Choice Stepping Reaction Time test using Exergame technology for fall risk assessment in older people

Andreas Ejupi, *IEEE Member*, Matthew Brodie, *IEEE Member,* Yves J Gschwind, Daniel Schoene, Stephen Lord and Kim Delbaere

***Abstract*— Accidental falls remain an important problem in older people. Stepping is a common task to avoid a fall and requires good interplay between sensory functions, central processing and motor execution. Increased choice stepping reaction time has been associated with recurrent falls in older people. The aim of this study was to examine if a sensor-based Exergame Choice Stepping Reaction Time test can successfully discriminate older fallers from non-fallers. The stepping test was conducted in a cohort of 104 community-dwelling older people (mean age: 80.7 ± 7.0 years). Participants were asked to step laterally as quickly as possible after a light stimulus appeared on a TV screen. Spatial and temporal measurements of the lower and upper body were derived from a low-cost and portable 3D-depth sensor (i.e. Microsoft Kinect) and 3D-accelerometer. Fallers had a slower stepping reaction time (970 ± 228 ms vs. 858 ± 123 ms, P = 0.001) and a slower reaction of their upper body (719 ± 289 ms vs. 631 ± 166 ms, P = 0.052) compared to non-fallers. It took fallers significantly longer than non-fallers to recover their balance after initiating the step (2147 ± 800 ms vs. 1841 ± 591 ms, P = 0.029).**

This study demonstrated that a sensor-based, low-cost and easy to administer stepping test, with the potential to be used in clinical practice or regular unsupervised home assessments, was able to identify significant differences between performances by fallers and non-fallers.

I. Introduction

Falls in older people are common and a major public health problem. More than 30% of the people older than 65 years and more than 50% in those above 80 years fall at least once a year. Falls can be attributed to a wide variety of causes, with poor balance, limited mobility and slow reactions being commonly reported [1-2]. In real-life situations stepping is the most effective way to avoid a fall [3]. The selection of an appropriate response and its execution are important to maintain balance [4]. Studies have demonstrated that impaired stepping is prevalent in older people, especially in people with a higher risk of falls and balance impairments [3-5].

For a targeted and tailored fall prevention program it is necessary to identify people at high risk and to accurately determine their individual fall risk factors first. Clinical fall risk assessments are often described as subjective and qualitative [6]. Because of limited health care resources objective test equipment (e.g. force platforms or electronic walkways) is not always available. In addition, such clinical assessments usually have to be administered by a trained health professional. Quick, easy to administer and simple tests are needed which can be applied by the individual to assess fall risk on a regular basis. Therefore, low-cost and portable measuring instruments have been increasingly used in laboratory research settings and hold great promise for more regular task-specific assessments [6-8]. In addition, Exergaming, which merges motion sensors and videogame technology to promote physical activity in a new form, is used. In an on-going research project "iStoppFalls" [9], where this work is part of it, this method is applied to deliver home-based balance and strength training to prevent falls in older people.

We examined the feasibility of a low-cost and portable 3D-depth sensor (Microsoft Kinect) in combination with a 3D-accelerometer (Philips) to measure temporal and spatial stepping parameters in an Exergame Choice Stepping Reaction Time test. The test was conducted with 104 community-dwelling older people. With the long-term goal to use this stepping test in an unsupervised home assessment and to predict falls more accurate we analysed the performance differences in fallers and non-fallers.

II. Methods

A. Participants

A sample of 104 community-dwelling older adults (mean age: 80.7 ± 7.0 years) was recruited from retirement villages in Sydney, Australia. The sample was drawn from two randomized controlled trials, 71 people took part in the SureStep interactive step training trial (ACTRN12613000671763) and 33 took part in the iStoppFalls trial (ACTRN12614000096651). Participants in the SureStep trial undertook the assessments at the 4-month retest, while participants in the iStoppFalls trial underwent the assessments at baseline. The inclusion criteria were living in the community, aged 65 years or older and being ambulant with or without the use of a walking aid. The exclusion criteria were: medically unstable, suffering from major cognitive impairment (Mini-Cog < 3), neurodegenerative disease or color blindness. Written informed consent was obtained from all participants prior to data collection. The study was approved by the University of New South Wales Human Studies Ethics Committee.

