Simple and Easy Assessment of Falling Risk in the Elderly by Functional Reach Test Using Elastic Stick

SHIN-ICHI DEMURA[1] and TAKAYOSHI YAMADA[2]

[1]Graduate School of Natural Science and Technology, Kanazawa University, Kanazawa, Japan
[2]Department of Natural Science and Technology, Fukui National College of Technology, Sabae, Japan

DEMURA, S. and YAMADA, T. *Simple and Easy Assessment of Falling Risk in the Elderly by Functional Reach Test Using Elastic Stick.* Tohoku J. Exp. Med., 2007, **213** (2), 105-111 —— Dynamic balance ability related to maintaining postural stability during movement is closely tied to fall risk in the elderly. The functional reach (FR) test has been developed to evaluate their dynamic balance. Although a simple and new FR test using an elastic stick has been proposed by modifying the above original FR test, the abilities related to both FR tests are judged to differ because of the large difference in the testing method. This study aimed to compare center of gravity fluctuation, muscle activity and functional reach distance as measured by the original FR test and the elastic stick FR test. First, reach distance, back/forth and right/left moving distance of the center of gravity, and activity of the lower leg muscles (soleus and tibialis anterior) were compared between both tests based on data obtained from 30 young male adults. All parameters except for the right/left moving distance were significantly larger in the elastic stick FR test. Next, the reach distance was examined in both FR tests using 53 elderly subjects; it was significantly longer in the elastic stick FR test, but showed no significant sex difference. The reach distance in both tests was significantly shorter (about 7 cm) in the elderly than in young adults. In conclusion, the elastic stick FR test involves greater leg muscle strength exertion and forward transferring of the center of gravity as compared with the original FR test. Because the elastic stick FR test relates largely to leg muscle function and equilibrium function, it may be more useful for evaluating the dynamic balance ability of the elderly. —————— functional reach; elastic stick; lower-limbs muscle function; equilibrium function
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Functional reach (FR) test is useful for evaluating the elderly's dynamic balance related to maintaining postural stability during movement (Duncan et al. 1990, 1992). Because dynamic balance ability of the elderly relates closely to fall accident, their measurement/evaluation is inferred to be necessary for preventing fall accidents of the elderly.

Significant and moderate relationships were observed between a reach distance in a FR test and the following parameters: instrumental activities of daily living score (IADL), social mobility scale (Life space), gait speed, and time of one-footed standing (Weiner et al. 1992). Significant and high relationships were found among reach distance and leg strength and ankle motion-range

(Ono and Ryuushi 2002).

A previous study (Duncan et al. 1990) examined relationships between a reach distance in the FR test and center of gravity excursion using the elderly with no lower-limb and equilibrium disorders, and reported that the FR test can discriminate among people with or without fall experience because of their significant and high relationship ($r = 0.71$). In addition, the FR test can evaluate multiple functions of the lower-limbs in addition to a decrease in lower-limb muscle function or equilibrium function with aging, and may be a simple and useful test to predict fall accidents.

The FR test using an elastic stick, which is simpler than the original FR test, was proposed (Morio et al. 2004). In this test, the subject's ability to hold an upright posture is measured by a shortened distance of an elastic stick when they reach forward with an elastic stick toward the wall. This test was used to evaluate the equilibrium function of the elderly (Morio et al. 2004). The elastic stick FR test does not need a large place or a tester to measure the reach distance. Therefore, this FR test may be more convenient and practical.

However, despite the similarity of the FR tests, the measurement methods differ. Namely, the original FR test requires subjects to reach with the hand while maintaining the hand at acromion height, but such a condition is not needed in the elastic stick FR test. Because hand position and waist flexion in the elastic stick FR as compared with the original FR test are largely entrusted to each subject's FR achievement strategy, it is hypothesized that abilities related to achievement in both tests and their contribution differ significantly.

