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Usefulness, assessment and normative data of the Functional Reach Test in older adults: A systematic review and meta-analysis

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ABSTRACT

Objective: To identify the evidence about the usefulness of the Functional Reach Test to evaluate balance and falls risk; to verify the Functional Reach Test assessment method and other variables that could interfere in its results; and to establish normative data for older adults.
Data sources: Manual and electronic searches (MEDLINE, Embase, Web of Science, LILACS, CINAHL, AgeLine and PsycINFO) were conducted with no language restrictions and published since 1990.
Study selection: Observational studies about the Functional Reach Test in older adults with no specific health condition were selected.
Data extraction: Two independent reviewers extracted data from studies and a third reviewer provided consensus. The studies methodological quality was appraised using the Newcastle-Ottawa Scale. Studies were submitted to critical analysis and meta-analysis.
Results: 40 studies were selected (8 prospective and 32 cross-sectional). 33 studies used the Functional Reach to assess balance and 21 studies the falls risk. The meta-analysis of Functional Reach normative data was 26.6 cm [95%CI: 25.14; 28.06] for community-dwelling older adults (n = 21 studies) and was 15.4 cm [95%CI: 13.47; 17.42] for non-community older adults (n = 5 studies), with statistics differences between settings. Functional Reach Test performance was found to decrease with age. Sex and prospective history of falls did not influence the test results. Methodological quality analysis determined high to low risk of bias of the studies.
Conclusion: This review revealed that the method of assessment and data of the Functional Reach Test varied greatly. Different values should be used for community- and non-community-dwelling older adults.

1. Introduction

The Functional Reach Test (FRT) was created in 1990 by Duncan et al. (1990) to measure the limits of stability of individuals while reaching forward in a standing position. The limits of stability is defined as the maximum distance that the center of mass can be moved safely without changes in the base of support (Alexander, 1994). Limits of stability control is essential to performing activities of daily living safely, especially those that involve reaching for a target or object in different directions (Newton, 2001; Pickerill & Harter, 2011). Postural mechanisms and strategies (anticipatory and compensatory) are used to maintain or recover the limits of stability (Wernick-Robinson, Krebs, & Giorgetti, 1999).

Initially, laboratory tests were used to assess the limits of stability using a force platform to record the center of pressure excursion while individuals leaned in different directions (Murray, Seireg, & Sepic, 1975). The goal of the researchers who created the FRT was to transform the laboratory measurement of the limits of stability into a quick, easy-to-use, and affordable clinical test that requires few materials and is suited to different settings (Duncan et al., 1990). Because of its practicality in the clinical setting, the FRT has been incorporated into other balance evaluations, such as the Berg Balance Scale (Berg et al., 1989) and the Balance Evaluation Systems Test (Horak, Wrisley, & Frank, 2009). The study of FRT development used a sample composed of healthy individuals recruited from the general population (21–87 years old) and provide data by age group and sex (Duncan et al., 1990). Currently, the FRT is applied in different populations and health conditions (Clark et al., 2005; Costarella et al., 2010; Demura & Yamada, 2007; Duncan et al., 1992; Ingemarsson et al., 2000; Jonsson, Henriksson, & Hirschfeld, 2003; Kerr et al., 2010; Mann et al., 1996;

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Newton, 2001; Portnoy et al., 2017). Older adults are one of the populations most often studied and assessed by the FRT because of changes in body balance control (Nolan et al., 2010; Takahashi et al., 2006), decreased limits of stability (Clark et al., 2005), and increased risk of falling (Duncan et al., 1992). In a sample of older adults in the United States between 70 and 87 years old, the mean value for the FRT in men was 33.4 ± 3.9 cm, and, women, 26.5 ± 8.9 cm (Duncan et al., 1990). However, different FRT values have been found in other populations (Costarella et al., 2010; Silveira, Matas, & Perracini, 2006). Among the factors that could explain such divergences are variations in how the FRT is carried out. Over time, researchers have made modifications to the FRT method of assessment, such as extending hands (Gabbard & Cordova, 2013; Lin et al., 2004; Robinovitch & Cronin, 1999), reaching with both arms (Kage et al., 2009), differing the numbers of trials (Duncan et al., 1992; Ingemarsson et al., 2000; Smith, Hembree, & Thompson, 2004), changing the base of support (Lindemann et al., 2003), and using elastic bands (Demura & Yamada, 2007). Other factors that can contribute to differences in performance and normative values for the FRT are: age (Duncan et al., 1990; Silveira et al., 2006; Thapa et al., 1994), body composition variables (height, weight, length of arms and legs) (Isles et al., 2004; Silveira et al., 2006; Thapa et al., 1994), physical factors (reduced flexibility and strength) (Thapa et al., 1994), and psychological factors (fear of falling, demotivation, and depression) (Newton, 1997, 2001).

Even though the FRT was developed to assess dynamic balance when standing while reaching forward, some studies have questioned its utility in assessing risk of falling and limits of stability (Jonsson et al., 2003; Thomas & Lane, 2005; Wallmann, 2001). Wallmann (2001) and Thomas and Lane (2005) have suggested that the FRT is not a suitable measure to discriminate older adults with and without falls. Furthermore, Jonsson et al. (2003) and Wallmann (2001) concluded that the trunk movements while performing the FRT make the reach task different than the limits of stability.

The wide use of the FRT to evaluate older adults and the questions surrounding the test have led to the need for a systematic review about this topic. The objectives of the present systematic review were: 1) to identify evidence of the use of the FRT to assess dynamic balance and risk of falling; 2) to verify the FRT assessment method and other variables (anthropometric, physical) that could change the test results; and 3) to establish normative values for the FRT in older adults with no specific health condition. This information can help create a reference guide about the FRT application, use, and comparison of normative data to be used in clinical practice and future research with older adults.

2. Methods

This systematic review was developed according to the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) (Liberati et al., 2009) and was previously registered on the PROSPERO website register number CRD42017052884.

