

## Preliminary evaluation of a self-guided fall risk assessment tool for older adults



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### ABSTRACT

Falls are a major health problem for older adults with significant physical and psychological consequences. The first step of successful fall prevention is to identify those at risk of falling. Recent technology advancement offers the possibility of objective, lowcost and self-guided fall risk assessment. The present work evaluated the preliminary validity and usability of a Kinect camera-based selfinitiated fall risk assessment system in a hospital setting. A convenience sample of 29 female participants (77.5 ± 7.9 years old) enrolled in this study. This low-cost self-guided system included a Kinect depth-sensing camera, a PC-based computer, and custom-built software. An onscreen Fall Risk Assessment Avatar (FRAAn) utilizing visual and verbal instructions led participants through a fall risk assessment consisting of self-report measures and clinically validated balance and mobility tests. Participants also completed clinical fall risk evaluation (Timed-Up and Go, and Berg Balance Scale) led by a researcher. User experience was evaluated by the System Usability Scale (SUS). Results indicate that FRAAn-based outcome measures (postural sway metrics, and sit-to-stand speed) were highly correlated with clinical fall risk measures, and were able to differentiate individuals with increased fall risk. Additionally, 83% participants reported high usability (SUS > 80), indicating the system is well received among older users. Overall, our results indicate that the FRAAn system has promise for providing a self-guided fall risk assessment, and is well received by older users. This affordable, portable and self-guided system has potential to facilitate objective fall risk assessment in older adults in various settings.

### 1. Introduction

Falls are the leading cause of fatal and nonfatal injuries in older adults (Rubenstein, 2006). Over one out of four older adults over the age of 65 fall annually (Bergen, 2016), resulting in more than \$50 billion annual medical costs (Florence et al., 2018). Given the adverse consequence of falls in older adults, considerable research has focused on identifying individual fall risk factors and providing targeted fall prevention (Gillespie et al., 2012). This collective research has revealed that falls and fall-related injuries are predictable and preventable with interventions targeting modifiable risk factors (Gillespie et al., 2012). However, despite the increase in the understanding of falls and their prevention, the age-adjusted fall death rate among older adults nearly

doubled in the last decade (Kramarow, Chen, Hedegaard, & Warner, 2015). This highlights the need for innovative approaches.

While the American Geriatric Society as well as the Centers for Disease Control and Prevention (CDC) recommends screening of fall risk for older adults at least annually by physicians (Stevens & Phelan, 2013), effective fall risk screening is still underutilized and not routinely integrated into clinical practice. There are several reasons for the lack of fall risk assessment in current practice ranging from overreliance on unreliable subjective measures (i.e. physician judgement or self-report), lack of cost-effective assessment technology and clinical time constraints (Sun & Sosnoff, 2018). Consequently, many older adults do not undergo comprehensive fall risk screening or receive targeted prevention strategies. There is a clear need for accessible, cost-effective,

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valid, and comprehensive community-based measures of fall risk to facilitate the adoption of fall prevention programs (Sun & Sosnoff, 2018).

Novel technology, such as inertial sensors, smartphone, low-cost video/depth camera, pressure sensors and motion ambient sensors, offer an alternative approach that can efficiently capture and analyze movement data and may provide an easy-to-implement objective fall risk assessment (Roeding, Hsieh, & Sosnoff, 2017; Sun & Sosnoff, 2018). More specifically, low cost video/depth sensing camera (i.e. Microsoft Kinect™ and Orbbec Astra) provides marker-less 3D motion tracking of body joints by using its built-in and externally validated human skeleton modelling algorithms (Sun & Sosnoff, 2018). These technology successfully eliminates the need for markers and calibration procedures characteristic of traditional motion capture, thereby enabling fast and user-friendly 3D body motion analysis (Sun & Sosnoff, 2018). Additionally, the video/depth sensing systems, due to its compatible computer interface, can provide automated interaction with the user and potentially allowing the user to complete the structured fall risk assessment without additional supervision (Sun & Sosnoff, 2018).