The purpose of this study was to clarify the uses of both tests and the relationships between center of gravity fluctuation, muscle activity and functional reach performance.

METHODS

Subjects

Thirty healthy young male students, selected from a general male student population (age: 22.3 ± 2.0 yr, height: 173.1 ± 5.6 cm, body-mass: 65.7 ± 8.1 kg), gave

consent to the purpose of this study and participated. Fifty-three elderly people, participating in the physical fitness test conducted by the local administration (23 males: age, 70.6 ± 4.9 yr; height, 160.0 ± 7.2 cm; body-mass, 56.0 ± 5.7 kg, and 30 females: age, 69.3 ± 4.4 yr; height, 151.1 ± 4.1 cm; body-mass, 51.1 ± 6.3 kg), gave consent to the experiment and participated in this study. Their physical characteristics were not significantly different as compared with normal values of the Japanese population (Laboratory of Physical Education Tokyo Metropolitan University 2000). It is believed that these characteristics were almost the same as the Japanese population of the same age group. All subjects were judged as right-handed, based on a dominant hand survey (Oldfield 1971) before the experiment. Left-handed Japanese are often made left-handed during the infant stage. Therefore, all subjects in this study are likely right-handed. Written informed consent was obtained from all subjects. Moreover, experimental protocol in this study was approved by inquiry committee of study intended for human "Kanazawa University Health and Sports Science Ethics Committee."

Experimental design and procedure

FR test. A FR test was conducted according to previous study (Duncan et al. 1990). Each subject stood on the line with a yardstick, which was fixed at a dominant acromion height on the wall, and adjusted to the middle fingertip of the dominant hand ahead of the starting point of the yardstick as shown in Fig. 1. Then, a tester measured the distance when the subject maximally extended the fingertip while holding an upright posture. Subjects were instructed to reach their hand as far as possible without moving their feet after enough practice. Reach strategy was not controlled.

FR test using an elastic stick (Elastic stick FR test). An elastic stick FR test was conducted according to the previous study (Morio et al. 2004). Each subject maximally extended the dominant hand from an upright posture while touching the top of an elastic stick fixed at a dominant acromion height on the wall as shown in Fig. 1. Subjects pushed and shortened the elastic stick by extending the dominant hand. A shortened distance of the elastic stick was measured. Elastic fescue (SASHI-2, Kokuyo, Tokyo) was used as the elastic stick. This elastic stick can be shortened without a large external force. Anti-slip material made of rubber was attached to the top of an elastic stick, so as not to move the contact point between the top of an elastic stick fixed at acromion

