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ORIGINAL ARTICLE

An alternative postural control test: Correlation of modified functional reach with limits of stability

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Purpose: To evaluate the correlation of Functional Reach Test (FRT) and its modified versions (mFRTs) with the outcomes of Limits of Stability (LoS), and to identify the most appropriate test method to use in postural control assessment.
Methods: Forty-six participants were included in the study. The participants performed FRT and mFRTs: firm ground dominant arm (FRT), firm ground both arms (FRTFB), soft ground dominant arm (FRTSD), soft ground both arms (FRTSB) and firm ground lateral FRTs. LoS was carried out with static posturography. The correlation of FRT and mFRTs with LoS parameters was evaluated as reaching distance and movement time.
Results: A strong positive correlation was found between FRTFB and LoS-I (forward direction) endpoint excursion and maximum excursion ($p<0.001$, $r=0.690$; $p<0.001$, $r=0.637$), respectively. A negative moderate correlation was obtained between the movement time in FRTSD and the movement velocity in LoS-I ($p=0.011$; $r=-0.463$).
Conclusion: We revealed that FRTFB is the most suitable version to be used in postural control measurements. Besides, to evaluate the movement time in postural control, FRTSD may be used when posturography is not applicable.
Keywords: Functional reach, Postural control, Balance assessment, Stability limit.

Alternatif bir postüral kontrol testi: modifiye edilmiş fonksiyonel uzanmanın kararlılık sınırları ile korelasyonu

Amaç: Fonksiyonel Uzanma Testi (FUT) ve modifiye edilmiş versiyonlarının (mFUT) Kararlılık Sınırları (KS) sonuçlarıyla korelasyonunu değerlendirmek ve postüral kontrol değerlendirmesinde kullanılacak en uygun test yöntemini belirlemekti.
Yöntem: Çalışmaya 46 katılımcı dahil edildi. Katılımcılar FUT ve mFUT'lan uyguladılar. Bunlar: Sert zemin dominant kol FUT (SDFUT), Sert zemin çift kol FUT (SÇFUT), yumuşak zemin dominant kol FUT (YDFUT), yumuşak zemin çift kol FUT (YÇFUT) ve sert zemin lateral FUT (sağ-sol). KS testi statik posturografi ile yapıldı. FUT ve mFUT'lerin KS parametreleri ile korelasyonu, ulaşma mesafesi ve hareket süresi parametreleri ile değerlendirildi.
Bulgular: SÇFUT ve KS-I (ileri yön) ulaşılan son nokta ile maksimum son nokta (sırasıyla $p<0,001$, $r=0,690$; $p<0,001$, $r=0,649$) arasında güçlü bir pozitif korelasyon bulundu. YDFUT'deki hareket süresi ile KS-I'deki hareket hızı arasında negatif orta düzeyde bir korelasyon elde edildi ($p=0,011$; $r=-0,463$).
Sonuç: SÇFUT'un postüral kontrol ölçümlerinde kullanılacak en uygun versiyon olduğunu ortaya koyduk. Ayrıca postüral kontrolde hareket süresini değerlendirmek için posturografinin uygulanamadığı durumlarda YDFUT kullanılabilir.
Anahtar kelimeler: Fonksiyonel uzanma, Postüral kontrol, Denge değerlendirmesi, Kararlılık sınırı.

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Static Posturography (SP) is one of the objective tools for evaluating postural control. It is based on the dynamometric platforms that record the fluctuations of the center of pressure (CoP) of individuals. SP consists of 10 sub-tests, including Limits of Stability (LoS). In essence, LoS assesses similar components of balance with the Functional Reach Test (FRT).[1] LoS is defined as the maximum limit that a subject can intentionally move the center of gravity (COG) while maintaining a fixed base of support in the standing position.[1,2] FRT is also defined as the maximum distance that an individual can reach forward beyond arm's length while maintaining a fixed base of support in the standing position. While SP is a quite expensive system that enables the evaluation of postural control effectively, FRT is an easy-to-use, inexpensive, and fast method that does not require extra consumables. Therefore, instead of SP, FRT can be preferred for clinical use which is a simple way of assessing postural control at a standing position.[3] FRT has been used for measuring the biomechanics, postural control, and balance in patients suffering from physical weakness, vestibular dysfunction, and stroke.[4,5] In the literature, there are also many studies demonstrating various modified versions of FRT. However, there is limited information on which standard test (FRT), or its modified versions (mFRTs) reflect the balance skills better.

