the manufacturer of the DynaPort.

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