Functional Reach Test

Yard Stick

Young adults: 39.2 ± 4.1 cm
Elderly people: 33.7 ± 5.6 cm

Elastic Stick Functional Reach Test

Young adults: 44.3 ± 4.9 cm
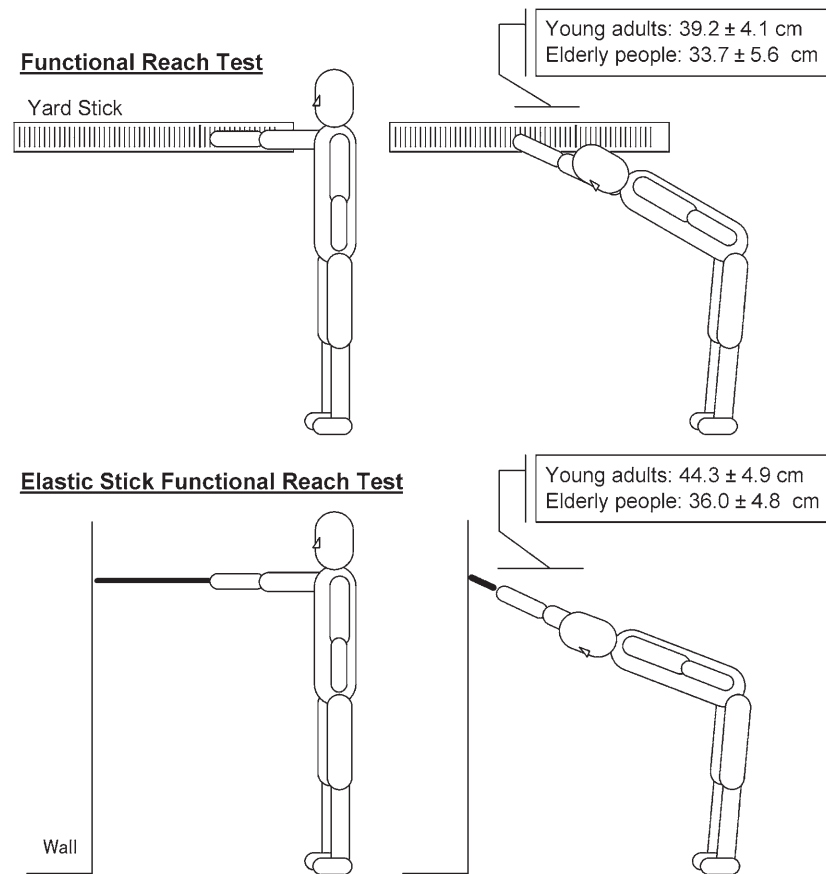Elderly people: 36.0 ± 4.8 cm

Wall

Fig. 1. Movement characteristics of the functional reach test and the elastic stick functional reach test.

height and wall. Subjects were also instructed to reach their hand as far as possible without moving their feet after enough practice.

Measurements were conducted twice. Both tests were conducted randomly on the same day so as to eliminate any possible bias. In addition, reliability coefficients of both FR tests were very high (FR test: 0.92 and elastic stick FR test: 0.91).

Parameters

For young male adults, body-sway of center of pressure (CFP), which reflects two-dimensional fluctuation of center of body gravity, electromyogram (EMG) of soleus and tibialis anterior muscles, and reach distance during both FR tests were measured. The CFP was measured by a center of gravity analysis system (G5500, Anima, Tokyo). Moving distances of the center of gravity of the body in the bilateral (X-axis) and anteroposterior (Y-axis) directions were distances from starting to reach completion using time series CFP data. Because the FR test requires subjects to reach with only one hand,

large trunk rotation occurs. Therefore, the center of gravity can be swayed in a right-left direction, in addition to a back and forth direction because of the need to keep the body stable. Body sway of a right-left direction reflects the CFP of the X direction. CFP data was recorded at a 20Hz sampling frequency. EMG was measured with an electromyogram finder (MM2200, Anima). Activities of soleus and tibialis anterior muscles were calculated by the sum of the time course of EMG data and divided by achievement time, which was defined from starting to finishing of the movement. Lower leg muscles selected in this study were reported to have a high contribution to achieving FR in a previous study (Duncan et al. 1990). EMGs of both muscles were recorded at a 500 Hz sampling frequency at the same time. In addition, electrodes to measure EMG were attached to center of each muscle at intervals of 5 mm. The elderly were measured for reach distance in both FR tests. CFP and EMG data were synchronized and recorded onto a computer at the same time.

Statistical analysis

Mean differences of each parameter in FR and elastic stick FR tests were examined by a paired *t*-test. The size of the mean difference was examined by an effect-size (ES). ES is interpreted as follows: small-not more than 0.2, moderate-about 0.4, and large-over 0.8. The relationships among parameters were examined by Pearson's product-moment correlation coefficient. The probability level of 0.05 was used as indicative of a statistical significance.