FRT is designed to assess the anteroposterior stability of an individual by measuring the maximum distance that an individual can reach forward beyond arm's length while maintaining a fixed base of support in the standing position.[6,7] It was proven in adults for accuracy, test-retest reliability, criterion validity, construct validity and predictive validity, and its sensitivity.[8,9]
Various types of mFRTs have been described so far involving sitting balance in individuals with spinal cord injury, two arms FRT as well as lateral side FRT.[10-14] The administration of modified functional reach tests is based on the positional alterations of standard method FRT. In the literature, significant differences were found between the modified and standard FRT results in several studies.[15,16] Although various outcomes have been obtained between the FRT methods, there is no consensus yet in the literature on which test method to prefer in postural control evaluation. In addition, whether FRT can be replaced with LoS is yet unknown. Therefore, the aim of this study was to evaluate the correlation of FRT and mFRTs with the outcomes of LoS.

METHODS

Study design and participants

This is a cross-sectional observational study which was performed following the STROBE recommendations.[17] Asymptomatic individuals of both genders participated in this study. Participants were recruited through direct contacts with those who have applied to the Audiology department of Hacettepe University. The recruitment and data collection occurred between March and July 2018. Our inclusion criteria included as follow: age between 18 and 40 years old; no neurological or orthopedic disorder; no drowsiness and balance disorder; no external or middle ear disorders; a minimum threshold of Snellen 0.7 logMAR. All participants provided written informed consent form prior to participating the study. The study was approved by the local ethics committee of Hacettepe University with approval ID: GO 18/19-33.

Sample size

The sample size was determined using the software G*Power with the following input data: a bivariate normal correlation model, a desired statistical power of 80%, a significance level of 0.05, and an expected correlation of 0.5, which resulted in 30 participants. However, we included 46 participants to obtain more data and to increase the accuracy of our research.

Procedure

All procedures were performed at Hacettepe University, Department of Audiology, Vestibular Laboratory. All participants completed the "Hand Preference Determination Form" for the determination of the dominant arm before the FRT procedure. The participants were informed about each procedure before the tests were applied. All tests were carried out in one session.

Functional Reach Test (FRT): FRT was administered according to the procedure outlined by Duncan et al.[3] By taking into consideration of the height differences in each

participant, ten measuring tapes (150 cm long) were mounted on the wall with 3 cm intervals in the vestibular laboratory. All participants were asked to take off their shoes and stand on white cardboard with predetermined standing lines. According to the test protocol, participants were asked to make a position that third metacarpal joint of the dominant arm with a closed fist and stood upright position with shoulder flexed at 90 degrees at sagittal plane. This was determined as initial position. Participants were then given the command: "Reach forward as far as you can without touching the wall or taking a step forward or lifting your heels up". The final point where participants reached forward was determined as the ending position. (See Figure 1). The distance between the starting and ending position of the 3rd metacarpal joint of fist was measured in centimeter and defined as functional reach.

Table 1. Characteristics of the participants (N=46).