2.1. Search strategies

Studies relevant to this systematic review were found using both electronic and manual searches. Electronic searches were conducted in the MEDLINE (via PubMed), Embase, Web of Science, LILACS, CINAHL, AgeLine and PsycINFO databases. Manual searches were carried out using ProQuest to identify dissertations and theses on the theme; and searching for publications by the authors who developed the FRT and among the references contained in the articles selected in the electronic search. Three thematic word groups were used to conduct the searches: 1) older adults (age, aged, aged 80 and over, aging, elderly, elderly people, elders, old people, older people, old adults, older adults, older person, senior, seniors), 2) FRT (FR, FRT, Functional Reach, Functional Reach test, Forward Functional Reach, Forward Reach test, Multi-Directional and Reach, Limits of Stability) and 3) research design (epidemiological, case control, observational study, longitudinal, retrospective, prospective, cross sectional, clinical study, correlational study, prognosis, diagnostic accuracy, predictive value, sensitivity and specificity). Within each group, the words were combined using the Boolean operator OR, and interaction among sets using the operator AND (Appendix A). Searches were conducted in October 2016 and were updated in November 2017, without language restrictions. The FRT was created in 1990 (Duncan et al., 1990), therefore only studies published as of this date were included in this review.

2.2. Eligibility criteria

Studies were included if they: 1) were observational studies; 2) had total sample or subgroups 60 years old or older; 3) used samples from any type of setting (community, home care, long-term care, hospitals, and clinics); 4) used FRT as one of the main outcomes; 5) provided descriptions or references to the FRT assessment method; 6) provided quantitative FRT values (central tendency measures); and 7) used the FRT to assess dynamic balance or risk of falling. Studies were excluded if they presented: 1) a focus on a particular medical condition (e.g., dizziness, frailty); 2) biomechanical assessment of the FRT; and 3) FRT assessments with other purposes (e.g., to determine frailty or disability).

2.3. Data selection and extraction

Two independent reviewers selected the studies and extracted the data, while a third reviewer helped reach consensus in case of disagreements. Studies were preselected based on an appraisal of the titles and abstracts. The preselected studies were then read in full to confirm that they met the eligibility criteria. Forms were created for recording information about the type of study, sample characteristics, FRT assessment method, explanatory variables, FRT values, and FRT use to assess balance and/or falls. No secondary outcomes were gathered. Additional data about the FRT (e.g., lateral and posterior) were not considered for the analysis.

2.4. Appraisal of methodological quality

Methodological quality was appraised using the Newcastle-Ottawa Scale (Wells et al., 2001), which provides three versions for each type of observational study design (cohort, case-control, and cross-sectional). Cohort and case-control studies are evaluated based on three dimensions, 1) selection (four items –maximum four points); 2) comparability (one item – maximum two points); and 3) exposure/outcomes (three items – maximum three points). The maximum possible score for this version is nine, and scores equal to or greater than seven are considered high methodological quality (McPheeters et al., 2012). Cross-sectional studies are appraised using an adaptation version (Herzog et al., 2013; Patra et al., 2015), in which the following dimensions are analyzed: 1) selection (three items – three points maximum); 2) comparability (one item – two points maximum); and 3) outcomes (two items – two points maximum). The maximum possible score of this version is seven points, and the higher the score, the higher the methodological quality.

2.5. Study analysis

The content of the selected articles was submitted to descriptive and critical analysis by type of methodology (cross-sectional or prospective cohort). Quantitative analysis was made by meta-analysis with random effects model, assuming the heterogeneity of the studies, with a 95% confidence interval, using the Rstudio® software. One-arm meta-analysis of the normative values was employed, in which all studies (both cross-sectional and longitudinal) that presented FRT mean values and standard deviations (converted into standard error) relative to

community vs. non-community-dwelling older adults were included. For studies with community-dwelling older adults, subgroup analysis and meta-regression were used to explore the impact of sex and age on FRT normative values, respectively. Priority was given to sex-stratified data (which is why some studies appear twice); but in the absence of such data, the analysis included the values presented for both sexes (all participants). Regarding age, preference was given to data from the general sample; however, studies that used the age-range were included more than once in the meta-analysis, with the mean value of the group in years. Meta-analysis for risk of falls was only conducted with prospective studies.

3. Results

After removing duplicates, 2170 studies were found. Seventy-four studies were selected to be read in full. Thirty-four studies did not meet the eligibility criteria (Appendix B); thus, 40 studies were included in the present systematic review (Fig. A1).

3.1. Study characteristics

Eight prospective (Brauer, Burns, & Galley, 2000; Duncan et al., 1992; Fujimoto et al., 2015; Haines et al., 2008; Lin et al., 2004; Morita et al., 2005; Murphy et al., 2003; Sugihara et al., 2006) and 32 cross-sectional (Almeida et al., 2012; Aslan et al., 2008; Balasubramanian, Boyette, & Wludyka, 2015; Billek-Sawhney & Gay, 2005; Campos, Vianna, & Campos, 2013; Cho & Kamen, 1998; Costarella et al., 2010; Duncan et al., 1990; Franzen et al., 1999; Gabbard & Cordova, 2013; Gai et al., 2010; Gómez, 2008; Hageman, Leibowitz, & Blanke, 1995; Hosek & Sackett, 1997; Isles et al., 2004; Jonsson et al., 2003; Lindemann et al., 2003; Lobo, 2012; Newton, 1997, 2001; Nolan et al., 2010; Norris & Medley, 2011; Queiroz, Lira, & Sasaki, 2009; Robinovitch & Cronin, 1999; Rockwood et al., 2000; Silveira et al., 2006; Takahashi et al., 2006; Tantisuwat, Chamonchant, & Boonyong, 2014; Teixeira et al., 2011; Thapa et al., 1994; Uritani et al., 2016; Wallmann, 2001) studies were included in this review. The present review is based on the compilation of FRT data from a total of 7583 older adults. As Newton (2001, 1997) used the same sample, to avoid overlapping data, we considered only data from Newton (2001) to calculate the total number of older adults in the present review.