Results

Table 1 shows the results of mean differences between the FR and elastic stick FR tests for reach distance, moving distance of the center of gravity of the body, lower leg muscle activity, and relationships among parameters in both tests in young adults. All parameters except for the X-axis moving distance were significantly larger in the elastic stick FR test. ESs for reach distance and integral EMG of the tibialis anterior value per achievement time were large (ES = 1.12-1.41). Relationships among parameters in both tests were significant and high (r = 0.81-0.97) except for reach distance (r = 0.65). A significant and high relationship was observed between the Y-axis and X-axis moving distances of the center of gravity of the body ($r > 0.98$), but not among the other parameters (| r | = 0.00-0.41). Table 2 shows the results of two-way analysis of variance (sex × method) and multiple comparisons for reach distance in the elderly. No sex difference was observed, but a value in the elastic stick FR test was significantly longer. Table 3 shows the results of a two-way analysis of variance (age × method) and multiple comparisons for reach distance in young adults and the elderly. The reach distance in both FR tests was significantly longer (about 7 cm) in young adults.

Discussion

The reach distance was significantly longer in the elastic stick FR test than the original FR test (about 5 cm), and the difference was large (ES = 1.12). Anteroposterior moving distance and lower leg muscle activity were also larger in the former test, and in particular a large difference

TABLE 1. Results of paired *t*-test and correlations among parameters of both functional reach tests in young adults ($n = 30$).

		FR Mean	FR S.D.	ESFR Mean	ESFR S.D.	r	t-value	p	ES	FR A	FR B	FR C	FR D	ESFR A	ESFR B	ESFR C	ESFR D
Reach distance (cm)	A	39.23	4.12	44.30	4.90	0.65*	5.45*	0.000	1.12††								
Bilateral moving distance of center of body gravity (cm)	B	6.99	3.38	7.45	3.12	0.89*	1.22	0.232	0.14	−0.25				−0.01			
Anteroposterior moving distance of center of body gravity (cm)	C	6.79	3.12	8.12	3.34	0.97*	6.70*	0.000	0.41†	−0.31	0.99*			0.00	0.98*		
Activity of tibialis anterior muscle (mv)	D	11.12	1.23	13.57	2.12	0.81*	7.56*	0.000	1.41††	0.08	−0.40	−0.41		−0.28	−0.29*	−0.22	
Activity of soleus muscle (mv)	E	9.92	3.45	11.45	3.55	0.95*	5.68*	0.000	0.44†	0.14	0.00	−0.03	0.14	0.30	−0.07*	−0.03	0.13

*$p < 0.05$, ††ES > 0.8, †ES > 0.4. FR, functional reach; ESFR, elastic stick functional reach.

TABLE 2. Results of two-way (sex × method) analysis of variance for both functional reaches in the elderly (n = 53).

	Male (n = 23)		Female (n = 30)		two-way ANOVA						Post-hoc (Tukey's HSD)
	Mean	S.D.	Mean	S.D.	Sex	p	Method	p	Int	p	
FR	32.8	6.24	34.4	4.83							
ESFR	34.8	5.63	36.9	3.75	2.26	0.139	10.06*	0.003	0.10	0.757	Method: ESFR > FR

*p < 0.05. Int, Interaction; FR, functional reach; ESFR, elastic stick functional reach.

TABLE 3. Results of two-way (age × method) analysis of variance for both functional reaches between young adults and the elderly.

	Young-adult (n = 30)		Elderly (n = 53)		two-way ANOVA						Post-hoc (Tukey's HSD)
	Mean	S.D.	Mean	S.D.	Age	p	Method	p	Int	p	
FR	39.2	4.12	33.7	5.55							Age: Youg-adults > Elderly
ESFR	44.3	4.90	36.0	4.77	30.43*	0.000	11.67*	0.000	0.02	0.957	Method: ESFR > FR

*p < 0.05. Int, interaction; FR, functional reach; ESFR, elastic stick functional reach.

