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NON-INVASIVE FALL RISK ASSESSMENT IN COMMUNITY DWELLING ELDERLY WITH WIRELESS INERTIAL MEASUREMENT UNITS

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Abstract

Falls are among the most serious accidents among the elderly leading to increased injuries, reduced functioning and mortality. In 2009, about 2.2 million nonfatal fall injuries were reported among the elderly population (CDC, 2010). In this study, eleven community dwelling elderly (aged 65-84 years) participated in fall risk assessment camp at sterling senior center organized by Northern Virginia Fall Prevention Coalition (NVFPC). Three custom made wireless inertial measurement units (IMUs) were attached on trunk and both shanks. All participants performed postural and locomotor tasks such as sit-to-stand (STS) and timed up and go (TUG). Temporal and kinematic parameters were obtained. Raw signals obtained were denoised using ensemble empirical mode decomposition and savistzky-golay filtering. The mean and standard deviation of TUG time and STS completion time for participants were found to be 11.3±6.6 sec and 3.58±2.07 sec respectively. The high variation in the result may be due to the use of assistive devices (i.e., cane and walker) by two participants. The objective of this study is to classify fall prone community dwelling individuals using non-invasive system. Four participants were classified as fall prone, three without fall risk and four were at potential risk based on their objective assessment and task performance. This system provides a platform for identifying fall prone individuals and may be used for early fall interventions among the elderly.

Keywords

Inertial measurement units; Timed up and go; Ensemble empirical mode decomposition; Fall; community dwelling elderly

INTRODUCTION

The elderly population is growing at a rapid pace and the senior most baby boomers i.e. born between 1946 and 1964 will likely turn 65 in 2011[1]. Currently, there are 40 million people in the US aged 65 and above, and it is expected to double and reach 89 million by the year 2050 [2]. Furthermore, in the 65 years and above age bracket, the "oldest old" i.e. 85 years and over is projected to increase from 15 percent currently to over one-fifth of the total 65 years and above population by the year 2050 [2]. Falls have been seen to be one of the leading causes of injury death among the elderly individuals and the most cited cause of nonfatal accidents and trauma related hospital admissions [3]. Approximately, 2.2 million elderly individuals underwent treatment in emergency departments in 2009 for nonfatal fall injuries and around 581,000 were later hospitalized [3]. Fall related injuries can lead to death, disability, nursing home treatment and direct medical expenses [4, 5]. About 82% of fall related fatalities in 2008 were in the age group of 65 and above [3]. The direct medical costs alone for falls was around $19 billion in 2000 [4], adjusting for price inflation it would be around $28.2 billion in 2010 dollar terms [3]. Additionally, the number of fall related accidents have increased significantly from the year 2000 data point further exacerbating the costs of medical care. Lacerations, hip fractures or head traumas are common injuries faced by twenty to thirty percent of individuals who experience falls [3]. Fall injuries reduce the mobility of elderly individuals [6, 7] and pose a significant social and economic cost to society as a whole. Thus, it becomes imperative to determine fall risk elderly individuals and introduce early fall interventions among them.

The timed “Up and Go” (TUG) test, designed and developed by Podsiadlo and Richardson [8] has been used to investigate functional mobility among the elderly individuals. TUG test consists of day to day movement activities like standing up, walking, turning and sitting down. Previous research studies which used the TUG test indicate the total time was different between the two community-dwelling elderly groups - history of falls in the last six months and no fall history [9]. Thus, the TUG test acts as a good screening tool for identification of fall risk prone elderly individuals. Sit-to-stand being an important daily life movement activity [10] is another standard clinical test for elderly mobility [11]. Sit-to-stand movement has been classified into four stages flexion momentum, extension, deceleration and stabilization based on kinematic and kinetic events [12] [13]. Age seems to have a profound influence on standing balance [14] and postural instability has been reported as a major issue among the elderly individuals [15].

The current study attempted to investigate and classify fall prone community dwelling elderly individuals using non-invasive systems and procedures like postural stability, sit-to-stand and timed up and go (TUG).

METHODS

Participants

Data was collected on eleven community dwelling elderly (age 60±8 years). Participants (height 163.28±12.07 cm and body weight 86.18±22.19 kg) were asked to perform a timed up and go task, sit-to-stand using arm-rest and knee support, walking and their postural stability was determined with eyes open and eyes closed in a senior center facility. All participants were ambulatory, did not require the use of any assistive devices, and were able to rise from chair without assistance and free of orthopedic injury. All participants who participated in the study provided written consent prior to participating.