Community-dwelling older adults were the most common sample (n = 31 studies (Almeida et al., 2012; Balasubramanian et al., 2015; Billek-Sawhney & Gay, 2005; Brauer et al., 2000; Cho & Kamen, 1998; Costarella et al., 2010; Duncan et al., 1990, 1992; Franzen et al., 1999; Fujimoto et al., 2015; Gabbard & Cordova, 2013; Gai et al., 2010; Hageman et al., 1995; Hosek & Sackett, 1997; Isles et al., 2004; Jonsson et al., 2003; Lin et al., 2004; Lindemann et al., 2003; Morita et al., 2005; Murphy et al., 2003; Newton, 1997, 2001; Nolan et al., 2010; Norris & Medley, 2011; Silveira et al., 2006; Sugihara et al., 2006; Takahashi et al., 2006; Tantisuwat et al., 2014; Teixeira et al., 2011; Uritani et al., 2016; Wallmann, 2001)) (Table A1).

Regarding the prospective studies, sample size ranged between 45 (Murphy et al., 2003) and 1373 (Haines et al., 2008) individuals, for a total of 3597; of these, 2 samples consisted only of women (Brauer et al., 2000; Morita et al., 2005), and 1 sample was composed only of men (Duncan et al., 1992). With the exception of Haines et al. (2008) with inpatient geriatric/rehabilitation ward populations, the prospective studies were conducted with community-dwelling older adults (n = 7 studies (Brauer et al., 2000; Duncan et al., 1992; Fujimoto et al., 2015; Lin et al., 2004; Morita et al., 2005; Murphy et al., 2003; Sugihara et al., 2006)). About the cross-sectional studies, the samples ranged between 16 (Cho & Kamen, 1998) and 690 (Rockwood et al., 2000) older adults, for a total of 3986 individuals; of these, 3 study samples were composed only of women (Gai et al., 2010; Hosek & Sackett, 1997; Isles et al., 2004), and one of them with men (Nolan et al., 2010), while one study (Gabbard & Cordova, 2013) did not specify the sex of the participants. Most of the cross-sectional studies were conducted with community-dwelling older adults (n = 24 studies) (Almeida et al., 2012; Balasubramanian et al., 2015; Billek-Sawhney & Gay, 2005; Cho & Kamen, 1998; Costarella et al., 2010; Duncan et al., 1990; Franzen et al., 1999; Gabbard & Cordova, 2013; Gai et al., 2010; Hageman et al., 1995; Hosek & Sackett, 1997; Isles et al., 2004; Jonsson et al., 2003; Lindemann et al., 2003; Newton, 1997, 2001; Nolan et al., 2010; Norris & Medley, 2011; Silveira et al., 2006; Takahashi et al., 2006; Tantisuwat et al., 2014; Teixeira et al., 2011; Uritani et al., 2016; Wallmann, 2001). The other settings used in the cross-sectional studies were: nursing home (n = 1 study (Thapa et al., 1994)), day care (n = 1 study (Gómez, 2008)), physical therapy clinic (n = 1 study (Campos et al., 2013)), hospital (n = 1 study (Queiroz et al., 2009)), combined sample with two different settings (nursing home + day care, n = 1 study (Robinovitch & Cronin, 1999), and nursing home + community, n = 2 study (Aslan et al., 2008; Rockwood et al., 2000)); and separate samples in two different settings (nursing home and community n = 1 study (Lobo, 2012)).

3.2. FRT to assess balance and falls

The FRT was used as a tool to assess dynamic body balance in 28 cross-sectional (Almeida et al., 2012; Aslan et al., 2008; Balasubramanian et al., 2015; Billek-Sawhney & Gay, 2005; Costarella et al., 2010; Duncan et al., 1990; Franzen et al., 1999; Gabbard & Cordova, 2013; Gómez, 2008; Hageman et al., 1995; Hosek & Sackett, 1997; Isles et al., 2004; Jonsson et al., 2003; Lindemann et al., 2003; Lobo, 2012; Newton, 1997, 2001; Nolan et al., 2010; Norris & Medley, 2011; Queiroz et al., 2009; Robinovitch & Cronin, 1999; Rockwood et al., 2000; Silveira et al., 2006; Takahashi et al., 2006; Tantisuwat et al., 2014; Teixeira et al., 2011; Thapa et al., 1994; Uritani et al., 2016) and 5 prospective studies (Duncan et al., 1992; Haines et al., 2008; Lin et al., 2004; Morita et al., 2005; Sugihara et al., 2006). All of the prospective studies (Brauer et al., 2000; Duncan et al., 1992; Fujimoto et al., 2015; Haines et al., 2008; Lin et al., 2004; Morita et al., 2005; Murphy et al., 2003; Sugihara et al., 2006) and 13 cross-sectional studies (Aslan et al., 2008; Balasubramanian et al., 2015; Campos et al., 2013; Cho & Kamen, 1998; Franzen et al., 1999; Gai et al., 2010; Gómez, 2008; Newton, 2001; Norris & Medley, 2011; Queiroz et al., 2009; Takahashi et al., 2006; Teixeira et al., 2011; Wallmann, 2001) adopted the FRT to assess risk of falling.