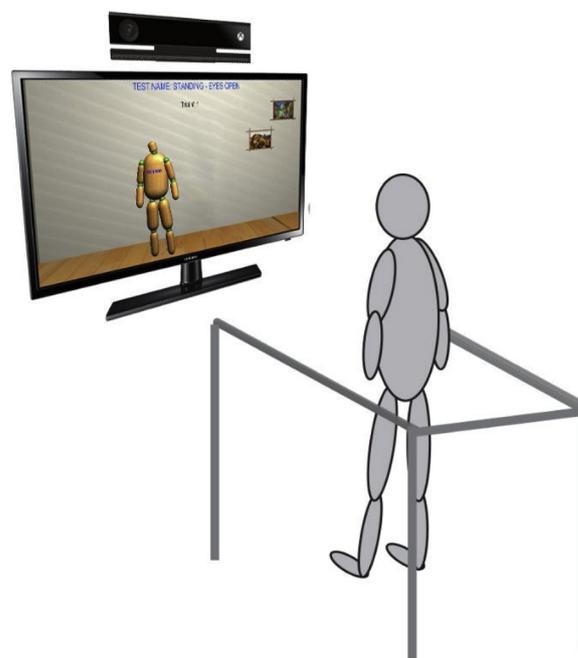
Indeed, the Kinect depth sensor has been previously investigated as a potential fall risk screening tool. For instance, Yeung, Cheng, Fong, Lee, & Tong, (2014) compared the Kinect-based center of mass sway estimation during quiet standing with forceplate and motion capture system, and found that the Kinect estimation is highly correlated with the gold standard measures. Ejupi and colleagues have also investigated the Kinect-based functional tests for faller discrimination using retrospective and prospective designs (Ejupi, Brodie et al., 2016; Ejupi, Gschwind, Valenzuela, Lord, & Delbaere, 2016). They concluded that Kinect-based systems are capable to differentiate future fallers from non-fallers, and also feasible to use in clinical and in-home settings. To date, however, most of current fall risk screening systems are still designed to be utilized/interpreted by clinicians or caregivers and not by older adults themselves (Sun & Sosnoff, 2018). Furthermore, a recent systematic review highlights that even though it is essential to determine the usability of these systems to maximize their acceptance, the usability of a system is typically not part of the reported evaluations (Roeding et al., 2017; Sun & Sosnoff, 2018).

Recently, our research group developed a comprehensive self-guided fall risk assessment system to be used by older adults without supervision (Sun et al., 2018). We envisioned a system that is automated, affordable, intuitive, touch free, unobtrusive, and safe. These criteria lead us to develop a system with a relatively inexpensive commercially available imaging technology (Microsoft Kinect™). More specifically, we developed a system for seniors that incorporates assessments that resemble clinical tests of balance and mobility (i.e. balance, sitting to standing transition) as well as collecting other pertinent information associated with risk of falling (i.e. health history, balance confidence, history of falling, etc.). It is worth noting that although Kinect sensor has been discontinued, similar commercially available depth-sensing body movement tracking camera (i.e. Orbbec Astra, etc.) can be integrated into this system. The design process of this system has been described in previous work (Sun et al., 2018), the aim of the current investigation is to provide a preliminary test of the system validity in fall risk screening and evaluate its usability among seniors with a range of function. We hypothesize that the sensor-derived measures from this system will be associated with clinical balance and mobility assessments, and able to differentiate individuals with elevated fall risk in similar fashion to current clinical practice. We further expect this system to be well received by older users as measured by standard usability scale.

## 2. Methods

### 2.1. Participants

A convenience sample of 30 participants enrolled in this



**Fig. 1.** Schematic of system setup. The system includes a Kinect V2 camera, a PC-based computer and a display screen. On screening display includes an avatar that provide standardized verbal instruction and visual demonstration of the required movements.

investigation. Participants were directly recruited from a bone health clinic in a local hospital. The inclusion criteria for participation were 65 years and older, able to stand upright for 30 s without aid, and walk for at least 10 m with or without aid. The exclusion criteria were: amputation and/or use of lower limb prosthesis or other device; and presence of neurological or muscular disease that influence balance or mobility. All participants were recruited and screened for eligibility by a physician from the bone health clinic. It is worth noting that participants who visited the bone health clinic all reported concerns about their bone health (due to osteopenia or osteoporosis), and thus had elevated fall-related injury risk. This case control study was conducted between March and September 2017. The study was approved by the hospital's Institutional Review Board.