	Mean±SD
Age (years)	23.93±4.72
Height (cm)	169.32±8.43
Weight (kg)	67.22±13.86
Body Mass Index (kg/m2)	22.30±3.32

Modified Versions of the Functional Reach Test (mFRTs): Although various modified versions of FRT were described in the literature, the applied mFRTs in this study were created by researchers to make it possible to investigate the correlation of mFRTs with LoS. Four different mFRTs were explained below (See Figure 1).

a) Firm-ground Both-arms FRT (FRTFB)

This test was carried out on firm ground. Participants were asked to take a position that their tip of the index finger of both hands was together and stood upright position with shoulder flexed at 90 degrees at the sagittal plane. This was determined as initial position. Participants were then given the command: "Reach forward as far as you can without touching the wall or taking a step forward or lifting your heels up". The final point where participants reached forward was determined as the ending position.

b) Soft Ground Dominant Arm FRT (Dominant Arm) (FRTSD)

This test was carried out on the soft ground. Participants were asked to take a position that third metacarpal joint of the dominant arm with a closed fist and stood upright position with shoulder flexed at 90 degrees at sagittal plane. This was determined as initial position. Participants were then given the command: "Reach forward as far as you can without touching the wall or taking a step forward or lifting your heels up". The final point where participants reached forward was determined as the ending position.

c) Soft Ground Both Arm FRT (FRTSB)

This test was carried out on the soft ground. Participants were asked to take a position that their tip of the index finger of both hands was together and stood upright position with the shoulder flexed at 90 degrees at sagittal plane. This was determined as initial position. Participants were then given the command: "Reach forward as far as you can without touching the wall or taking a step forward or lifting your heels up". The final point where participants reached forward was determined as the ending position.

d) Firm-ground Lateral (Right/Left) FRT (FRTRL; FRTLL)

These tests were carried out on firm ground. Participants were asked to take a position that third metacarpal joint of right/left arms with a closed fist and stood upright position with their shoulder flexed at 90 degrees at frontal plane. This was determined as initial position. Participants were then given the command: "Reach lateral (right/left) as far as you can without touching the wall or taking a step lateral side or lifting your heels up". The final point where participants reached lateral(right/left) side was determined as the ending position. These procedures were applied for both right and left arms separately.

All these FRT and mFRTs were repeated three times and the average of the last two tests was recorded. All participants were secured against falling during the tests. The distance between the starting and ending position of the 3rd metacarpal joint in each test was measured in centimeters and recorded. In this study, the foam-pad was used for the modified versions

that require a soft ground. A foam-pad, measuring 45.7×45.7×12.7, with a density of 60kg/cm^3, and 172.4-kilopascal stress force was used.

In addition, the movement time of FRT and mFRTs was manually recorded in all individuals. Movement time was measured by the stopwatch and was applied in each procedure. Time was started simultaneously with the starting command, and it was stopped manually when the movement was completed.

Limits of stability

In our study, LoS was evaluated via Neurocom Balance Master®, which has a fixed force plate of 18"x60" to measure the CoG position, the postural control, and the vertical forces applied to the feet of the patient. Before starting the test, it was ensured that the participants were in an appropriate upright position on the SP force platform. Participants were asked to move their bodies without taking a step or lifting their feet up. They were then requested to place their cursors in one of the eight different square boxes on the computer screen at eyesight. Participants were informed to begin the test with an acoustic signal. The outcomes of endpoint excursion (EPE), maximum excursion (MXE) (%), and movement velocity (degree/second) were recorded. EPE refers to the distance intentionally covered by the subject in his very first attempt toward the target. MXE refers to the amount of distance the subject actually covered or moved his CoG. Movement velocity refers to the average speed at which the COG shifts.[18]

In our study, the correlation of FRT and mFRTs with LoS parameters was evaluated. The test methods involved the forward reach capabilities (FRT, FRTFB, FRTSD, FRTSB), which were correlated with the forward results of the LoS test. The correlation of these forward reach test methods was evaluated with LoS-I which indicates the first direction in the anterior direction. The correlation of the FRTRL method was assessed using LoS-III which indicates the third condition on the lateral direction. The correlation of the FRTLL method was assessed using LoS-VII which indicates the seventh conditions on the lateral direction. In this context, the outcomes of FRT and mFRTs were associated with EPE and MXE in LoS in terms of reaching distance while they were associated with movement velocity in LoS in terms of movement time.