Data for the FRT varied greatly among studies. FRT values not stratified by sex, age, or setting ranged between 9.9 ± 10.7 cm (Haines et al., 2008) and 38.4 ± 6.0 cm (Uritani et al., 2016) (Table A1). In studies with community-dwelling older adults, in which data was sex-stratified (n = 10 (Almeida et al., 2012; Costarella et al., 2010; Duncan et al., 1990; Gai et al., 2010; Hosek & Sackett, 1997; Isles et al., 2004; Nolan et al., 2010; Silveira et al., 2006; Takahashi et al., 2006; Thapa et al., 1994; Uritani et al., 2016)), the lowest FRT value presented by women was 17.4 ± 6.0 cm (Almeida et al., 2012), and the highest, 35.4 ± 5.2 cm (Isles et al., 2004). Among men, the lowest value was 18.6 ± 6.7 cm (Almeida et al., 2012), and the highest, 38.4 ± 6.0 cm (Uritani et al., 2016). Regarding the youngest age group (60–70 years old), values varied between 17.6 ± 6.1 cm (Almeida et al., 2012) and 36.7 ± 5.7 cm (Hageman et al., 1995), and among the oldest age group (> 80 years old), 15.0 ± 6.1 cm (Sugihara et al., 2006) and 27.3 ± 6.4 cm (Norris & Medley, 2011). FRT values for older adults in non-community settings were lower, ranging between 9.9 ± 10.7 cm (Haines et al., 2008) and 18.2 ± 5.4 cm (Gómez, 2008) (Table A1).

The prospective studies that assessed falls (n = 8 (Brauer et al., 2000; Duncan et al., 1992; Fujimoto et al., 2015; Haines et al., 2008; Lin et al., 2004; Morita et al., 2005; Murphy et al., 2003; Sugihara et al., 2006)) using the FRT, had a follow-up period between 3 (Sugihara et al., 2006) and 14 (Murphy et al., 2003) months. FRT values for older adults who had fallen in the follow-up period ranged between 15.1 ± 8.5 cm (Lin et al., 2004) and 35.8 ± 7.3 cm (Fujimoto et al.,

Table A1
Characteristics of the observational studies included in the systematic review regarding the Forward Functional Reach Test.

Study	Sample and Setting	Functional Reach Test values (cm) for Balance and for Falls	
CROSS-SECTIONAL STUDIES			
Duncan et al. (1990)	Community-dwelling n= 34 (n= 14/41.2% ♀; n= 20/58.8% ♂) *subgroup analysis: 70-87 yrs	Yardstick FRT: ♂= 33.4±3.9cm ♀= 26.5±8.9 cm	Electronic FRT: ♂= 30.7±4.9cm ♀= 28.6±5.2 cm
Hageman et al. (1995)	Community-dwelling n= 24 (n= 12/50% ♀; n= 12/50% ♂), 65.3±3.9 yrs	TOTAL= 36.7±5.7cm	*FRT data divided by the individual's height to normalize the scores.
Hosek and Sackett (1997)	Community-dwelling n= 46 (100% ♀), 65- 94 yrs	TOTAL ♀= 22.9±6.8 cm	Age: 65-75 yrs= 24.4±6.4 cm 76-85 yrs= 23.7±7.0 cm > 86 yrs= 17.9 ±5.8 cm
Jonsson et al. (2003)	Community-dwelling n= 27 (n= 18/66.6% ♀; n= 9/33.3% ♂), 71.3±4.0 yrs	TOTAL= 29.4±5.4 cm	FRT experimental (displacement of the finger marker): 27.9±5.6 cm
†Lindemann et al. (2003)	Community-dwelling n= 67 (both sexes)	Age: 60-69 yrs (n=20)= 49cm 70-79 yrs (n=24)= 51cm 80-89 yrs (n-23)= 43cm	*data in median adjusted to demi-span
Isles et al. (2004)	Community-dwelling n= 181 (100% ♀)	Age ♀: 60-69 yrs (n= 90)= 36.8±0.5cm 70-79 yrs (n=91)= 34.1± 0.5cm	
Billek-Sawhney, and Gay (2005)	Community-dwelling n= 89 (n= 70/78.7% ♀; n= 19/21.3% ♂) 84.1 yrs (65-99 yrs)	Mean of 3 trials= 17.7±7.8 cm	First trial= 17.2±8.3 cm Second trial= 17.7±8.6 cm Mean of 2 trials= 17.5±7.8 cm
Silveira et al. (2006)	Community-dwelling n= 33 (n=17/51.5% ♀/ n=16/48.5% ♂) *subgroup analysis: 70-87 yrs	Sex: ♀= 27.1 ±2.8cm ♂ = 29.7 ±2.8cm	
Takahashi et al. (2006)	Community-dwelling n= 383 (n=234/61% ♀; n=149 /39% ♂), 78.6±5.9 yrs	TOTAL= 24.9±9.3 cm Sex: ♀= 24.5±9.0 cm ♂= 25.5±9.8 cm	**Non-significant association with fall history**
Costarella et al. (2010)	Community-dwelling n=35 (n= 11 /31% ♀; n= 19/69% ♂)	Age: 65 -74 yrs (n= 19): 69.2±3.3 yrs TOTAL: = 23.5±4.8 cm ♀= 24.0±4.4 cm ♂= 25.7±3.8 cm	Age: ≥ 75 yrs (n= 16) 78.9± 3.2 yrs TOTAL: 21.4±6.0 cm ♀= 18.5±6.0 cm ♂= 22.8±6.2 cm
Nolan et al. (2010)	Community-dwelling n= 43 (100% ♂)	Age: 60-69 yrs ♂ (n= 22) FRT- Left arm= 33.9±6.0 cm FRT- Right arm= 33.3±5.9 cm	Age: 70-79 yrs ♂: (n =21) FRT- Left arm= 29.5±6.5 cm FRT- Right arm= 28.7±6.5 cm
Norris and Medley (2011)	Community-dwelling n= 78 (n= 57/73% ♀; n= 21/27% ♂), 81.7±5.9 yrs *subgroup analysis: age 70-89 yrs	TOTAL= 27.3±6.4 cm	Falls risk - No risk FRT≥ 25.4 cm: n= 48 (62%) - Low risk FRT ≥15.2 cm < 25.4 cm: n= 30 (38%) **Significant association with fall history**
Almeida et al. (2012)	Community-dwelling n= 267 (n=205/77% ♀; n= 62/ 23% ♂), 70.2±7.3 yrs *n=227 for FRT analysis	TOTAL: 17.6±6.1cm Age: 60 - 69 yrs= 18.6±6.6cm ≥ 70 yrs= 16.5±5.4cm	Sex: ♀= 17.4±6.0cm ♂= 18.6±6.7cm
Gabbard and Cordova (2013)	Community-dwelling n= 33, 66±6.7 yrs *no mention of sample sex	TOTAL= 35.9 cm	
Tantisuwat et al. (2014)	Community-dwelling n= 60 (both sexes) subgroups: 60-69 yrs (64.1±2.9 yrs): n= 30 70-79 yrs (74.0±2.9 yrs): n= 30	Age: 60-69 yrs (n= 30)= 22.8±4.7cm 70-79 yrs (n=30)= 24.5±7.3cm	
Uritani et al. (2016)	Community-dwelling n= 665 (n= 477/71.7% ♀; n= 188/28.3% ♂) 67.2±4.5 yrs	TOTAL= 35.4 ± 5.2cm ♀ 38.4 ± 6.0 cm ♂	Age: 60 - 69 yrs (n= 440) ♀= 36.0 ± 5.1 cm ♂= 38.4 ± 5.4 cm 70 - 79 yrs (n= 225): ♀= 33.9 ± 4.9 cm