### 2.2. System setup

The hardware components of the system include a Microsoft Kinect V2 camera, a PC-based computer and a display screen (Fig. 1). The display screen and Kinect sensor were placed in front of the participant at 2 m distance. The display screen was placed at approximate eye sight, whereas the Kinect sensor was placed at 1 m height. A Fall Risk Assessment Avatar (FRAAn) was displayed on the screen, and led the participant through a series of fall risk assessment. The fall risk assessment was based on the CDC fall risk assessment recommendations (Stopping Elderly Accidents, Death & Injuries - STEADI) (Stevens & Phelan, 2013). The FRAAn body model was chosen as a gender and ethnically neutral avatar, and designed based on general user experience guidance to enhance user acceptance (Nass, Moon, & Green, 1997). FRAAn verbally asked participants' age, gender, 12 month fall history, concerns about falling and perception of unsteadiness during daily ambulatory activity. Following the collection of demographics, participants complete a series of balance and mobility tests led by the avatar. Prior to each test, FRAAn provided synchronized standardized verbal instructions and visual demonstration of the required movements. The system stores the Kinect skeleton data to the computer for further data analysis. The system discards the video image once the skeleton data is captured, thus not only reduces the bandwidth and disk

storage requirements drastically, but also ensures user privacy. The system was developed using the Unity3D platform (Unity Technologies, San Francisco, CA) and Kinect SDK (Microsoft Corporation, Seattle, WA).

### 2.3. Procedure

Upon arrival at the clinic, participants were verbally informed of the experimental procedures and provided an opportunity to ask questions. After all queries were satisfied, participants provided written informed consent document. Participant provided demographic information, fall history during the past year, and self-report fear of falling scale (Fall Efficacy Scale - FES) (Yardley et al., 2005).

Following the completion of surveys, participants completed the self-guided fall risk assessment lead by FRAAn. In order to ensure safety of users, the designed tests were carried out with progressively increased difficulty (i.e. static balance test with eyes open precedes eyes closed test and tandem test, and if an individual could not complete a task after two attempts, the test was ended). Additionally, participants could ask FRAAn for repeated instructions, a rest or if they want to skip a given task or stop the assessment entirely. The total time for the assessment is less than 20 min.

Given the Kinect camera's capture range (1.5–4.5 m skeletal tracking range) and best practice recommendations for quantifying falls risk in older adults (CDC-STEADI) (Stevens & Phelan, 2013), a set of valid and reliable clinical tests focusing on static balance and mobility were selected and integrated in the system. Static balance assessments include a series of 30 s sway assessments varying visual input with eyes open (EO) and closed (EC), and modifications of base of support (tandem stance - TD). Muscle strength and coordination was assessed with the five-time sit-to-stand test (5STS) (Buatois et al., 2008), which is a clinical test that asks participants to stand up and sit down from a chair five times as quickly as possible.

After completion of the self-guided fall risk assessment, a set of clinical fall risk assessments (Timed Up and Go -TUG (Podsiadlo & Richardson, 1991), and Berg Balance Scale -BBS (Berg, Wood-Dauphinee, Williams, & Maki, 1992)) were also administered by trained research personnel. The BBS test consists of 14 physical tasks, such as transfer from sitting to standing position, standing with eyes closed, and picking up an object from the floor, all of which are part of normal daily activities. Each task performance is assigned 0–4 points by a trained personnel, to give a total score of 0–56. A BBS score below 45 was considered as increased risk of falls (Scott, Votova, Scanlan, & Close, 2007). The TUG test consists of the participant getting up from a chair, walking 3 m, turning at a designated spot, returning to the seat and sitting down. The time taken to perform the test is recorded using a stopwatch. TUG completion time greater than 13.5 s was considered with increased risk of falls (Shumway-Cook, Brauer, & Woollacott, 2000). The TUG was chosen as the reference standard in this work based on the CDC STEADI recommendation (Stevens & Phelan, 2013). The BBS was chosen as it is a common fall risk assessment tool used by clinicians. It is worth noting that although commonly used in clinical settings, TUG and BBS have both been reported to have limitations in fall incidence prediction among healthy, high-functioning older people (Muir, Berg, Chesworth, & Speechley, 2008; Schoene et al., 2013).

### 2.4. Usability test

Usability data were collected using the System Usability Scale (SUS), a standard questionnaire related to human-computer interaction consisting of a simple 10-item scale based on a 5-point Likert scale (Brooke, 1996). A SUS score above 68 is regarded as above average, and a SUS score above 80 is regarded as high and a score where participants are likely to recommend the product to friends (Sauro, 2011). Participants also provided feedback on the interface, instruction, demonstration, task complexity and system integration, as well as potential

barriers to implementing the technology.

### 2.5. Data acquisition and analysis

The Kinect V2 sensor provides 3D skeleton data of anatomical landmarks in world coordinates at a sampling frequency of 30 Hz. For standing balance assessment, the base of spine (BoS) marker was chosen as the point of interest, since its location approximate the whole body center of mass. BoS data was low pass filtered at 6 Hz with a 4<sup>th</sup> order Butterworth filter (Yeung et al., 2014). A set of sway metrics (sway path length, 95% confidence ellipse area – sway area, anterior-posterior sway range, mediolateral sway range) were derived following a standard procedure (Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996).

