



Introduction of Fall Risk Assessment (FRA) System and Cross-Sectional Validation Among Community-Dwelling Older Adults

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Objective To predict the risk of falls, Fall Risk Assessment (FRA) system has been newly developed to measure multi-systemic balance control among community-dwelling older adults. The aim of this study was to examine the association between FRA and fall-related physical performance tests.

Methods A total of 289 community-dwelling adults aged 65 years and older participated in this cross-sectional study. All participants underwent FRA test and physical performance tests such as Short Physical Performance Battery (SPPB), Berg Balance Scale (BBS), and Timed Up and Go Test (TUG).

Results Participants who were younger, male, highly educated, living with family members, having high body mass index, having high appendicular lean mass index, and having no irritative lower urinary tract syndrome were more likely to have higher FRA scores. SPPB ($\beta=1.012$), BBS ($\beta=0.481$), and TUG ($\beta=-0.831$) were significantly associated with FRA score after adjusting for the variables (all $p<0.001$).

Conclusion FRA composite score was closely correlated with SPPB, BBS, and TUG, suggesting that FRA is a promising candidate as a screening tool to predict falls among community-dwelling elderly people.

Keywords Aged, Falls, Risk assessment

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INTRODUCTION

Falls are common in older adults, and cause loss of independence, hospitalization from trauma, injury-related death, and increased health care cost. Fall-related injuries such as fracture, head trauma, and major lacerations can lead to decline in physical performance, admission to nursing homes, and increased use of health care services [1,2]. However, falls can be prevented by identifying people at high risk and intervening with modifiable risk factors [3] through exercise, vitamin D supplementation, nutritional therapy, cognitive behavioral therapy, education, and improving their living environment [4].

Currently, several representative physical performance tests such as the Short Physical Performance Battery (SPPB), Berg Balance Scale (BBS), and Timed Up and Go test (TUG) are being used to predict the risk of falls in elderly people [5-9]. Although these tests are easy to use without requiring expensive equipment or much time to perform, they cannot be used to differentiate balance deficits [10]. Furthermore, causes of a fall are often multifactorial. There is no established gold standard of identifying people with different levels of risk of falls. Therefore, there is a great need to establish a validated and reliable tool to comprehensively assess the risk of falls.

Lower-extremity weakness and balance impairment are known to be the most important intrinsic factors for falling in community-dwelling older adults [11,12]. Low muscle mass is also known to increase fall risk [13]. Numerous composite physical performance tests have been used to screen older adults for fall risk. For comprehensive fall risk assessment, Physiological Profile Assessment (PPA) has been suggested to determine physiological fall risk from five measures: visual contrast sensitivity, lower limb proprioception, quadriceps strength, simple reaction time, and postural sway [14,15].

Although some computerized balance function assessments are already being used in clinical setting for screening elderly persons to assess fall risk and examine balance dysfunction, they are not comprehensive tools [16,17]. The computerized force platform measures postural control balance only [16], while the Biodex Balance System evaluates an individual's capacity to maintain dynamic postural stability [17]. On the other hand, the Fall Risk Assessment (FRA) system is a new composite and comprehensive instrument system developed by

InBody Co. Ltd. to predict the risk of falls. FRA system is composed of three machines: a balance measuring instrument, an InBody body composition analyzer, and a leg muscle dynamometer. Therefore, FRA system can measure sensory, nervous, integrated balance abilities, and musculoskeletal systems. The authors have recently demonstrated the test-retest reliability of the FRA system [18].

The objective of the present study was to examine the cross-sectional concurrent validity between the FRA and validated falls predicting performance tests in community-dwelling older people. Concurrent validity and predictive validity are two types of criterion-related validity. Concurrent validity is demonstrated when a test correlates well with a measure that has previously been validated.