(*continued on next page*)

Table A1 (*continued*)

			♂= 38.3 ± 6.8 cm
Newton (1997)	Community-dwelling n= 251 (n= 199/79% ♀; n= 53/21% ♂), 74.3± 7.7 yrs *same sample as Newton, 2001 [3]	TOTAL= 22.6±8.4cm	
Newton (2001)	Community-dwelling n= 254 (n= 199/78.5% ♀; n= 55/21.5% ♂) 74.1±7.9 yrs	TOTAL= 22.6± 8.4 cm	Falls risk (last 6 months): Non-fallers (n= 198)= 23±8.1 cm Fallers ≥1 fall (n= 56)= 21.3±10.3 cm **Significant association with fall history**
Cho and Kamen (1998)	Community-dwelling n= 16 (n= 12/75% ♀; n= 4/25% ♂)	No value for total FRT	Falls risk (last 12 months) Non-fallers (n= 8, 72.6 yrs)= 25.8 cm Fallers ≥2 fall (n= 8, 76.3 yrs)= 26.5 cm **Non-significant association with fall history**
Franzen et al. (1999)	Community-dwelling n= 52 (n= 39/75% ♀; n= 13/25% ♂), 79.5±6.8 yrs	TOTAL= 21.9±7.8 cm	Falls risk (last 6 months) Non-fallers (n= 35): 65-74 years: 24.5±6.9 cm 75-84 years: 20.8±7.7 cm ≥85years: 17.7±4.9 cm Fallers (n=17): 65-74 years: 23.3±11.2 cm 75-84 years: 26.7±7.3 cm ≥85 years: 15.1±7.3 cm **Non- significant association with fall history**
††Wallmann (2001)	Community-dwelling n= 25 (=18/72% ♀; n= 7/28% ♂)	No value for total FRT	Falls risk (last 12 months) Non-fallers (n=15, 74.9±8.6 yrs): 27.2±5.7 cm Fallers ≥1 fall (n= 10, 72.7±9.2 yrs): 26.4±11.4 cm **Non- significant association with fall history**
Gai et al. (2010)	Community-dwelling n= 83 (100% ♀)	No value for total FRT	♀ Falls risk (last year) Non-fallers (n= 40, 68.7 yrs): 23.5±5.0cm Fallers ≥1 fall (n= 43, 70.2 yrs): 20.7 ± 6.0cm
			Significant association with fall history Functional Reach < 17cm increase the risk for falls
Teixeira et al. (2011)	Community-dwelling n=50 (n= 43/86% ♀; n= 7/14% ♂), 69.9±5.8 yrs	FRT >25cm: n= 19 (38%) FRT 15-25cm: n= 28 (56%) FRT <15cm: n= 3 (6%)	Falls risk (last 6 months) Non-fallers (n= 38): 23.1±6.5cm Fallers (n= 12): 26.5±5.4cm **Non- significant association with fall history**
Balasubramanian et al. (2015)	Community-dwelling n= 39 (n= 26/ 66.7% ♀; n= 13/ 33.3% ♂) 73.3±6.9 yrs	TOTAL: 27.9±5.4cm	Falls risk (last year) Non-fallers (n=15): 28.1±7.1cm Fallers ≥1 fall (n=14): 27.9±3.8cm Recurrent fallers ≥2 falls (n=14): 28.0±4.3cm **Non- significant association with fall history**
Thapa et al. (1994)	Nursing Homes n= 303 (n= 218/72% ♀; n= 85/28% ♂), 81.0±7.5 yrs *n=246 able to perform the FRT	TOTAL= 17.1±6.7cm Sex: ♀= 16.6cm ♂= 15.4cm	Age: <75 yrs= 17.9cm 75-85 yrs= 15.5cm >85 yrs= 14.7 cm
Lobo (2012)	Nursing Home n= 49 (n= 36/73.5% ♀; n=13/26.5% ♂), 78.3 yrs Community-dwelling n= 63 (n=53/84.1% ♀; n= 10/15.8% ♂), 78.7 yrs	Nursing Home: ♀= 14.2±3.1 cm ♂= 17.5±6.7 cm	Community-dwelling: ♀= 19.1±5.7 cm ♂= 25.5±5.4 cm
Rockwood et al. (2000)	Community-dwelling + Nursing Homes 78.1 yrs (69-104 yrs) both sexes *subgroup analysis: n= 690 Cognitively Intact: n=843 n=119 + 34 (physically unable to complete the FRT + refused to perform the test)	TOTAL= 29.0 (23-34) cm *Median (Interquartile Range)	
Aslan et al. (2008)	Community-dwelling + Rest Homes n= 115 (n= 50/43.5% ♀; n= 65/56.5% ♂) 69.1±3.8 yrs *subgroup analysis: age 65-75 yrs	TOTAL= 17.8±7.0 cm Sex: ♀= 16.2±6.8 cm ♂= 19.0±7.0 cm	Falls risk (last 12 months): Non-fallers (n= 86): 18.8±6.5 cm Fallers (n=29): 14.7±7.6 cm **Significant association with fall history**