For sit to stand assessment, vertical displacement of head marker was chosen as the point of interest (Ejupi, Brodie et al., 2016), as its data integrity was best suited for sit to stand tracking. Head data was low pass filtered at 2 Hz with a 4<sup>th</sup> order Butterworth filter (Ejupi, Brodie et al., 2016). Vertical displacement of head marker was offset corrected by the initial head position during the start of the test. The global start and end of the STS cycle was defined as vertical displacement crossover a predetermined 5 cm threshold (Ejupi, Brodie et al., 2016). The overall 5STS completion time was used as the sole outcome measure for this test. Speed-related features of sit-to-stand performance was calculated but not presented in this work. All data was processed using customized MATLAB program (Mathworks, Inc., Natick, MA)

### 2.6. Statistical analysis

Given the progressive increased difficulty in FRAAn assessment, when the participant was unable to complete a certain task (i.e. unwilling to try, loss of balance in static balance tasks, or unable to complete the STS task within 30 s), the max value of the group (sway metrics in balance tasks) or max allowable score (30 s for STS task) was assigned. Spearman rank correlation coefficients were calculated to quantify the association between FRAAn-based measures and clinical fall risk measures. Correlation threshold was set as weak ( $\rho \leq 0.4$ ), moderate ( $0.4 < \rho \leq 0.7$ ), and strong ( $\rho > 0.7$ ) (Dancey & Reidy, 2007).

Additionally, the absolute agreement between FRAAn-based STS tracking and manual stopwatch tracking was compared with Bland-Altman limit of agreement method (Bland & Altman, 1986). The Bland-Altman limit of agreement is a robust statistical approach to indicate the level of agreement between any two measuring technologies (Bland & Altman, 1986). Since a high correlation between any two methods does not necessarily mean that the two methods are in good agreement, the Bland-Altman technique is utilized in many studies to investigate the presence of absolute agreement between the two technologies.

For comparison of key outcome measures between low and high fall risk individuals (categorized as TUG > 13.5 (Shumway-Cook et al., 2000)), Mann-Whitney U test was used on all FRAAn derived outcome measures (Sway metrics and STS performance) and SUS measures, whereas independent *t*-test was used on clinical fall risk measures (FES, TUG, BBS).

Signal processing were performed in MATLAB (Mathworks, Inc., Natick, MA), whereas statistical analyses were performed with SPSS (Version 24. IBM Corp. Armonk, NY). Alpha value was set at 0.05 for all statistical analyses.

## 3. Results

Because of the majority of patients who attend the bone health clinic was female, only one male participant was tested among the total 30 participants, therefore, data from the single male participant was removed to avoid the effect of gender in data interpretation. Of the

**Table 1**  
Characteristics of low/high risk individuals.

	Low-Risk (n = 20)	High-Risk (n = 10)	p-value
Age, years	74.6 ± 6.2	80.8 ± 9.2	0.042
Height, cm	158.4 ± 5.3	159.1 ± 9.5	0.795
Weight, kg	66.5 ± 13.2	68.3 ± 16.7	0.747
FES	22.9 ± 6.7	33.3 ± 8.9	0.002
BBS	53.9 ± 2.3	36.9 ± 14.6	< 0.001
TUG (s)	9.9 ± 1.4	26.8 ± 15.7	< 0.001

**Table 2**  
Correlations between the FRAAn based measures and clinical fall risk measures. \* p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001.

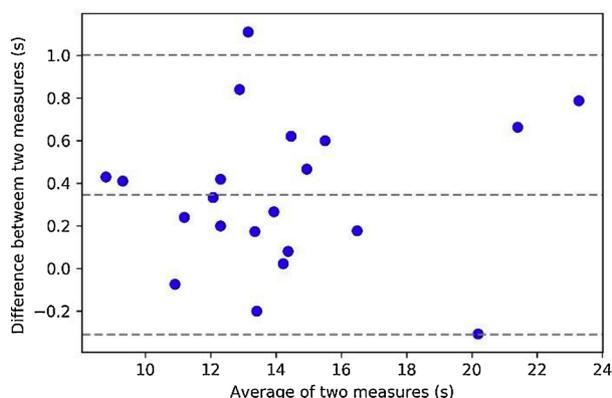
FRAAn tests	FRAAn-based measures	Clinical measures		
		FES	TUG	BBS
Eyes Open	sway path	0.35	0.26	-0.25
	sway area	0.36*	0.29	-0.30
	AP sway range	0.22	0.10	-0.09
	ML sway range	0.42*	0.58***	-0.53**
Eyes Closed	sway path	0.40*	0.38*	-0.42*
	sway area	0.45**	0.41*	-0.49**
	AP sway range	0.37*	0.38*	-0.37*
	ML sway range	0.41*	0.42*	-0.46*
Tandem	sway path	0.55**	0.56**	-0.56**
	sway area	0.50**	0.50**	-0.53**
	AP sway range	0.51**	0.53**	-0.57***
	ML sway range	0.55**	0.53**	-0.57***
Sit to Stand	Time	0.52**	0.78***	-0.60**