A medical history was recorded during a face-to-face interview, including the presence of medical conditions and self-reported history of falls in the past 12 months. A fall was

Andreas Ejupi is with the Austrian Institute of Technology, Assistive Healthcare Information Technology Group, Vienna, Austria (e-mail: andreas.ejupi.fl@ait.ac.at) and Neuroscience Research Australia, Sydney, Australia. Matthew Brodie, Yves J Gschwind, Daniel Schoene, Stephen Lord and Kim Delbaere are with Neuroscience Research Australia, University of New South Wales.

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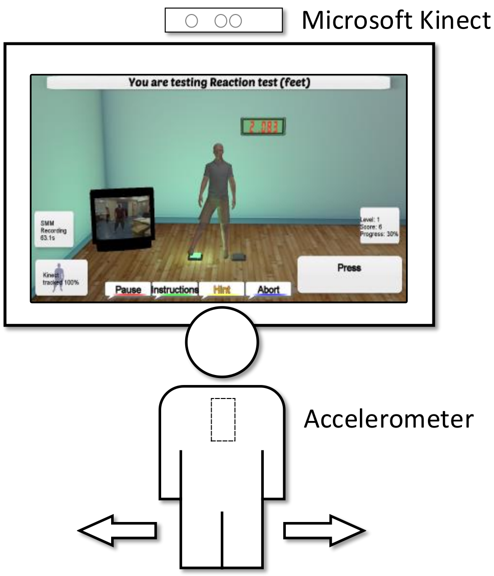

Fig. 1. Schematic representation of the sensor-based Exergame Choice Stepping Reaction Test. Participants were asked to step laterally as quickly as possible after a light stimulus, indicated by the Exergame, appeared on the TV screen.

defined as 'an unexpected event in which the person comes to rest on the ground, floor, or lower level' [10].

B. Protocol

The Choice Stepping Reaction Test using videogame technology was developed as part of the iStoppFalls project [9]. The participant is represented as an avatar on the TV screen with two lights on each side (Fig. 1). Participants can control the avatar's movement with the Kinect. The left or right light flashes up in random order using the same time interval. Participants were instructed to take a step "on the light" to turn it off as fast as possible using the left foot when the left light flashed and the right foot when the right light flashed. Participants were also instructed to transfer weight while taking a step. In total 40 steps were assessed in two trials with a short break of less than a minute after 20 repetitions. The first five repetitions were classified as practice steps and excluded from further data analysis. The complete test took about 15 minutes including instructions.

C. Data Acquisition

Skeleton data of anatomical landmarks were recorded using the Microsoft Kinect Software Development Kit with a sampling rate of 30 Hz. The Kinect sensor was placed in front of the TV screen at a height of 80 cm and a distance of 2 m from the participants. In addition, 3D-accelerometer (ADXL362, ± *8 g*) data were acquired in 50 Hz with a custom-made and wearable device from Philips Research Europe. Participants were asked to wear the sensor attached to a cord around their neck. The sensor was placed at the height of the sternum. Participants were asked to wear the device below their clothes touching the skin.

D. Data Analysis

Temporal and spatial parameters were examined to quantify performance differences in fallers and non-fallers. Parameters from the lower and upper body were measured with the Microsoft Kinect and the body-worn accelerometer.

From the Microsoft Kinect signals the medial-lateral skeleton data of the left and right feet were analyzed. A step task was divided into two parts: response and execution. All parameters are representing the average value of all steps across all trials. We calculated the reaction time, defined as the time from the cue signal to the movement initiation (Fig. 2). The movement time was defined as the time from the initiation to the first foot-contact. The overall time from the cue signal to the first foot-contact was defined as the total step time. In addition, the step length and the variability of the step length were examined.

From the accelerometer signal the vector sum (VS) of all three directions was calculated as shown in (1).

$$VS = sqrt(X^2 + Y^2 + Z^2) \quad (1)$$

Reaction time was defined as the time from the cue signal to the first movement of the trunk. The movement initiation was detected as a significant increase in the acceleration measure compared to the mean value. During the test participants were asked to step sideways and back to the initial position. The stability time was determined as the time from the movement initiation until the participants regained their balance, i.e. reached a similar level of acceleration prior to the step, compared to the mean value. In addition the RMS acceleration was analyzed for the VS, media-lateral (ML) and anterior-posterior (AP) signals.