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Robinovitch and Cronin (1999)	Nursing Homes + Day care n= 46 (n= 23/50% ♀; n= 23/50% ♂), 79±6 yrs	TOTAL= 14.4±8.0 cm	
Gómez (2008)	Day Care n= 38 (n= 25/65.8% ♀; n= 13/34.2% ♂), 81.5±5.4 yrs	TOTAL: 18.2±5.4 cm	Falls risk (last year) - No risk FRT >20 cm (n=13/ 34.2%) Non-fallers: n= 8 (61.5%) Fallers: n= 5 (38.4%) - Risk FRT <20 cm (n=25/ 65.8%) Non-fallers: n=12 (48.0%) Fallers: n=13 (52.0%)
†††Queiroz et al. (2009)	Hospital n= 40 (n= 17/42.5% ♀; n= 23/57.5% ♂), 69.6 yrs	No value for total FRT	Falls risk (last 6 months) - Low risk FRT >24.5 cm (n=24): 31.4 cm - Moderate risk FRT 15.2-25.4 cm (n=10): 21.8 cm - High risk FRT <15.2 cm (n= 6): 12.1 cm Non-fallers: n=28 (70%) Fallers (≥1 fall): n=12 (30%)
Campos et al. (2013)	Physiotherapy and Geriatric outpatients n= 155 (n=131/84% ♀; n= 24/16% ♂), 70.6±7.5 yrs	No value for total FRT	Falls risk (last year) Non-Fallers (n= 90): 24.2±7.1cm Fallers ≥1 fall (n= 60): 25.0 ±7.3cm **Non- significant association with fall history**
PROSPECTIVE COHORT STUDIES			
Duncan et al. (1992)	Community-dwelling n= 217 (100% ♂), 70-104 yrs	♂ FRT ≥ 25.4 cm: n= 119 (57.7%) FRT > 15.2 cm < 25.4 cm: n= 47 (22.8%) FRT ≤ 15.2 cm: n= 16 (7.7%) Unable to reach: n= 24 (11.6%)	♂Falls risk (6 months follow-up) Non-fallers (n= 161, 74.14±4.7 yrs): 25.9±10.9cm Fallers ≥1 falls (n= 56, 77.4±7.3 yrs): 19.8±11.9cm Recurrent non-fallers 0 or 1 fall (n= 191, 74.5±5.26 yrs): 25.3±10.9cm Recurrent fallers ≥2 falls (n= 26, 78.8±7.5 yrs): 16.3±13.4cm **Significant association:**
			Worse FRT for recurrent fallers vs recurrent non-fallers; and for fallers vs non-fallers **Subjects with impaired reach are at higher risks for recurrent falls (≥2 falls):** **Unable to reach: OR= 8.09/ OR adjusted= 8.07** **FRT ≤ 15.2 cm: OR= 4.03/ OR adjusted= 4.02** **FRT > 15.2 cm < 25.4 cm: OR = 2.0; OR adjusted= 2.0** **FRT ≥ 25.4 cm: Reference** *** Non-significant association between FRT and fallers (≥1 falls)**
Brauer et al. (2000)	Community-dwelling n= 100 (100% ♀) 71±5 yrs	No value for total FRT	♀Falls risk (6-month follow-up) Non-fallers (n= 65, 72.3±0.6 yrs): 29.6± 0.8cm Fallers ≥1 fall (n= 35, 74.1±1.1 yrs): 29.1±1.3cm Frequent Fallers ≥2 falls (n=16, 74.3±1.8 yrs): 29.3±2.2cm Recurrent Fallers at least 1 fall in the past (n=19, 75.1± 1.3 yrs): 29.3±1.6cm **Non- significant association with falls**
Murphy et al. (2003)	Community-dwelling n= 50 (n= 37/74% ♀; n= 13/26% ♂), 72.3±8.6 yrs *analysis: n=45 (5 subjects were considered accidental fallers and were excluded from the analysis).	No value for total FRT	Falls risk (14 months follow-up) Non-fallers (n=34, 71.4 ± 7.5 yrs): 27.4±7.1 cm Fallers ≥1 fall (n=11, 79.6± 6.6 yrs): 17.8±6.4 cm Risk FRT ≤ 20 cm: Sensitivity= 73% (8/11) Specificity= 88% (30/34) **Significant association with falls** **Significant correlation with falls (*r*=-0.52)**
Lin et al. (2004)	Community-dwelling n= 1200 (n= 491/40% ♀; n= 709/59% ♂), 73.4 yrs	TOTAL= 14.8cm 65-74 yrs= 15.8±8.1cm >75 yrs= 12.6±8.8cm	Falls risk (past year) Non-fallers (n= 1073): 11.5±7.7 cm Fallers (n= 127)= 15.1±8.5 cm

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Table A1 (*continued*)