remaining 29 female participants (77.5 ± 7.9 yrs old), ten participants (34.5%) were classified as high-fall risk based on TUG performance exceeding 13.5 s (Shumway-Cook et al., 2000). Significant differences in age, FES, BBS and TUG between low-risk and high-risk individuals were observed with the high risk group being older and having greater fear of falling, balance and mobility impairment (Table 1).

All participants were able to complete the standing balance test in the eyes open condition, whereas 1 high-risk participant was unable to safely complete the eyes closed test, and 12 participants (5 low-risk, 7 high-risk) were unable to safely complete the tandem test. Five high-risk participants were unable to complete the 5STS test within 30 s.

Spearman correlation coefficients between each FRAAn measures and clinical fall risk measures are presented in Table 2. In eyes open test, only mediolateral sway range was moderately correlated with clinical fall risk scores, whereas in eyes closed and tandem stance conditions, all sway metrics were moderately correlated with clinical fall risk measures. Sit-to-stand completion time was also significantly correlated with all clinical fall risk measures.

Fig. 2A shows the Bland-Altman plot for the difference in STS



**Table 3**  
Group differences of key outcome measures. \* p < 0.05; \*\* p < 0.01; \*\*\* p < 0.001.

Condition	Sway Metrics	Low-risk Median (25 <sup>th</sup> /75 <sup>th</sup> quartile)	High-risk Median (25 <sup>th</sup> /75 <sup>th</sup> quartile)
Eyes Open	Sway Path*	0.022 (0.015,0.036)	0.061 (0.028,0.091)
	Sway Area	17.170 (8.976,54.135)	145.504 (35.249,259.317)
	Sway Range AP	0.006 (0.004,0.012)	0.011 (0.008,0.012)
	Sway Range ML **	0.002 (0.002,0.004)	0.010 (0.004,0.019)
Eyes Closed	Sway Path **	0.028 (0.016,0.035)	0.076 (0.040,0.231)
	Sway Area **	17.134 (9.041,43.004)	255.426 (48.571,1639.856)
	Sway Range AP **	0.007 (0.005,0.009)	0.018 (0.009,0.052)
	Sway Range ML **	0.003 (0.002,0.004)	0.011 (0.004,0.047)
Tandem	Sway Path *	0.152 (0.089,0.527)	0.782 (0.436,0.782)
	Sway Area *	649.921 (167.830,4745.570)	8170.890 (3116.284, 8170.890)
	Sway Range AP *	0.014 (0.009,0.071)	0.091 (0.061,0.091)
	Sway Range ML *	0.026 (0.016,0.069)	0.100 (0.045,0.100)
Sit to Stand	Time ***	12.460 (11.600,14.265)	25.535 (17.378,30.000)

completion time between FRAAn and manual stopwatch recording. The absolute difference between each data pair is plotted against their mean. The two horizontal lines represent the 95% limits of agreement (range of error) calculated as 1.96 times the standard deviation from the mean differences between two methods. The figure illustrates that the mean difference between two methods is less than 0.4 s, with high correlation (rho = 0.99) between the two methods (Fig. 2b).

Table 3 illustrates group differences of FRAAn-derived sway metrics as a function of conditions (Eyes Open, Eyes Closed, Tandem, Sit-to-Stand). In the eye open condition, significant differences between low-risk and high-risk groups were observed in sway path length and mediolateral sway range. In the eyes closed and tandem conditions, significant differences between low-risk and high-risk groups were observed in all derived sway metrics. For STS test, significant group differences were also observed.