MATERIALS AND METHODS

Study participants

This cross-sectional study involved 289 community-dwelling older adults (87 men and 202 women) aged 65 years or older who were capable of communication and ambulation. Participants were recruited through advertisements at a senior welfare center in Seoul, Korea from January 18, 2016 to January 29, 2016. Exclusion criteria were: Mini-Mental State Examination score <24; use of antithrombotic drugs within a week; history of stroke, severe visual impairments or visual field defects, epilepsy, uncontrolled hypertension (systolic blood pressure >150 mmHg or diastolic blood pressure >90 mmHg), unstable diabetes mellitus (fasting plasma glucose \geq 140 mg/dL or <70 mg/dL), syncope, heart disease such as myocardial infarction and heart failure, liver failure, renal failure on dialysis, and psychiatric diseases such as schizophrenia, alcohol dependence, and eating disorder. Those with history of stroke, myocardial infarction, syncope, or uncontrolled hypertension were excluded to prevent any cardiovascular event due to increased blood pressure during leg muscle strength test. Those with severe visual impairments were excluded as such condition could prevent accomplishing the reaction time test. All participants gave written informed consent. Those who were unable to give their informed consent were not enrolled. The study protocol was approved by the Institutional Review Board of Kyung Hee University Medical Center (No. 2015-10-502).

Variables and data collection

A fall within the last 12 months was self-reported. A fall was defined as “an event that results in a person unintentionally coming to rest on the ground or a lower level, not due to a major intrinsic event (e.g., stroke or syncope) or overwhelming hazard” [19]. An injurious fall was defined as a fall that resulted in sprains, contusions, lacerations, or fractures.

Health assessments were made using self-administered questionnaires and interviews conducted by trained staff. A standardized questionnaire covering basic demographic data, fall history, medical comorbidities, and current medication use was distributed to each participant prior to physical examinations, evaluation with FRA systems, and physical performance tests. Physical examinations included measurements of weight, height, body mass index (BMI), blood pressure, random plasma glucose test, and the Korean version of the Mini-Mental State Examination (K-MMSE).

Fall Risk Assessment system

The FRA system is a composite and comprehensive assessment tool developed to predict the risk of falls. It is composed of three parts: a balance measuring instrument, a body composition analyzer, and a leg muscle dynamometer (Fig. 1). The modified clinical test of sensory interaction in balance (mCTSIB), reaction time and latent reaction time tests, and integrated balance ability test were performed with the balance measuring instrument (FRA510S and IB-LS; InBody Co. Ltd., Seoul, Korea). Leg muscle mass was with the body composition analyzer (InBody 570). Leg muscle strength tests were performed on the leg muscle dynamometer (IB-LS).



Fig. 1. Three components of Fall Risk Assessment (FRA) system: balance measuring instrument, InBody body composition analyzer, and leg muscle dynamometer.

mCTSIB for sensory system score

The mCTSIB is designed to assess how well a person is using different sensory inputs when one or more sensory systems are compromised. For this test, participants were asked to maintain their balance through four different conditions while standing on the force platform (Fig. 2A). During Condition 1, the subject stood on a firm surface with eyes open, allowing all sensory inputs through visual, somatosensory, and vestibular organs for maintaining balance. During Condition 2, the visual input was disabled by asking the subject to stand on a firm surface with eyes closed. During Condition 3, the somatosensory system was compromised by asking the subject to stand on a foam surface with eyes open. Finally, during Condition 4, visual and somatosensory information was compromised by asking the subject to stand on a foam surface with eyes closed.

During each condition, the FRA system measured the linear distance from the initial point of center of pressure (COP) to the swayed point of COP in two-dimensional plane every 16 ms for a total of 30 seconds. Sway index was obtained by calculating the average of all measured linear distances. Thus, it represented the average absolute displacement of the COP. The sway index score was derived from each sway index of Conditions 2, 3, and 4. High sway index indicated poor ability to maintain balance. Low sway index score in Condition 2 indicated that somatosensory and vestibular functions were compromised. Low sway index score in Condition 3 indicated that visual and vestibular functions were compromised. Low sway index score in Condition 4 indicated that vestibular function was disrupted.