			Significant discriminant ability for falls in the past year (AUC= 0.623) Falls (12 months follow-up) **Non-Significant association with falls.**
Morita et al. (2005)	Community-dwelling n= 402 (100% ♀), 69.0±5.8 yrs	TOTAL ♀= 23.5±6.7cm	♀ Falls risk (12 month follow-up) Non-fallers (n= 317, 68.8±5.6 yrs)= 23.7±6.2cm Fallers ≥1 fall (n= 85, 70±6.4 yrs)= 23.1±8.1cm **Non- significant association with falls**
††† Sugihara et al. (2006)	Community-dwelling n= 88 (n= 66/72.5% ♀; n= 25/27.5% ♂), 80.6±6.9 yrs	TOTAL= 15.0±6.1 cm	Falls risk (3 months follow-up) Non-fallers: n=67 (76%) Fallers ≥1 fall: n=21 (24%) FRT cut-off for fall risk< 14.5 cm Sensitivity= 68.2% Discriminant= 78.8% **Significant association with falls**
Fujimoto et al. (2015)	Community-dwelling n= 174 (n= 133/76.4% ♀; n=41/23.6% ♂) 75.8±5.7 yrs	No value for total FRT	Falls risk Baseline: Non-fallers (n= 141, 75.3 ± 5.6 yrs): 32.4±7.0cm Fallers ≥1 fall (n= 33, 77.6 ± 5.4 yrs): 29.7±7.1cm Follow-up (12 months follow-up): Non-fallers (n= 130, 75.1 ± 5.5 yrs): 32.0 ±7.0cm Fallers ≥1 fall (n= 11, 77.6 ± 6.5 yrs): 35.8 ± 7.3 cm **Non- significant association with falls history (baseline) and at follow-up period**
Haines et al. (2008)	Inpatient geriatric and Rehabilitation wards n= 1373 (n= 694/50.5% ♀; n= 679/49.45% ♂) Development set: 74.4±13.9 yrs Validation set: 75.6±13.5 yrs	Development set= 9.9± 10.7cm Validation set= 10.3±11.1cm	Falls risk (time: hospital falls recorded) FRT cut-off falls <4 cm (high risk) for incidence rate FRT cut-off falls < 14 cm (high risk) for event rate **Poor predictive accuracy when the optimal cut-off was applied.**
			Falls in the previous 6 months: Development set: n =311 (52%) Validation set: n= 300 (53%) Falls during rehabilitation: Development set: n= 124 (21%) Validation set: n=89 (16%)

FRT = Functional Reach Test.
† Authors were contact to provide Functional Reach data in mean and standard deviation. The mean of the original data is not available.
†† The author was contacted and provided Functional Reach data by mean and standard deviation, number of fallers and non-fallers.
††† The authors did not respond the email contact asking for data.
Gray cell: Studies that did not have values for total FRT.
Dark gray cell: Studies that evaluated the falls risk based on the FRT.

2015), while values for older adults who had not fallen ranged between 11.5 ± 7.7 cm (Lin et al., 2004) and 32.0 ± 0.7 cm (Fujimoto et al., 2015). In cross-sectional studies that assessed history of falls (n = 13 (Aslan et al., 2008; Balasubramanian et al., 2015; Campos et al., 2013; Cho & Kamen, 1998; Franzen et al., 1999; Gai et al., 2010; Gómez, 2008; Newton, 2001; Norris & Medley, 2011; Queiroz et al., 2009; Takahashi et al., 2006; Teixeira et al., 2011; Wallmann, 2001)), retrospective follow-up period ranged between 6 (Franzen et al., 1999; Newton, 2001; Queiroz et al., 2009; Teixeira et al., 2011) and 12 months (Balasubramanian et al., 2015; Campos et al., 2013; Cho & Kamen, 1998; Gai et al., 2010; Gómez, 2008; Wallmann, 2001). The lowest and highest FRT values, for older adults who had fallen varied between 14.7 ± 7.6 cm (Aslan et al., 2008) and 27.9 ± 3.8 cm (Balasubramanian et al., 2015), and among those who had not fallen, 17.7 ± 4.9 cm (Franzen et al., 1999) and 28.1 ± 7.1 cm (Balasubramanian et al., 2015).

Among the 8 prospective studies (Brauer et al., 2000; Duncan et al., 1992; Fujimoto et al., 2015; Haines et al., 2008; Lin et al., 2004; Morita et al., 2005; Murphy et al., 2003; Sugihara et al., 2006) that assessed the FRT as a measure to predict falls, only 2 studies (Murphy et al., 2003; Sugihara et al., 2006) identified an association with the test, and one study (Haines et al., 2008) demonstrated poor predictive precision when the FRT cutoff point was set at < 14 cm. Of the 11 cross-sectional studies (Aslan et al., 2008; Balasubramanian et al., 2015; Campos et al., 2013; Cho & Kamen, 1998; Franzen et al., 1999; Gai et al., 2010; Newton, 2001; Norris & Medley, 2011; Takahashi et al., 2006; Teixeira et al., 2011; Wallmann, 2001) that assessed the association between falls and the FRT, only two (Gai et al., 2010; Newton, 2001) found such an association (Table A1).

3.3. Description of FRT assessment method

The FRT assessment method varied greatly among studies (Table A2). Only 2 studies (Billek-Sawhney & Gay, 2005; Duncan et al., 1992) followed the original FRT description (Duncan et al., 1990). Twenty-five studies (Almeida et al., 2012; Aslan et al., 2008; Billek-Sawhney & Gay, 2005; Brauer et al., 2000; Cho & Kamen, 1998; Franzen et al., 1999; Fujimoto et al., 2015; Gabbard & Cordova, 2013; Gai et al., 2010; Hageman et al., 1995; Haines et al., 2008; Isles et al., 2004; Jonsson et al., 2003; Lindemann et al., 2003; Murphy et al., 2003; Newton, 1997; Queiroz et al., 2009; Robinovitch & Cronin, 1999; Silveira et al., 2006; Sugihara et al., 2006; Takahashi et al., 2006; Teixeira et al., 2011; Thapa et al., 1994; Uritani et al., 2016; Wallmann, 2001) used the original study (Duncan et al., 1990) as a reference to support the assessment description of the FRT, 3 studies (Balasubramanian et al., 2015, Nolan et al., 2010, Tantisuwat et al., 2014) used other references, and 11 studies (Campos et al., 2013, Costarella et al., 2010, Duncan et al. 1992, Gómez, 2008, Hosek and Sackett, 1997, Lin et al., 2004, Lobo, 2012; Morita et al., 2005, Newton, 2001, Norris and Medley, 2011, Rockwood et al., 2000) did not cite any references. Six studies (Balasubramanian et al., 2015, Brauer et al., 2000, Gai et al., 2010, Newton, 1997, Nolan et al., 2010, Queiroz et al., 2009) cited references

Table A2
Description of the Forward Functional Reach Test method of assessment in the studies included in the systematic review.