### 3.1. System usability

A total of 24 participants (82.8%) reported high system usability

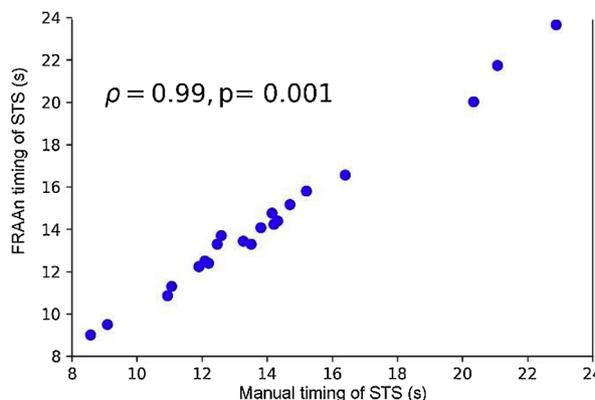


Fig. 2. Comparison between FRAAn-derived and manual timing of 5STS completion. Bland-Altman plot and scatter plot with Spearman correlation coefficient.

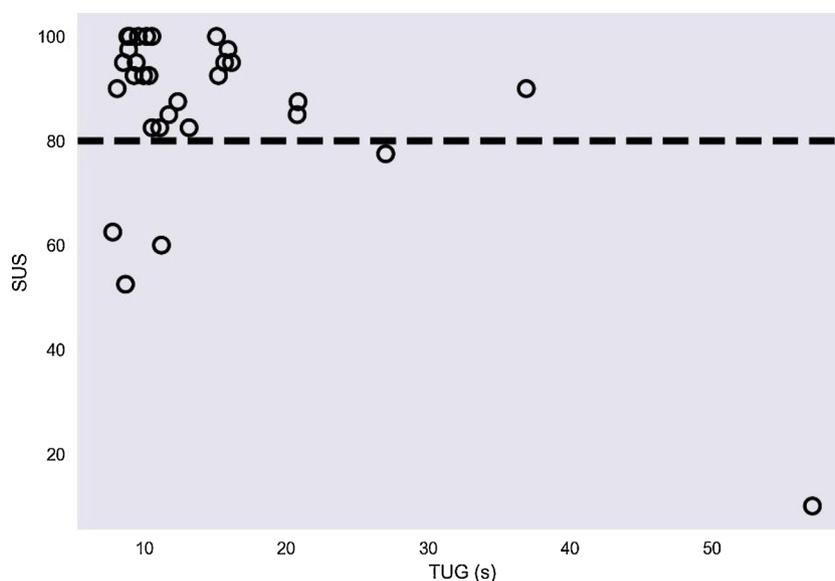


Fig. 3. System usability as a function of physical capability (TUG completion time). Dash line represents SUS = 80, which is regarded as high usability and a score where participants are likely to recommend the product to others.

(SUS > 80) with a mean score of 92.6. No significant group difference was found between low-risk and high-risk groups in SUS (Mann-Whitney U = 95.0, Z = -0.231, p = 0.82). For those who reported below average (< 68) usability ratings (Sauro, 2011), three participants were from the low-risk group (SUS range 52.5–62.5), while an impaired participant (TUG > 50 s) reported poor perceived usability (SUS = 10) (See Fig. 3) with self-reported safety concerns and difficulty in seeing and understanding the avatar demonstration.

#### 4. Discussion

Technology-based fall screening and prevention tools have the potential to increase effectiveness of current healthcare practice without increasing the delivery costs. This exploratory work evaluated the validity and usability of a novel self-initiated, affordable, automated fall risk assessment system. Unlike most other existing technologies for fall screening, this system was designed to be used by community-dwelling older adults. The FRAAn system enables objective assessment of balance and sit-to-stand transition, as well as collection of related health information in a fully autonomous manner.

Overall, our initial investigation indicate that the FRAAn system has the potential for assessing fall risk in comparison to validated clinical fall risk measures. Specifically, FRAAn-based outcome measures were associated with a variety of validated clinical fall risk measures (TUG, BBS, FES). And the FRAAn system was accurate in movement tracking (as demonstrated by the STS tracking accuracy). These results are comparable with previous work on sensor-based fall risk evaluations (Ejupi, Brodie et al., 2016; Yeung et al., 2014) in tracking accuracy. Additionally, this work is also consistent with previous findings on using mediolateral postural sway amplitude (Piirtola & Era, 2006) and STS measure [21] to discriminate high risk individuals.