was found in the tibialis anterior muscle activity (ES = 1.41). It is judged that the elastic stick FR test as compared with original FR test imposes large burdens on lower legs muscle to maintain the body stability because center of body gravity transfers forward significantly. As the results above state, it is considered that EMG and the reach distance in the FR test with the elastic stick became larger. The elastic stick FR test needs large forward movement of the center of gravity of the body while holding an upright posture to enhance the reach distance. At this point, a greater load is imposed on the lower leg muscles, especially the tibialis anterior muscle, and large anteroposterior body sway may occur in the elastic stick FR. Moreover, the equilibrium function is also greatly required to hold a stable, upright posture. From the above, it is inferred that the lower-limb muscle function and equilibrium function largely contribute to reach distance because of a larger, forward tilting posture during the elastic stick FR test. A decrease in muscle function of the lower limbs increases the likelihood of falling accidents in the elderly (Greenspan et al. 1994; Dargent-Molina et al. 1996). Thus, it is useful to measure and evaluate the lower-limb muscle function or equilibrium function using the elastic stick FR test with a larger contribution than the original FR test.

Moreover, in an FR test, a subject stands along a line with a yardstick, and extends the middle fingertip of the dominant hand ahead as shown in Fig. 1. However, with the elastic stick FR test, the reaching hand does not have to be held at an acromion height because it is fixed only to the top of the elastic stick at the acromion height. Namely, the reaching hand position is dependant on the FR effort that each subject exerts. This condition difference enables a larger forward body center of gravity moving distance in an elastic stick FR test, and produces a larger involvement by the lower-limb muscle function and the equilibrium function. In addition, because the reaching hand position is limited, subjects' psychological anxiety with transferring forward the center of gravity when reaching is reduced. Also, the above may influence a longer reach distance. It will be necessary to examine relationships between movements of the upper limbs and reach distances in both tests. The elastic FR test

is considered to be more convenient and practical when considering a subject's psychological anxiety and a tester's requirement for measurement.

Reach distance in an elastic stick FR test in the elderly, similar to young adults, was significantly longer, and in both FR tests was longer in young adults than the elderly. Hence, reach distances in both FR tests are superior in young adults. The elderly's FR relates closely to instrumental activities of daily living score, social mobility scale (Life space), gait speed, and time of one-footed standing (Weiner et al. 1992). In addition, it was reported that FR is useful to predict fall occurrences (Duncan et al. 1992). In a senile stage, lower-limb muscle function and equilibrium function decreased markedly (Horak et al. 1989; Lord et al. 1991) and also the incidence of fall accidents increases (Jette and Branch 1981; Hurley and Hagberg 1998). The above-stated function decrease and falls largely affect the quality of life for the elderly (Campbell et al. 1981; Tinetti et al. 1986). It is inferred that an elastic stick FR test is more useful than the original FR test to evaluate age-related decreases of lower-limb muscle function and equilibrium function, or to predict fall occurrences. To establish a more convenient and valid FR test, it may be required to examine the change due to aging of reach distance and relationships between reach distance and lower-limb muscle function and equilibrium function by further studies.

On the other hand, although a relationship between reach distances in the original FR and elastic stick FR tests was not evident in young adults and the elderly (r = 0.63 and 0.65), relationships between fluctuation of the center of gravity and lower limb muscle activity in both FR tests in the young adults were high (r = 0.81-0.97). Conditions of hand position during reaching differ significantly between both tests. Namely, although hand position in the original FR test requires one to remain at acromion height, such a constraint is not required for the elastic stick FR test. This difference in measurement condition brings about large differences in not only the involvement of flexibility of the shoulder joint, and rotation and flexion of the trunk and waists during reaching, but also subject's psychological anxiety with transferring forward their center of gravity. Namely, in spite of the same FR tests, differences of the above-stated factors related to the reaching hand are considered to largely affect relationships between their reach distances.