Maintaining balance while standing on a firm, flat surface involves roughly 70% somatosensory input, 20% vestibular input, and 10% visual input whereas standing on a foam surface or a slope involves roughly 70% vestibular input, 20% visual input, and 10% somatosensory input. Thus, the sway index score of Conditions 2, 3, and 4 can be used to differentiate balancing ability of somatosensory, visual, and vestibular systems [20]. The sensory system score was calculated by weighting the sway index scores of Conditions 2, 3, and 4 by 70%, 10%, and 20%, respectively.

Reaction time and latent reaction time tests for reaction score

The reaction time and latent reaction time tests were



Fig. 2. Fall Risk Assessment (FRA) system and body composition analyzer. (A) A participant performing mCTSIB using the balance measuring instrument to obtain sensory score (Condition 3: on the foam surface). (B) A participant performing reaction time and latent reaction time tests by balance measuring instrument to obtain reaction score. (C) A participant performing shifting velocity test (left) and another participant performing diagonal A type target tracking test (right) using the balance measuring instrument to obtain integrated balance ability score. (D) A participant performing leg muscle mass test by body composition analyzer (left) and another participant performing leg muscle strength test by leg muscle dynamometer (right) to obtain muscular system score. mCTSIB, modified clinical test of sensory interaction in balance.

also performed on the force platform. At the beginning of the test, four fan-shaped buttons appeared on the upper side of the screen and the subject's finger was placed on the semi-circular button on the lower center of the screen (Fig. 2B). This test measured the reaction time and latent reaction time in unit of seconds. The reaction time was defined as the time taken for the subject to touch the illuminated fan-shaped button from the moment 4 buttons lit up on the screen while the latent reaction time was defined as the time taken for the subject to take the finger off the semi-circular button and press the illuminated button when one of these 4 buttons lit up on the screen. The test was repeated 10 times. The average value was used to calculate the reaction time score and the latent reaction time score. The reaction score was obtained from the mean value of reaction time scores and latent reaction time scores.

Shifting velocity test and target tracking test for integrated balance ability score

The integrated balance ability test was comprised of shifting velocity test and target tracking test. The shifting velocity test measured how fast participants shifted their COP. First, a red spot appeared at the center of the screen to represent the subject's COP. When a target appeared randomly in one of 8 directions on the screen, the subject shifted his or her COP to the target (Fig. 2C). After staying with the target for 2 seconds, another target appeared and the participant repeated the same process for 7 more directions. The shifting velocity was calculated by dividing the distance from the center to the target by the time spent to shift the COP to the target. Shifting velocity score was obtained as the mean of 8 shifting velocities.

The target tracking test measured how successfully participants pursued a moving target and moved their COP to that target. First, a red spot appeared at the center of the screen to represent the subject's COP, much like

the shifting velocity test. A round target appeared on the screen, moving at a speed of 1 cm/s, 2 cm/s, 3 cm/s, 4 cm/s, or 5 cm/s in directions of left-and-right, front-and-rear, diagonal A (right-front to left-rear), and diagonal B (left-front to right-rear) (Supplementary Fig. S1). The subject shifted his or her COP to track the target without moving his or her feet. Positions of COP were checked once every 16 ms and recorded as either 'inside' or 'outside' the target during the total examination time. The success rate of target tracking was calculated by dividing the total count of 'inside' and multiplying by 100. Integrated balance ability score was calculated as the mean of the shifting velocity score and the target tracking score.

Leg muscle mass and leg muscle strength test for muscular system score

The leg muscle mass was measured by the body composition analyzer (InBody 570) which used bioelectrical impedance analysis (Fig. 2D). The muscle mass of both legs was obtained as the leg muscle mass score.

To measure the strength of leg muscles, participants were asked to extend their knees until the thigh and the lower leg made an angle of 60° (Fig. 2D). The muscle strength was measured twice for each leg and twice for both legs using the leg muscle dynamometer. The maximum of these two measured values was adopted. The muscular system score was derived from the mean of the leg muscle mass score and the composite leg muscle strength score.