The overall system usability was received favorably, with 83% participants reporting high usability (SUS > 80). It is worth noting that those who reported below average usability ratings (SUS < 68) were at two ends of the functionality spectrum (as measured by TUG), which could be due to the perceived challenge of the assessment (too challenging or too easy) or comorbidity in addition to mobility impairment (i.e. vision/hearing/cognitive impairment, etc.). Unfortunately, we did not quantify sensory abilities nor cognition in this current investigation. This possibility highlights the need to further evaluate the association between technology acceptance and functional

mobility and other comorbidities among older adults to enable individualized technology solutions for enhancing quality of life.

We acknowledge certain limitations, most of which related to the pioneering use of a new technology. First, while clinical fall risk screening methods (BBS, TUG) have been shown to be a good predictor of physical capacity, the predictive ability for future falls status are poor to moderate (Muir et al., 2008; Schoene et al., 2013), as fall may be resulted from physical capacity, environmental factors and exposures to challenging activities (Klenk et al., 2017). Therefore, further research to assess the predictive ability of technology-based fall risk screening with a prospective research design and comprehensive fall status classification is warranted. Secondly, a larger and gender-balanced sample is needed to provide stronger conclusion regarding discriminative ability and the user acceptance of FRAAn system, as the lack of male participants in this research, due to the prevailing female patients attending the bone health clinic, may limit our findings from generalizing to the entire population. Given the exploratory nature of this work, a convenient sample of 30 participants was chosen based on our previous work using this prototype device (Hsieh, Moon, Ramkrishnan, Ratnam, & Sosnoff, 2018). All eligible participants were consecutively recruited by the clinical research staff at the hospital. Therefore, this sample may not be representative of the entire population (Altmann, 1974). However, we believe this sampling method is the most suitable for this research, as the aim of this research is to validate the device in measuring balance performance and associated risk of falls. Data collected from this work will be used to calculate the required sample size to power a larger scale prospective-design future study. Lastly, given that numerous outcomes have been identified as fall risk factors, such as vision, cognition, proprioception, balance, mobility, and muscle strength, a comprehensive multi-factorial fall risk screening system is needed. It is important to note that this system is designed to provide fast, easy-to-implement fall risk screening among older adults on a regular basis. Therefore, not all risk factors of falls (i.e. blood pressure, neuropathy, etc.) need to be evaluated in this system, and should be further evaluated by clinicians.

#### 5. Conclusion

In this work, we evaluated the preliminary validity and usability of a recently developed self-guided fall risk screening system. Overall, our results indicate that the FRAAn system has the potential for assessing

fall risk, and it is well received among older users. The initial success of this system will facilitate identification of fall risk factors that could allow for individualized fall prevention intervention. Furthermore, this affordable/portable system allows objective assessment to be conducted more regularly compared to clinic/laboratory based assessment.

### Conflict of interest

The authors declare no conflict of interest.