Statistical analysis

Descriptive analyses were expressed in mean (X) and standard deviation (SD) for all variables. Whether the data are distributed as normally were determined by using the Shapiro-Wilk test. All data were normally distributed. Pearson correlation coefficients were used to test the association between FRT and mFRTs and LoS. The correlation coefficient was interpreted as follows: very weak if $0.00 \leq r \leq 0.199$, weak if $0.200 \leq r \leq 0.399$, moderate if $0.400 \leq r \leq 0.599$, strong if $0.600 \leq r \leq 0.799$ and very strong if $0.800 \leq r \leq 1.000$. The significance was set at 0.05. SPSS 26.0 V software (SPSSInc., Chicago, IL) was used for all analyses.

RESULTS

Forty-six adults participated in this study (21 males, 25 females). Characteristics of the participants are presented in Table 1.

Regarding reaching distance, a strong positive correlation was found between FRTFB and LoS-I EPE and MXE ($p<0.001$, r:0.690; $p<0.001$, r:0.637), respectively. (See Figure 2). A moderate positive correlation was observed between FRT, FRTSD, FRTSB and LoS-I EPE and MXE. There was no correlation between FRTRL and LoS-III EPE and MXE ($p>0.05$). No statistically significant correlation was found between FRTLL and LoS-VIII EPE and MXE ($p>0.05$). Regarding movement time, there was a moderate negative correlation between FRTSD and LoS-I movement velocity ($p<0.001$, $r=-0.463$) (See Figure 3); however, there was no correlation between the FRT and LoS movement velocity in other tests ($p>0.05$) Correlation coefficients values for FRT, mFRTs and LoS are shown in Table 2.

DISCUSSION

The aim of this study was to investigate whether any correlation exists between functional reach test with modified versions and the limits of stability parameters. Two main conclusions were reached. First, we found that there was a strong correlation between FRTFB and LoS-I EPE and MXE regarding reaching distance. Second, regarding movement time it was demonstrated that a moderate negative

correlation existed between FRTSD and LoS-I movement velocity. Currently, there is a lacking knowledge as to whether FRT with modified versions would be used instead of FRT. Besides, no consensus has been established in clinical or research based regarding the optimal limits of stability for different applications. Therefore, considering all above, the examination of FRT together with mFRTs was preferred to be correlated with LoS in this study. In addition, LoS was only used based on the idea that they allowed the measurement of the correlation between movement time and reaching distance.

There are several studies comparing various measurements on limits of stability.[19,20] A previous study corroborated that FRT and LoS would not be replaced with each other.[1] The differences between FRT and LoS tests depended probably on the specificity of the task. It was proven that FRT was not an appropriate indicator to differentiate between individuals with and without the risk of falling.[21] While FRT has been reported to be commonly used as a clinical test measuring the LoS,[22] fundamental differences are present between FRT and LoS. Unlike LoS, FRT measures trunk flexibility as well as LoS. In the literature, several studies have recommended correlations between FRT and trunk flexibility.[23,24] For example, Thomas et al.[25] documented that the FRT reflects the flexibility of the trunk rather than movement of the CoG. However, LoS measures the movement of CoG without support from trunk flexibility.

In our study, FRT and mFRTs were performed on firm and soft grounds with the dominant arm and both arms to demonstrate which FRT strategy was more reliable by comparing LoS parameters. We explored that there was a strong correlation between FRTFB and LoS-EPE, MXE. In the literature, Kage et al.[26] investigated whether 1-arm or 2-arms FRT on firm ground better reflects the CoP excursion in elderly people and found that 1- arm functional reach has been found more valid and reflects CoP excursion better. This study is inconsistent with our results. On the other hand, Pradhan et al.[14] performed 1-arm and 2-arms FRT on firm ground in children suffering from balance disorders between the ages of 3 and 9. They concluded that the two-arm functional reach test was more difficult to implement in children with a balance disorder. They also stated that the 2-arm functional reach test was more decisive in the assessment of balance disorder. Although the outputs vary by age groups, we advocate that the two-arm FRT on firm ground can be used for the postural control evaluation as it limits the body rotation

Table 2. Correlation coefficient values between FRTs and the LoS regarding reach distance and movement time.