Composite FRA score

The mean value was set as 70 for all scoring systems and 15 was added or subtracted for every 1 standard deviation increment or decrement, respectively. The composite FRA score was produced by weighting 10% to the sensory system score, 20% to the reaction score, 40% to the muscular system score, and 30% to the integrated balance ability score per the company's instruction.

Statistical analysis

Data were analyzed using SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). Baseline characteristics of participants for categorical variables are summarized as the number of participants and percentages and the average FRA score of each category is presented as mean and standard deviation. Comparisons of the average FRA

score between each category were performed using t-test and one-way analysis of variance (ANOVA) test. Pearson correlation analysis was performed between FRA and SPPB, BBS, or TUG. Scatterplots between FRA and other performance tests were drawn. Simple and multiple linear regression models were performed to find the best linear equation to explain the relationship between FRA and other performance tests. Adjustments were made for age, sex, and covariates showing an association ($p < 0.1$) with composite FRA score. Statistical significance level was set at $p < 0.05$.

RESULTS

The mean age of 289 participants included in this cross-sectional study was 76.7 ± 4.8 years (range, 65–92 years). Characteristics of these participants and average FRA score of each category are shown in Table 1. Approximately 40.1% of participants aged 75–79 years, 69.9% of participants were females, 79.6% of participants had high educational status, 58.5% of participants were living alone, 9.0% of participants had past history of an injurious fall, 3.5% of participants used walking aids, 10.4% of participants used psychotropic drugs, 13.5% of participants did physical activity more than 600 MET-min/week, and 51.5% of participants were obese.

Participants with a higher FRA score were more likely to be younger (p for trend < 0.001), male, have high educational status, have high BMI (p for trend = 0.0037), live with other family members, and not have irritative lower urinary tract symptoms (LUTS). Table 2 shows Pearson correlation coefficients between FRA and other physical performance tests. Significant (all $p < 0.001$) correlations of FRA with SPPB ($r = 0.394$), BBS ($r = 0.399$), and TUG ($r = -0.362$) were found.

Table 3 shows regression coefficients of SPPB, BBS, and TUG by simple and multiple linear regression analysis using FRA as a dependent variable. In the adjusted model, increase of SPPB by 1 point was significantly ($p < 0.001$) associated with increase of FRA by 1.012, increase of BBS by 1 point was significantly ($p < 0.001$) associated with an increase of FRA by 0.481 while an increase of TUG by 1 second was significantly ($p < 0.001$) associated with a decrease of FRA by 0.831. Analyses were adjusted by age, sex, educational status, living alone, use of assistive device, BMI, appendicular lean mass index (ALMI), diz-

Table 1. FRA scores by participant characteristics (n=289)

Variable	No. of participants (%)	Composite FRA score	p-value
Age (yr)			<0.001***
65-69	20 (6.9)	75.1±6.2	
70-74	76 (26.3)	68.7±6.7	
75-79	116 (40.1)	67.0±7.9	
80-84	63 (21.8)	66.9±7.0	
≥85	14 (4.8)	61.7±7.7	
Sex			0.001**
Male	87 (30.1)	70.0±6.9	
Female	202 (69.9)	66.8±7.7	
Educational status ^{a)}			<0.001***
High	230 (79.6)	68.8±7.6	
Low	59 (20.4)	63.6±6.4	
Living alone			0.001**
No	120 (41.5)	69.6±8.0	
Yes	169 (58.5)	66.5±7.1	
Injurious fallers			0.799
No	263 (91.0)	67.7±7.7	
Yes	26 (9.0)	68.1±7.3	
Use of an assistive device			0.322
No	279 (96.5)	67.8±7.7	
Yes	10 (3.5)	65.4±5.6	
Psychotropic drug user ^{b)}			0.553
No	259 (89.6)	67.8±7.5	
Yes	30 (10.4)	67.0±8.9	
Physical activity (MET min/wk) ^{c)}			0.201
<600	250 (86.5)	67.5±7.5	
≥600	39 (13.5)	69.2±8.3	
BMI (kg/m ²)			0.009**
Underweight (<18.5)	6 (2.1)	62.3±6.1	
Normal weight (18.5-22.9)	63 (21.8)	65.4±8.0	
Overweight (23.0-24.9)	71 (24.6)	68.7±6.2	
Obesity (≥25.0)	149 (51.5)	68.5±7.0	
Dizziness			0.514
No	280 (96.9)	67.8±7.6	
Yes	9 (3.1)	66.1±8.4	
Visual deficit ^{d)}			0.054
No	236 (81.7)	68.2±7.7	
Yes	53 (18.3)	65.9±7.0	