E. Statistical Analysis

A two-sided Student's t-test for independent measures was used to evaluate differences between the faller and non-faller groups. P-values less of 0.05 (*) were considered to be statistically significant. Data and statistical analysis were performed in MATLAB 8.2 (R2013b).

III. Results

Participants were classified as 36 fallers, who had one or more falls within the past 12 months, and 68 non-fallers. There was no significant difference in age, gender and height between fallers and non-fallers in this study (Table 1).

Fig. 2 illustrates the lower body movement of an example faller and non-faller. From the Kinect measurements we observed that the mean stepping reaction time and total step

TABLE I. Characteristics of Fallers and Non-Fallers

Parameter	Fallers (n = 36)	Non-fallers (n = 68)	P
Age (years)	81.7 ± 8.3	80.1 ± 6.2	0.271
Female, n (%)	27 (75.0)	43 (63.2)	0.319
Height (cm)	161.3 ± 9.3	164. ± 4 9	0.102

^ P < 0.10, * P < 0.05, ** P < 0.01

TABLE II. GROUP DIFFERENCES FALLERS VS. NON-FALLERS

Parameter	Fallers (n = 36)	Non-fallers (n = 68)	P
Microsoft Kinect (Lower limb)			
Reaction time (ms)	970 ± 228	858 ± 123	**0.001****
Movement time (ms)	261 ± 67	255 ± 76	0.678
Total step time (ms)	1231 ± 242	1113 ± 151	**0.003****
Step length (mm)	270 ± 46	276 ± 62	0.612
Step length variability (mm)	32 ± 12	31 ± 11	0.864
Accelerometer (Trunk)			
Reaction time (ms)	719 ± 289	631 ± 166	**0.052^**
Stability time (ms)	2147 ± 800	1841 ± 591	**0.029***
Total stability time (ms)	2866 ± 888	2472 ± 636	**0.010***
RMS Acc VS (m/s^2)	0.644 ± 0.356	0.696 ± 0.334	0.465
RMS Acc ML (m/s^2)	0.940 ± 0.237	0.921 ± 0.203	0.675
RMS Acc AP (m/s^2)	0.566 ± 0.221	0.562 ± 0.201	0.927

^ P < 0.10, * P < 0.05, ** P < 0.01

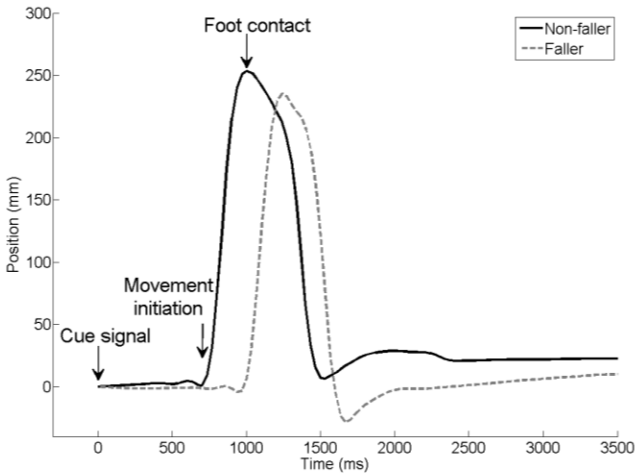

Fig. 2. Leg movement of a step to the side recorded with the Microsoft Kinect from an example faller and non-faller. Fallers showed a slower reaction time compared to non-fallers.

time in the fallers group was significantly slower than in the non-fallers group (Table 2). There was no difference in the step length, step length variability or the movement time of the lower limbs.