		Reach Distance						Movement Time		
FRT/LoS		LoS-I EPE	LoS-I MXE	LoS-III EPE	LoS-III MXE	LoS-VII EPE	LoS-VII MXE	LoS-I MVL	LoS-III MVL	LoS-VII MVL
FRT	r	0.480*	0.470*					-0.289		
	p	0.001	0.001					0.051		
FRTFB	r	690*	0.637*					-0.303		
	p	<0.001	<0.001					0.171		
FRTSD	r	0.413*	0.441*					-0.463*		
	p	0.006	0.002					0.001		
FRTSB	r	0.487*	0.415*					-0.268		
	p	0.001	0.004					0.071		
FRTRL	r			0.115	0.069				-0.085	
	p			0.446	0.650				0.575	
FRTLL	r					0.030	0.102			-0.014
	p					0.845	0.500			0.924

*p<0.05. r: Pearson correlation coefficient.
FRT Functional Reach Test; SP, Static Posturography; FRTFB, Firm Ground Both Arms Functional Reach Test; FRTSD, Soft Ground Dominant Arm Functional Reach Test; FRTSB, Soft Ground Both Arm Functional Reach Test; FRTRL, Firm Ground Right Lateral Functional Reach Test ; FRTLL, Firm Ground Left Lateral Functional Reach Test; LoS-I, Limits of Stability Forward; LoS-III, Limits of Stability Right-Lateral; LoS-VII, Limits of Stability Left Lateral; EPE, End-Point Excursion; MXE, Maximum Excursion; MVL, Movement Velocity.