Procedure

Participants wore three TEMPO nodes (one on each ankle, and one on the trunk at sternum level). The participants sat comfortably on chair with backrest and arm-rest with their thighs and feet parallel and were instructed to use arm-rest/ knee support while rising from chair. The spacing between feet was maintained at 15 cm. Chair popliteal height was 45 cm and knee angle was maintained from 85°-90° using Styrofoam. Participants were instructed to sit such that thigh did not rest on seat and only buttocks rested on it. Participants were asked to wait for an auditory signal before initiating movement. The signal was given at least 3 seconds after the handheld computer started data collection. The co-investigator demonstrated the TUG / STS task prior to data collection. Participants performed three Get-Up & Go task from a fixed height chair. During TUG task, no restriction was given regarding which foot to use for the first step, but all participants consistently used the same foot to initiate swing in all three trials. Participants were asked to stand still for 60 seconds for determination of postural stability data. Three trials were collected for each eyes open and eyes closed condition.

Data collection and processing

The inertial measurement unit (IMU) used is TEMPO (Technology-Enabled Medical Precision Observation) 3.1 which is manufactured in collaborative research with the inertia team in UVA [16]. It consists of MMA7261QT tri-axial accelerometers and IDG-300 (x and y plane gyroscope) and ADXRS300 as z-plane uniaxial gyroscope. The data acquisition was carried using a bluetooth adapter and Laptop through a custom built LabView VI [16]. Data are acquired with sampling frequency of 128Hz. This frequency is largely sufficient for human movement analysis in daily activities which occurs in bandwith [0.8-5Hz][17]. The data was later processed using custom software written in Matlab (the Mathworks, Inc.). We denoised IMU signals based on the Ensemble Empirical mode decomposition (EEMD) framework with Savitzky-Golay filter. A similar denoising method combining EMD with the Savitzky-Golay has been used for denoising lidar signals, referred to as EMD-Golay algorithm has already been proposed by Zhang et.al [18]. Empirical Mode Decomposition (EMD) [19, 20] is an adaptive time-frequency data analysis method and can adaptively divide the IMU signals into different intrinsic mode function (IMF) components according to different time scale, and noise mainly concentrates in the high-frequency component. The Savitzky-Golay (SG) filter method is time-domain smoothing [21]. We have used EEMD-Golay denoising on signals from trunk and both shanks. EEMD is a new technique which was developed to overcome the problem of mode mixing [22]. Essentially, it repeatedly decomposes the original signal into IMFs by using the original EMD algorithm. During each trial of the decomposition process, white noise of finite amplitude is added to the original signal. The ensemble means of the corresponding IMFs generated from each trial are subsequently treated as the IMFs of the EEMD algorithm. Here the number of ensemble trials chosen is 100 with ratio of standard deviation of the added noise to that of signal as 0.2. First half of the IMF's containing high frequency noise are filtered using savitzky-golay filter (polynomial order 3 and number of frames as 41) and then reconstructed to get the denoised signals.

Variables and analysis

There are in total eight postural transition and gait events which can be easily identified from denoised Sit-to-walk (STW) component data from sacrum, right and left shank IMUs'. They are (E1) Initiation of STW, (E2) peak flexion angular momentum, (E3) seat-off event, (E4) peak extension angular momentum, (E5) swing toe-off, (E6) swing heel strike, (E7) stance toe-off and (E8) stance heel strike. Previously based on similar postural transition events and gait events, STW phases have been defined and validated by Kerr et. al.[23, 24] and Buckley et.al.[25, 26]. In order to rely on easy detection algorithm, we have divided STW movement into 3 phases as flexion momentum phase (phase 1), combined extension and unloading phase (phase 2), and stance phase (phase 3). The first phase of STW is flexion momentum phase (Phase 1), which encompasses the beginning of the movement (E1) until seat off (E3). In this phase high flexion momentum is generated and is later followed by seat unloading. Initiation of STW event (E1) is defined by IMU situated at trunk to be as first local maxima before the peak flexion angular velocity (global minima) (E2) in denoised Gyro X signals (figure 2a-d). Seat off event (E3) is detected as minimum acceleration in denoised Acc Z signals when TUG signals are truncated to half of their total length (neglecting return data of TUG test). Also, denoised signals from trunk Gyro-X (across medio-lateral axis) were used to acquire trunk peak flexion and peak extension angular velocities. The denoised shank Gyro Z signals (across mediolateral axis) is used and its first peak is maximum mid-swing angular velocity and the local minima to left and right are swing toe off (E5) and swing heel strike (E6) events respectively. Similarly, stance toe off (E7) and stance heel strike (E8) can be computed. STW completion is the time from event E1 to event E7.