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### References

- Altmann, J. (1974). Observational study of behavior: Sampling methods. *Behaviour*, *49*, 227–266.
- Berg, K. O., Wood-Dauphinee, S. L., Williams, J. I., & Maki, B. (1992). Measuring balance in the elderly: Validation of an instrument. *Canadian journal of public health = Revue canadienne de sante publique*, *83*, S7–11.
- Bergen, G. (2016). Falls and fall injuries among adults aged  $\geq$  65 years—United States, 2014. *MMWR Morbidity and Mortality Weekly Report*, *65*.
- Bland, J. M., & Altman, D. (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet (London, England)*, *327*, 307–310.
- Brooke, J. (1996). SUS-A quick and dirty usability scale. *Usability evaluation in industry*, *189*, 4–7.
- Buatois, S., Miljkovic, D., Manckoundia, P., Gueguen, R., Miget, P., Vançon, G., et al. (2008). Five times sit to stand test is a predictor of recurrent falls in healthy community-living subjects aged 65 and older. *Journal of the American Geriatrics Society*, *56*, 1575–1577.
- Dancey, C. P., & Reidy, J. (2007). *Statistics without maths for psychology*. Pearson Education.
- Ejupi, A., Brodie, M., Gschwind, Y. J., Lord, S. R., Zagler, W. L., & Delbaere, K. (2016). Kinect-based five-times-sit-to-stand test for clinical and in-home assessment of fall risk in older people. *Gerontology*, *62*, 118–124.
- Ejupi, A., Gschwind, Y. J., Valenzuela, T., Lord, S. R., & Delbaere, K. (2016). A kinect and inertial sensor-based system for the self-assessment of fall risk: A home-based study in older people. *Human-Computer Interaction*, *31*, 261–293.
- Florence, C. S., Bergen, G., Atherly, A., Burns, E., Stevens, J., & Drake, C. (2018). Medical costs of fatal and nonfatal falls in older adults. *Journal of the American Geriatrics Society*.
- Gillespie, L. D., Robertson, M. C., Gillespie, W. J., Sherrington, C., Gates, S., Clemson, L. M., et al. (2012). Interventions for preventing falls in older people living in the community. *The Cochrane Database of Systematic Reviews*, *9*.
- Hsieh, K. L., Moon, Y., Ramkrishnan, V., Ratnam, R., & Sosnoff, J. J. (2018). Validating virtual time to contact with home-based technology in young and older adults. *Journal of Applied Biomechanics*, *1–7*.
- Klenk, J., Becker, C., Palumbo, P., Schwickert, L., Rapp, K., Helbostad, J. L., et al. (2017). Conceptualizing a dynamic fall risk model including intrinsic risks and exposures. *Journal of the American Medical Directors Association*, *18*, 921–927.
- Kramarow, E., Chen, L.-H., Hedegaard, H., & Warner, M. (2015). Deaths from unintentional injury among adults aged 65 and over: United States, 2000–2013. *NCHS Data Brief*, *199*.
- Muir, S. W., Berg, K., Chesworth, B., & Speechley, M. (2008). Use of the Berg Balance Scale for predicting multiple falls in community-dwelling elderly people: A prospective study. *Physical Therapy*, *88*, 449–459.
- Nass, C., Moon, Y., & Green, N. (1997). Are machines gender neutral? Gender-stereotypic responses to computers with voices. *Journal of Applied Social Psychology*, *27*, 864–876.
- Piirtola, M., & Era, P. (2006). Force platform measurements as predictors of falls among older people—a review. *Gerontology*, *52*, 1–16.
- Podsiadlo, D., & Richardson, S. (1991). The timed “Up & Go”: A test of basic functional mobility for frail elderly persons. *Journal of the American Geriatrics Society*, *39*, 142–148.
- Prieto, T. E., Myklebust, J., Hoffmann, R., Lovett, E., & Myklebust, B. (1996). Measures of postural steadiness: Differences between healthy young and elderly adults. *IEEE Transactions on Bio-medical Engineering*, *43*, 956–966.
- Roeling, K. L., Hsieh, K. L., & Sosnoff, J. J. (2017). A systematic review of balance and fall risk assessments with mobile phone technology. *Archives of Gerontology and Geriatrics*.
- Rubenstein, L. Z. (2006). Falls in older people: epidemiology, risk factors and strategies for prevention. *Age and Ageing*, *35*, ii37–ii41.
- Sauro, J. (2011). *Measuring usability with the system usability scale (SUS)*.
- Schoene, D., Wu, S. M. S., Mikolaizak, A. S., Menant, J. C., Smith, S. T., Delbaere, K., et al. (2013). Discriminative ability and predictive validity of the timed up and go test in identifying older people who fall: Systematic review and meta-analysis. *Journal of the American Geriatrics Society*, *61*, 202–208.
- Scott, V., Votova, K., Scanlan, A., & Close, J. (2007). Multifactorial and functional mobility assessment tools for fall risk among older adults in community, home-support, long-term and acute care settings. *Age and Ageing*, *36*, 130–139.
- Shumway-Cook, A., Brauer, S., & Woollacott, M. (2000). Predicting the probability for falls in community-dwelling older adults using the timed up & go Test. *Physical Therapy*, *80*, 896.
- Stevens, J. A., & Phelan, E. A. (2013). Development of STEADI: A fall prevention resource for health care providers. *Health Promotion Practice*, *14*, 706–714.
- Sun, R., & Sosnoff, J. J. (2018). Novel sensing technology in fall risk assessment in older adults: A systematic review. *BMC Geriatrics*, *18*, 14.
- Sun, R., Paramathayalan, V. R., Ratnam, R., Jain, S., Morrow, D. G., & Sosnoff, J. J. (2018). *Design and development of an automated fall risk assessment system for older adults*. *Aging, Technology and Health*. Elsevier135–146.
- Yardley, L., Beyer, N., Hauer, K., Kempen, G., Piot-Ziegler, C., & Todd, C. (2005). Development and initial validation of the Falls Efficacy Scale-International (FES-I). *Age and Ageing*, *34*, 614–619.
- Yeung, L., Cheng, K. C., Fong, C., Lee, W. C., & Tong, K.-Y. (2014). Evaluation of the Microsoft Kinect as a clinical assessment tool of body sway. *Gait & Posture*, *40*, 532–538.