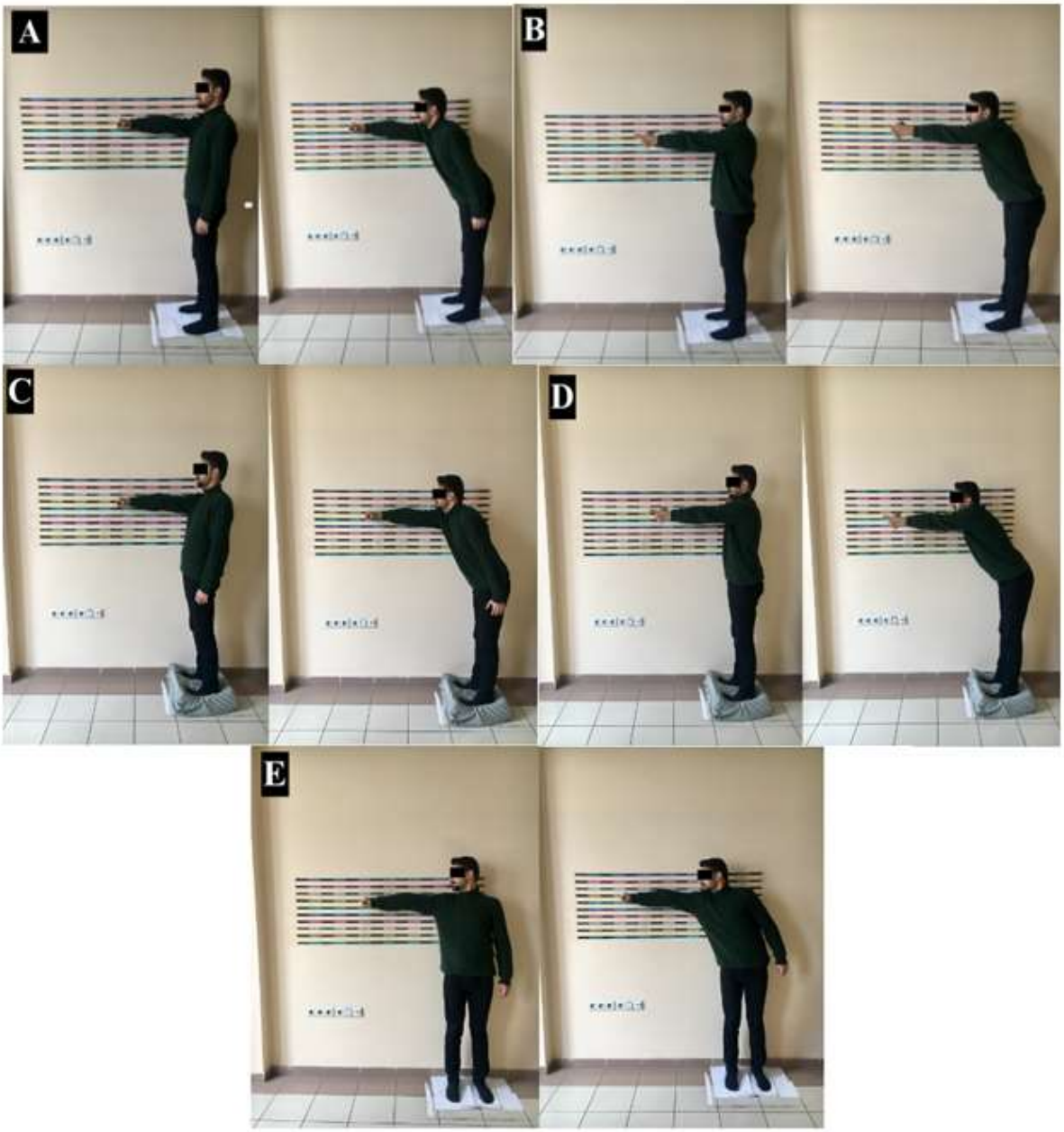

Figure 1. The initial and final position of standard FRT and mFRTs. A) Standard FRT- Firm ground dominant arm- (FRT), B) Firm ground both arms FRT (FRTFB), C) Soft ground dominant arm (FRTSD), D) Soft ground both arms (FRTSB), E) Firm ground lateral (Right) FRT (FRTRL).