Sit-to-stand (STS) events were identified from trunk Gyro-X (across medio-lateral axis) and were used to acquire trunk peak flexion and peak extension angular velocities. Seat off event is detected as minimum acceleration in denoised trunk Acc Z signals. Time to STS completion was from STS initiation to STS completion event.

RESULTS

STS completion time is defined from STS initiation to stabilization phase of standing. An average time spent by older adults to complete STS with arm rest was 3.83±2.62 seconds. STW completion time is defined from STW initiation to toe off of stance foot. However, during performance of STW task higher flexion and extension momentums are generated by the body in order to meet the requirement of body to raise its Center of mass (COM) and initiate gait.

Thus, in the case of STW, the event of stance toe off is reached before complete extension of trunk. The average time to complete STW in older participants was 2.03±1.17 seconds.

The trunk sway velocity and mean radius recordings obtained in all subjects in the open eyes and closed eyes conditions are shown in Table 2. The results showed that the mean trunk sway velocity and radius with closed eyes condition were greater than those measures with open eyes conditions.

Seven of the elderly participants (P1, P2, P3, P4, P5, P9, P11) spent more than 3 seconds to perform STS. As few subjects were unable to perform STS using knee support, thus we have discarded the STS evaluation using Knee support for our analysis. Total time to complete STW task in healthy older adults (1.82±0.27 seconds) is found to be significantly different to that of healthy younger adults (1.46±0.10 seconds) [25]. Two of the participants (P2 and P6) took more than 2 seconds to complete STW task. Two participants (P2 and P9) took more than 11 seconds to complete timed up and go task. TUG time (>11seconds) is correlated with falls, vestibular and balance disorders [27].

DISCUSSION

In order to study fall mechanisms to diagnose fall prone individuals, prevent falls from occurring, and assess the benefit of therapeutic techniques designed to reduce fall risk, technologies for gait monitoring and assessment are necessary. This study evaluated the characteristics of postural stability (eyes open and closed), TUG, STW and STS to predict fall risks individuals in community dwelling elderly aged age 65 or older. Numerous studies have shown that inability to rise from chair due to muscles weakness or joint stiffness [28, 29], mobility difficulty [30, 31] and balance deficits [32-34] are the indicator of high risk of fall in elderly. Buatois study [33] shows that the threshold of 3 seconds for STS (15 seconds for sit to stand transition) has been useful to be used as the prediction of elderly subjects at higher risk of recurrent falls. Our results showed that 64% of the participants were unable to complete the task within the time. Our TUG results indicated that 2 out of 11 participants are fall prone as they failed to complete the task within the required 11seconds. Buckley et al study [25] suggest that healthy old adult require more time, about 2 seconds to complete STW task compared to healthy young adults 1.56 second. STW is a complex task than STS as it involves gait initiation along with STS. The total time to complete STS was found to be 3.83±2.62 seconds which is more than that to complete STW (2.03±1.17 seconds). This can be explained by the complexity of STW task, as the participants have to generate higher flexion and forward momentum in order to successfully initiate gait from the sitting posture.

The identification of specific components of during the transition from sitting to walking movement among the elderly can help to identify mobility problem in different phase of the transition. In this study, as discussed in method section, the completion time of STW task was obtained directly from the IMU for more accurate reading compare manually timed. Our finding indicated two participants are out of healthy range (required more than 2 second to complete the task) and are at risk of fall. For postural stability measurement, there are two participants complete the task above the 75 % quartile for sway velocity and mean sway radius with eyes open and closed. One participant data was missing because he was not able to complete the task. In summary, participant *P9* has high risk of fall as he failed to complete four out of five tasks (Table 3). Two participants, (P2 and P5) failed three of the task and participant P4 failed in two tasks. 4 participants (P1, P3, P6 and P11) failed in single task and three participants (P7, P8 and P10) successfully completed the all the tasks within the target.

CONCLUSIONS

Data of postural stability (eyes open and closed), Sit-to-stand (STS), Sit-to-walk (STW) and timed up and go (TUG) were collected from eleven participates (65-84 years) through three TEMPO nodes. A novel denoising technique based on the Ensemble Empirical mode decomposition (EEMD) framework with Savitzky-Golay filter was proposed, since the nature of EEMD algorithm makes it suited for application of postural and locomotor data. After analyzing denoised data, we identified the fall prone individuals by evaluating the task completion time, as well as the participants' medical history. In our research, we implement a non-invasive system for locating fall prone individuals among the elderly. Research is being continued to further explore more effective signal processing methods and more sufficient samples to consolidate our conclusions.