Table 1. Continued

Variable	No. of participants (%)	Composite FRA score	p-value
Irritative LUTS ^{e)}			0.008**
No	106 (36.7)	69.2±6.6	
Yes	183 (63.3)	66.9±8.0	

Values are presented as number (%) or mean±standard deviation.

FRA, Fall Risk Assessment system; MET, metabolic equivalent of task; BMI, body mass index; ALMI, appendicular lean mass index; LUTS, lower urinary tract symptoms.

^{a)}High educational status was defined as attending education further than elementary school while low educational status was defined as completion of elementary school or below.

^{b)}Psychotropic drug use was defined as regular and persistent use of sedatives, hypnotics, antidepressants, or antipsychotics for at least last 6 weeks.

^{c)}Physical activity was defined as the total sum of walking, moderate-intensity physical activity, and vigorous intensity activity.

^{d)}Blurred vision or diplopia was classified as visual deficit.

^{e)}Urinary symptoms such as urgency, frequency, and nocturia were classified as having irritative LUTS.

*p<0.05, **p<0.01, ***p<0.001 (based on t-test and one-way ANOVA test).

Table 2. Pearson correlation between FRA and other physical performance tests

	Pearson correlation coefficient	p-value
SPPB	0.394	<0.001***
BBS	0.399	<0.001***
TUG	-0.362	<0.001***

FRA, Fall Risk Assessment system; SPPB, Short Physical Performance Battery; BBS, Berg Balance Scale; TUG, Timed Up and Go Test.

***p<0.001.

ziness, visual deficit, and irritative LUTS in the adjusted model. Age, BMI, and ALMI were used as continuous variables.

DISCUSSION

The main aim of this study was to establish the interrelationship between the newly developed FRA system and existing physical performance tests. Results of this study

Table 3. Regression coefficients of SPPB, BBS, and TUG by simple and multiple linear regression analysis using FRA as a dependent variable

	Unadjusted model		Adjusted model	
	β coefficient	p-value	β coefficient	p-value
SPPB	1.703	<0.001	1.012	<0.001***
BBS	1.017	<0.001	0.481	<0.001***
TUG	-1.356	<0.001	-0.831	<0.001***

Analyses were adjusted by age, sex, educational status, living alone, use of assistive device, BMI, ALMI, dizziness, visual deficit, and irritative LUTS. Age, BMI, and ALMI were used as continuous variables.

FRA, Fall Risk Assessment system; SPPB, Short Physical Performance Battery; BBS, Berg Balance Scale; TUG, Timed Up and Go Test; BMI, body mass index; ALMI, appendicular lean mass index; LUTS, lower urinary tract symptoms.

***p<0.001.

showed that FRA score had significant linear relationships with SPPB, BBS, and TUG.

The SPPB is a composite measure of lower-limb physical performance. It assesses standing balance, gait speed, and lower-limb strength [5,6,21]. Several studies have demonstrated that the SPPB is significantly correlated with falls in community-dwelling older adults. Mangani et al. [5] have reported that participants with history of falls have significantly lower adjusted means of the SPPB compared to non-fallers in 364 older participants. In another study of 2,710 Italian people aged over 65 years, participants scoring 0–6 in the SPPB are more likely to be recurrent fallers than those scoring 10–12 [6].