Fig. 3 shows the upper body acceleration of a typical faller and non-faller. Fallers needed longer to regain their balance after movement initiation compared to non-fallers. There was a trend for slower trunk reaction time for fallers (P = 0.052). In addition, the total stability time was slower

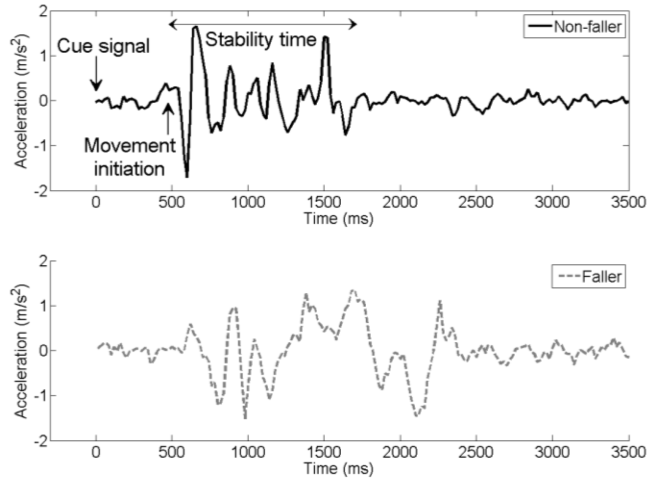

Fig. 3. Acceleration trace (VS) of the upper body movement (mean amplitude of the signal subtracted) for an example faller and non-faller. Fallers showed a slower reaction time and needed longer to stabilize after movement initiation.

for fallers. There was no group difference for the RMS acceleration.

IV. DISCUSSION AND CONCLUSION

In this study we examined the feasibility of a sensor-based, low-cost and portable Exergame Choice Stepping Reaction Time test to identify people at high risk of falls by analyzing the group differences between older fallers and non-fallers.

Recent technological studies have used an infrared laser sensor in a four square choice stepping test and a custom dance-mat with pressure sensors in a test with a high attention component [5,11]. In our study we used the Microsoft Kinect, a commercially available consumer device and a 3D accelerometer, in combination with Exergame technology. With this combination we were able to detect steps and large scale movements, using the Kinect, and smaller postural adjustments, using the accelerometer. We focused on lateral stepping as it has been reported that fallers step more frequent laterally than non-fallers [12] and that the lateral falls are most likely to result in hip fractures [13].

A Choice Stepping Reaction Test is a composite measurement of cognitive function, reaction time, strength and balance [4]. Our results confirm previous study findings in that fallers performed this test more slowly. In addition, we analyzed trunk movements with a body-worn sensor and observed a significant trend for a slower upper body reaction time. A large body of literature exists, that demonstrates that the reaction time increases with age [3,14,15] and that a slower reaction time is related to a higher risk of falling [4,16,17].

Furthermore, our results suggested that fallers needed significant longer to recover their balance after taking a step compared to non-fallers. In the literature, several studies associated falls with poor balance [1-2]. In addition, it has been shown that the time to regain a stable posture after executing a step increases with age [18]. These findings are in accordance with our results.

We acknowledge certain study limitations. The Microsoft Kinect has been used in research settings before and was applied for fall risk assessments in older people [19]. However, the device was primarily developed for consumer purposes, which means a low price but with limitations in accuracy compared to other more expensive 3D motion capture systems [20]. The resolution of the accelerometer was 4 mg with a range of ± 8 g, which was sufficient to detect reaction and stability time but might not be sufficient to detect very small differences in the accelerations between fallers and non-fallers. The recall of falls history might have underestimated the real number of falls. However, a reported history of falls has been shown to be a good predictor of future falls [21]. It is also acknowledged that as the fall surveillance period coincided with the intervention in the SureStep trial, stepping performance in the assessments may have been influenced by the exercises in those allocated to the intervention arm. Nevertheless, this study presents an important first step towards establishing the validity of combining Kinect Exergame technology with a 3D accelerometer to assess Choice Stepping Reaction Time in older people.

Exergaming holds great promise for regular, engaging and motivating exercises and fall risk assessments. We were able to demonstrate the feasibility of an Exergame Choice Stepping Reaction Time test. Our findings are in agreement with the literature on falls. By using the Exergame approach in combination with low-cost sensors and lateral stepping we developed a test which is simple, quick, easy to administer and able to discriminate between older fallers and non-fallers. Therefore, it has potential to be used in clinical practice or regular unsupervised home assessments. Further research will examine the predictive ability of this test in unsupervised home assessments.

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