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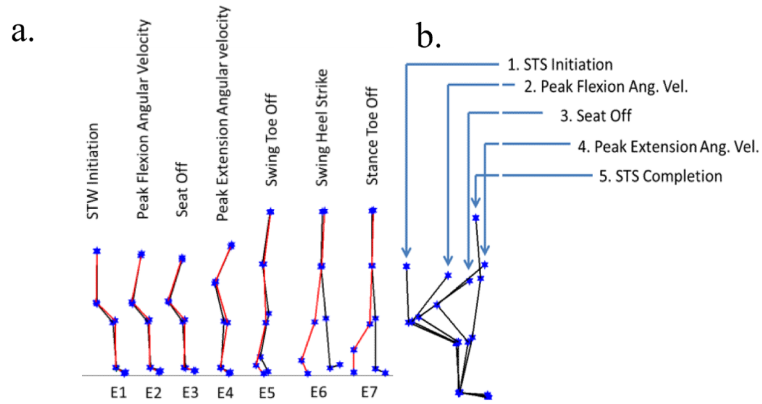

Figure 1.
a. Identified STW events b. STS events

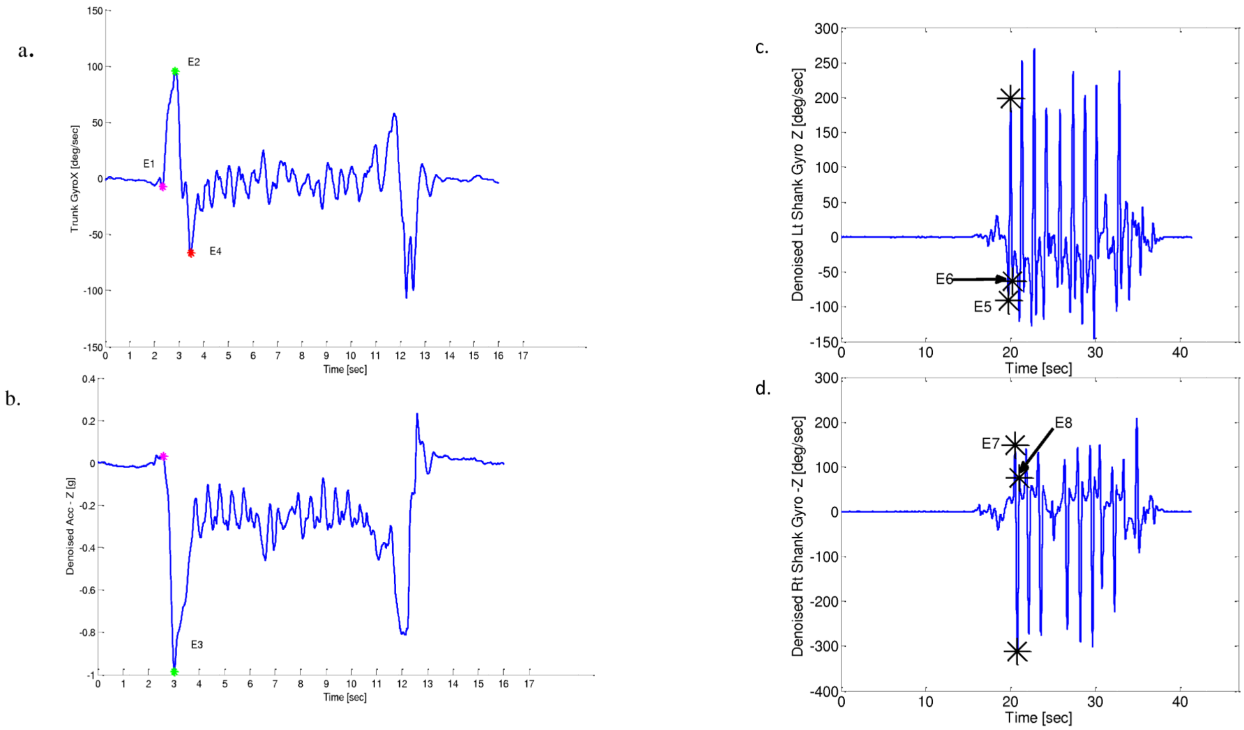

Figure 2.

a. STW event identification with E1 (STW Initiation), E2 (Peak Flexion Angular Velocity), E4 (Peak Extension angular velocity) b. E3 (Seat Off) c. E5 (Left foot Toe Off), E6 (Left foot Heel Strike) d. E7 (Right Foot Toe Off)