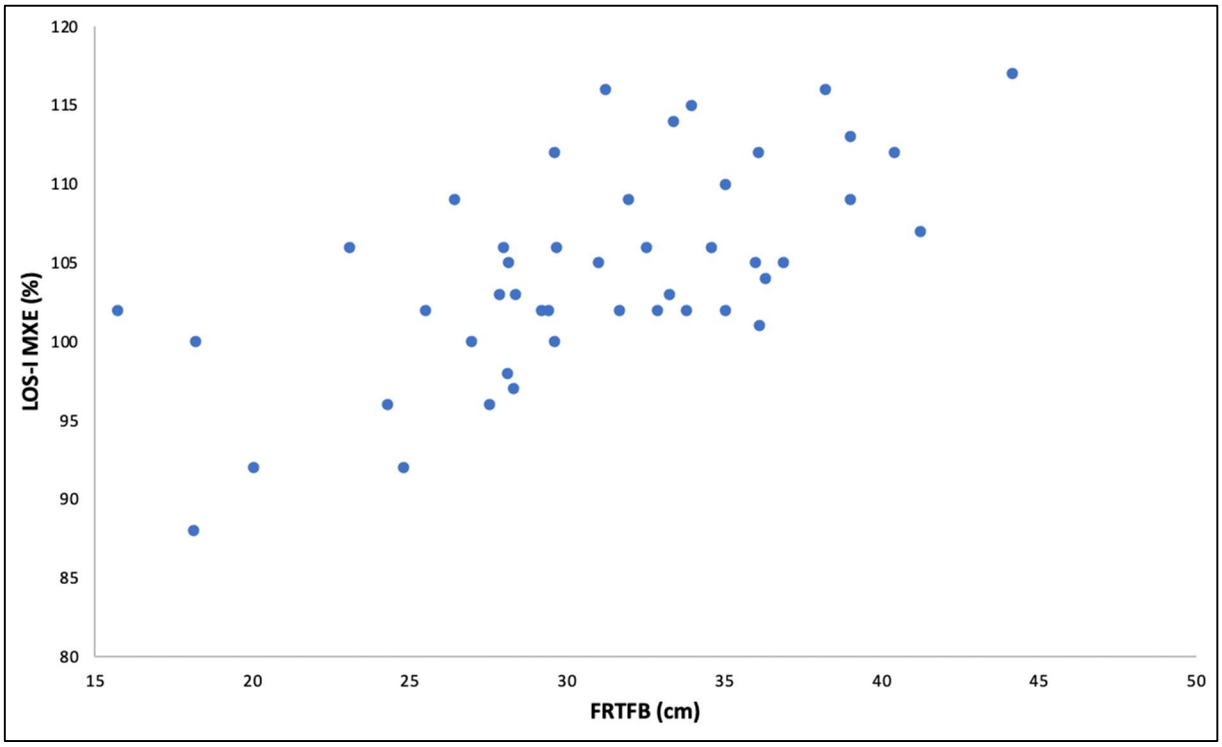

Figure 2. Scatterplot illustrating the association between FRTFB with LoS-I MXE (Pearson correlation test, p=0.001; r: 0.637).