Moreover, relationships among the other parameters in both tests differ little for young adults (Table 2). A high relationship was found between moving distances for bilateral and antero posterior moving distance of the center of gravity of the body, but not between reach distance and the other parameters. A FR test is useful to evaluate the equilibrium function from a high relationship between reach distance and center of gravity excursion distance in the elderly ($r = 0.71$) (Duncan et al. 1990). Namely, in spite of the same parameters, this study revealed insignificant relationships in both FR tests. This may depend on a difference in the subjects. The elderly have inferior lower-limb muscle function and equilibrium function. Therefore, they experience difficulty in transferring the center of gravity forward for their reaching hand, and individual differences in the above functions largely affects transfer of the center of gravity and reach distance. However, in the case of young adults with high physical function, their reach distance is considered to be mainly affected by other abilities, e.g., flexibilities of the shoulder, trunk, or waist.

Conclusion

In conclusion, reach distances in the elastic stick FR test, similar to the original FR test, show insignificant gender difference and are longer in the young adults than the elderly. However, the elastic stick FR test requires a larger exertion of the leg muscle strength and forward transfer of the center of gravity as compared with original FR test.

Acknowledgments

Reference

Campbell, A.J., Reinken, J., Allan, B.C. & Martinez, G.S. (1981) Falls in old age: a study of frequency and related clinical factors. *Age Ageing*, **10**, 264-270.

Dargent-Molina, P., Favier, F., Grandjean, H., Baudoin, C., Schott, A.M., Hausherr, E., Meunier, P.J & Breart, G. (1996) Fall-related factors and risk of hip fracture: the EPIDOS prospective study. *Lancet*, **348**, 145-149.

Duncan, P.W., Weiner, D.K., Chandler, J. & Studenski, S. (1990) Functional reach: a new clinical measure of balance. *J. Gerontol.*, **45**, M192-M197.

Duncan, P.W., Studenski, S., Chandler, J. & Prescott, B. (1992) Functional reach: predictive validity in a sample of elderly male veterans. *J. Gerontol.*, **47**, M93-M98.

Greenspan, S.L., Myers, E.R., Maitland, L.A., Resnick, N.M. & Hayes, W.C. (1994) Fall severity and bone mineral density as risk factors for hip fracture in ambulatory elderly. *JAMA*, **271**, 128-133.

Horak, F.B., Shupert, C.L. & Mirka, A. (1989) Components of postural dyscontrol in the elderly: a review. *Neurobiol. Aging*, **10**, 727-738.

Hurley, B.F. & Hagberg, J.M. (1998) Optimizing health in older persons: aerobic or strength training? *Exerc. Sport Sci. Rev.*, **26**, 61-89.

Jette, A.M. & Branch, L.G. (1981) The Framingham Disability Study: II. Physical disability among the aging. *Am. J. Public Health*, **71**, 1211-1216.

Laboratory of Physical Education Tokyo Metropolitan University (2000) *New Physical Fitness Standards of Japanese People*, 5th ed., Fumaido, Tokyo, Japan.

Lord, S.R., Clark, R.D. & Webster, I.W. (1991) Physiological factors associated with falls in an elderly population. *J. Am. Geriatr. Soc.*, **39**, 1194-1200.

Morio, H., Oomori, K. & Kondou, M. (2004) Reproducibility and validity of functional reach using elastic stick. *Jpn. J. Phys. Fitness Sports Med.*, Collected papers of the 59th symposium, 307.

Oldfield, R.C. (1971) The assessment and analysis of handedness: the Edinburgh inventory: *Neuropsychologia,* **9**, 97-113.

Ono, A. & Ryuushi, T. (2002) *Training for Fall Prevention of the Elderly,* Book House HD, Tokyo, Japan.

Tinetti, M.E., Williams, T.F. & Mayewski, R. (1986) Fall risk index for elderly patients based on number of chronic disabilities. *Am. J. Med.*, **80**, 429-434.

Weiner, D.K., Duncan, P.W., Chandler, J. & Studenski, S.A. (1992) Functional reach: a marker of physical frailty. *J. Am. Geriatr. Soc.*, **40**, 203-207.