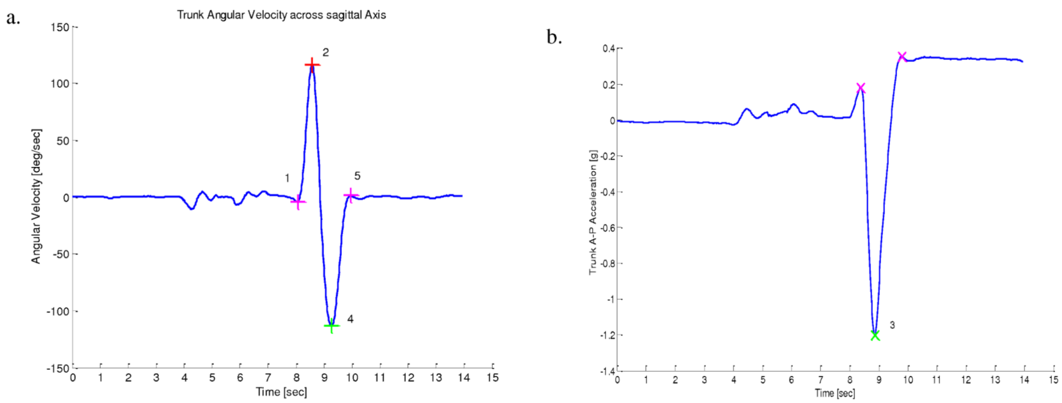

Figure 3.
STS event identification with a. 1. STS Initiation, 2. Peak flexion angular velocity, 4. Peak extension angular velocity, 5. STS Termination b. Seat Off

TableI

Mean and S.D. of STS with Arm Rest, STW, and TUG for all participants' data (n=11).

Activities	Time (sec)	Mean ±S.D.	CoV	Percentage
STS with Arm Rest	Phase I: initiation to peak flex Ang. Vel	0.79 ±0.24	30.60	20.70
	Phase II: peak flex Ang. Vel to seat off	0.28 ±1.48	534.48	7.22
	Phase III: seat off to peak ext Ang. Vel	1.66 ±2.54	153.40	43.20
	Phase IV: peak ext Ang. Vel to stance	1.11 ±0.47	42.60	28.89
	Total time to complete task	3.83 ± 2.62	68.33	100.00
STW	Phase I: initiation to peak flex Ang. Vel	0.45 ±0.12	26.53	22.19
	Phase II: peak flex Ang. Vel to seat off	0.40 ±0.74	184.60	19.64
	Phase III: seat off to peak ext Ang. Vel	0.46 ±0.62	134.59	22.69
	Phase IV: peak ext Ang. Vel to Swing Toe Off	0.18 ±0.26	145.09	8.69
	Phase V: Swing Toe Off to Swing Heel Strike	0.46 ±0.04	9.63	22.67
	Phase VI: Swing Heel Strike to Stance Toe Off	0.08 ±0.09	111.41	4.11
	Total time to complete task	2.03 ±1.17	57.50	100.00
TUG	Time Get Up and Go	11.31±6.65	58.82	100.00

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Table2

Mean and S.D. of trunk sway velocity and mean radius for all participants' data (n=11).

Activities	Mean ± S.D.	CoV
Open Eyes Sway Velocity (m/s)	0.0122 ± 0.0022	18.08
Open Eyes Mean Radius (m)	0.0026 ± 0.0009	35.30
Closed Eyes Sway Velocity (m/s)	0.0143 ± 0.0043	30.07
Closed Eyes Mean Radius (m)	0.0035 ± 0.0020	59.98

Table3

Mean total time to complete tasks, sway velocity, and radius for all participants' data (n=11).

ID	STS/ Arm rest (s)	STW (s)	TUG (s)	Sway Velocity EO (m/s)	Mean Radius EO (m)	Sway Velocity EC (m/s)	Mean Radius (m)	EC
P1	**3.48**	1.73	8.88	0.0115	0.0018	0.0116	0.0018	
P2	**11.85**	**5.34**	**30.67**	0.0129	0.0024	0.0124	0.0021	
P3	**4.45**	1.48	8.79	0.0100	0.0017	0.0105	0.0028	
P4	**4.38**	1.82	8.50	0.0129	0.0027	0.0135	0.0026	
P5	**3.53**	1.94	9.38	0.0146	0.0039	0.0217	0.0082	
P6	2.93	**2.11**	10.56	**Incapable**				
P7	2.90	1.50	8.80	0.0101	0.0018	0.0127	0.0031	
P8	1.48	1.48	7.16	0.0101	0.0018	0.0112	0.0026	
P9	**3.30**	1.59	**14.95**	0.0168	0.0037	0.0221	0.0054	
P10	1.98	1.26	7.37	0.0110	0.0022	0.0117	0.0020	
P11	**4.58**	1.80	9.34	0.0118	0.0035	0.0156	0.0045	