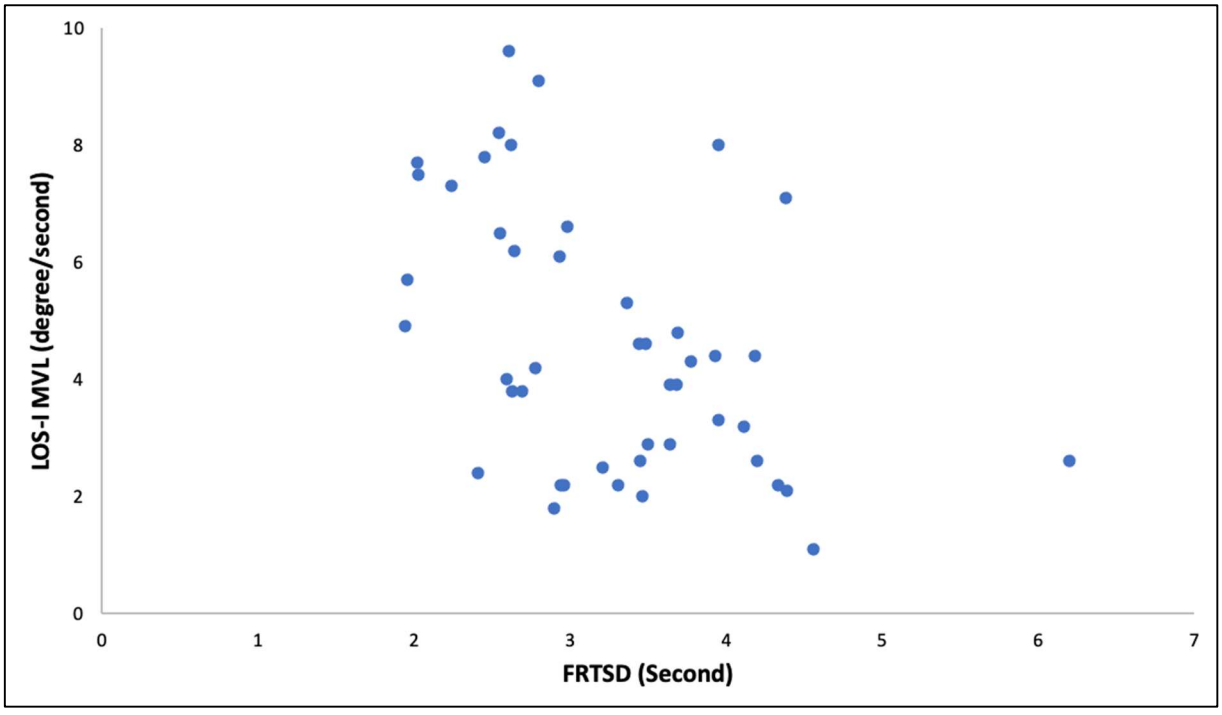

Figure 3. Scatterplot illustrating the association between FRTSD with LoS-I MVL (Pearson correlation test, p=0.001; r: -0.463).

and increases the difficulty of the test. Another result is that a moderate positive correlation was found between FRT and LoS-I EPE and MXE. LoS evaluates the intentional control of the CoG. Walmann[27] reported that there was no statistically significant correlation between the standard FRT method and LoS, proving that the reaching task in FRT was not similar to the bending task in LoS. Wernick-Robinson et al.[28] also indicated that different movement strategies could be used in FRT demonstrating no significant correlation between the relocation of the anterior in LoS and FRT measurement. Consequently, researchers revealed that reaching and bending tasks are different from each other as they do not have a maximum effect on the shifting of the CoG forward during compensatory movement strategies. In our study, the moderate correlation was obtained probably due to the fact that participants performed these tasks differently. We hypothesized that these differences could be attributed to individuals who used the biofeedback mechanism of the CoG during the LoS procedure. As the biofeedback mechanism enabled information for the correction of errors during the movement performance, the participants could activate the biofeedback mechanism by using the movement of the CoG cursor and adjust their actions accordingly.

Movement time was also evaluated manually during FRT and mFRTs. There was a negative correlation between FRTSD movement time and LoS-I movement velocity, while no correlation was found in other methods. In standard FRT, the initial position of the acromion level may show up differences between individuals. It is likely that the location of the 3rd metacarpal joint of fist at the initial position may have forward or backward deviation with the flexion and bending of the body. This individual change of the initial acromion position may affect the reaching distance during FRT procedure.[26] These changes in the reaching distance may spontaneously cause changes in the movement time. Another logical explanation would be the fact that postural limits affect the toleration of biomechanical instability during reaching and bending tasks.[29] Therefore, it is considered that although no correlation was found between standard FRT movement time and LoS movement velocity, there was a moderate correlation between the movement time in FRTSD and LoS movement velocity, which is partly more difficult task than another.

Limitations

This study had two main limitations that may have influenced the interpretation of the results. First, participants performed FRT and mFRTs in only anterior and lateral directions while LoS procedure was carried out eight different directions in SP. Therefore, the correlations of in eight different directions could not be evaluated. Second, the movement time was measured manually during FRT and mFRTs. To be able to obtain more objective results, a gyroscope that perceives the reaction time simultaneously with movement could have been used. Future studies are required to be conducted in order to rule out these limitations by using more sample size.

Conclusion

We revealed that FRTFB could be used in postural control measurements more reliably regarding reaching distance. Besides, to evaluate the movement time in postural control, FRTSD can also be used. In this context, mFRTs can be used to evaluate the patients in clinics when posturography is not available. However, it is important to emphasize that the application of mFRTs using both arms could be difficult in patients with neurological disorders such as stroke, Parkinson's disease, etc. However, considering these situations with obtained results in this study, mFRTs are worth investigating in patients with balance disorders, in different types of sports branches, stroke, Parkinson's disease, and in elderly with fall risk in future studies. Obtaining repetitive results by mFRTs can provide clinicians to assess the postural control in a routine clinical application which is a cost-effective, easy to use, inexpensive and fast method.

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Conflicts of Interest: *None*

Ethical Approval: The protocol of the present study was approved by Hacettepe University Ethics Committee (issue: GO 18/19-33 date: 02.01.2018)

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