The BBS assesses balance performance through functional tasks that require equilibrium. It is commonly used in the elderly. Previous investigations have shown that BBS is valuable in predicting the risk of falls in community-dwelling elderly [7,8]. The TUG is also well known for its ability to predict the probability for falls in community-dwelling older adults [22,23].

Somatosensory, visual, and vestibular systems and their interactions are essential for postural control. CTSIB was developed to assess the organization of sensory inputs in postural control [24]. The modified version of CTSIB, the mCTSIB, is a form of static platform posturography. It is a good indicator of imbalance in frail elderly. While mCTSIB is a static balance test, the shifting velocity test and target tracking test adopt dynamic balance test as a kind of integrated balance test. Mean velocity of COG shifts has been the most reliable method in assessing postural control until recently. FRA's target tracking is now a more comprehensive parameter of coordinated sensory-cognitive-motor function.

The reaction time is defined as the time taken for an actual response to an external stimulus perceived by the sensory neurons through a series of information-processing steps ending up in an action. Therefore, the reaction time can be used to quantitatively measure the reaction by nervous and muscular systems involved in the processes of falling [25]. It has been reported that the reaction time affects balance and that a delayed reaction time is a risk factor for falls [26].

It was an unexpected result that previous injurious falls for the last 12 months were not associated with FRA score. One potential explanation is that those with impairment might have decreased mobility which might have led to less exposure to situations in which falls might occur [27]. Exclusion of those with high risk of falling might have also contributed to this unexpected result. Further analysis of a prospective study is needed to determine the relationship between FRA low scorers and increased risk of falling.

The composite FRA score was produced by weighting 10% to the sensory system score, 20% to the reaction score, 40% to the muscular system score, and 30% to the integrated balance ability score per the company's instruction. However, equations or algorithms of the FRA system are proprietary (private) information of the company that developed them. The weighting is similar to a previous study showing that normal subjects rely on somatosensory (70%), vision (10%), and vestibular (20%) information on firm surface in their daily living environment [28].

The present study has some limitations. First, weighting scales of each item provided by InBody Co. Ltd. were determined based on a consensus of specialists referring

to published articles, leaving room to be proved through future studies. Second, the FRA system only assesses the static balance without including gait assessment. Nevertheless, the FRA score was highly correlated with 4-meter walking speed (one of SPPB), implicating that it might represent some dynamic balance. Finally, this validity test cannot be generalized to general population of older adults. This study was carried out for ambulatory community-dwelling elderly in a community facility with a broad exclusion criteria to minimize the least chance of health risks. In the future, a study at hospital setting involving patients such as patients with stroke and Parkinson disease who are at high risk for falling will be needed.

The significance of this study can be found in the fact that this is the first study to introduce the whole FRA system and show cross-sectional validity of the system. The FRA is a very unique system that checks comprehensive balance abilities together with reaction time, skeletal muscle mass, and leg muscle power. A number of factors are known to affect the risk of falling, including age, vision, muscle power, flexibility, sensation, balance, number and type of medications, cognitive impairment, and concomitant medical problems [29]. Although this FRA system alone may not fully predict the risk of falls, it poses a significant value as a helpful tool.

Through the current study, we verified that the FRA was closely correlated with SPPB, BBS, and TUG. It is a promising tool to predict falls among community-dwelling elderly people. A prospective study should be performed to establish the predictive validity of the FRA for predicting future events of fall.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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SUPPLEMENTARY MATERIALS

Supplementary materials can be found via <https://doi.org/10.5535/arm.2019.43.1.87>.

Fig. S1. (A) Eight directions of target appearance on the monitor screen and depiction of moving pathway of a subject's center of pressure (COP) in shifting velocity test. (B) A target moving at a speed of 2 cm/s and a red dot in the target representing COP of subject on the monitor screen in a target-tracking test.

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