ORIGINAL STUDY **Duncan et al. (1990)**	"Functional reach was measured using the simple clinical apparatus consisting of a leveled "yardstick" secured to the wall at right acromion height. Neither shoes nor socks were worn. Individuals were asked to make a fist and extend their arm forward, and the placement of the end of the third metacarpal along the yardstick was recorded. Subjects were then asked to reach as far forward as they could without losing their balance or taking a step and the placement of the end of the third metacarpal was again recorded. The upper extremity was not allowed to contact the wall during this maneuver. If subjects touched the wall or took a step during testing, the trials were repeated. No attempt was made to control the subjects' methods of reach. Each subject was given two practice trials and three test trials. Functional reach was defined as the mean difference between positions 1 and 2 over three trials."			
	fisted hand right upper limb (one arm)	comfortable BS fixed BS barefoot	2 practice trials 3 tests trials mean over 3 trials	Reference: Duncan PW, Weiner DK, Chandler J, Studenski S. Functional reach: a new clinical measure of balance. Journal of Gerontology. 1990;45:M192-7.
CROSS-SECTIONAL STUDIES				
Study	**Hand Position**	**Base of support**	**Number of attempts**	**Reference**
Hageman et al. (1995)	hand and arm extended (one arm)	fixed BS	5 trials mean over the last 3 trials data normalize by individual's height	Original
Hosek and Sackett (1997)	fisted hand dominant upper limb (one arm)	fixed BS	2 practice trials 3 tests trials mean over 3 trials	-
Jonsson et al. (2003)	left upper limb hand horizontally	fixed BS barefoot	several practice trials 5 tests trials	Original
Lindemann et al. (2003)	-	open stance	2 tests trials best performance	Original
Isles et al. (2004)	hand and fingers extended (one arm)	comfortable BS fixed BS barefoot	3 tests trials mean over 3 trials	Original
Billek-Sawhney, and Gay (2005)	fisted hand dominant upper limb (one arm)	comfortable BS fixed BS	one practice trial 3 tests trials mean over 3 trials	Original + Duncan PW, Studenski S, Chandler J, et al. Functional reach: predictive validity in a sample of elderly male veterans. Journal of Gerontology. 1992;47(3):M93–8.
Silveira et al. (2006)	fisted hand (one hand)	comfortable BS fixed BS barefoot	3 tests trials mean over 3 trials	Original
Takahashi et al. (2006)	-	fixed BS	-	Original + Weiner, D.K., Duncan, P.W., Chandler, J., Studenski, S.A. Functional reach: a marker of physical frailty. Journal of the American Geriatrics Society. 1992; 40: 203-7. + Jonsson, E., Henriksson, M., Hirschfeld, H. Does the functional reach test reflect stability limits in elderly people? Journal of Rehabilitation Medicine. 2003; 35: 26–30.
Costarella et al. (2010)	fisted hand (one hand)	fixed BS barefoot	3 tests trials mean over 3 trials	-
Nolan et al. (2010)	-	-	-	Isles RC, Choy NL, Steer M, Nitz JC. Normal values of balance tests in women aged 20–80. Journal of the American Geriatrics Society. 2004;52:1367-72.
Norris and Medley (2011)	fisted hand dominant upper limb (one arm)	fixed BS	2 practice trials 3 tests trials mean over 3 trials	-
Almeida et al. (2012)	hand and fingers extended (one arm)	barefoot	3 tests trials best performance	Original
Gabbard and Cordova (2013)	hand and fingers extended (one arm)	comfortable BS barefoot	3 tests trials best performance	Original
Tantisuwat et al. (2014)	one arm	barefoot	3 trials	Newton RA. Validity of the multi-directional reach test: a practical measure for limits of

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				stability in older adults. The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences. 2001, 56: M248–52.
Uritani et al. (2016)	-	comfortable BS	-	Original
Newton (1997)	-	-	-	Original + Weiner DK, Duncan PW, Chandler J, Studenski S. Functional reach: a marker of physical frailty. Journal of the American Geriatrics Society. 1992;40:203-7.
Newton (2001)	-	-	2 tests trials	-
Cho and Kamen (1998)	fisted hand (one arm)	-	3 trials	Original
Franzen et al. (1999)	fisted hand dominant upper limb (one arm)	-	3 trials	Original
Wallmann (2001)	fisted hand dominant upper limb (one arm)	fixed BS with socks	2 practice trials 3 tests trials mean over 3 trials	Original
Gai et al. (2010)	-	-	-	Original
Teixeira et al. (2011)	one arm	fixed BS barefoot	3 tests trials mean over 3 trials	Original
Balasubramanian et al. (2015)	-	-	-	Duncan PW, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. Journal of Gerontology.1992; 47: 93-8.
Thapa et al. (1994)	-	fixed BS	3 tests trials mean (discarded trials with 2.5 SD from the mean)	Original
Lobo (2012)	-	fixed BS	-	-
Rockwood et al. (2000)	-	-	2 practice trials 3 tests trials best performance	-
Aslan et al. (2008)	fisted hand (one hand)	comfortable BS fixed BS	3 tests trials mean over 3 trials	Original + Isles RC, Choy NL, Steer M, Nitz JC. Normal values of balance tests in women aged 20–80. Journal of the American Geriatrics Society. 2004;52:1367-72.
Robinovitch and Cronin (1999)	hand and fingers extended left upper limb (one arm)	feet shoulder-width apart barefoot	3 tests trials mean over 3 trials	Original + Duncan PW, Studenski S, Chandler J, et al. Functional reach: predictive validity in a sample of elderly male veterans. Journal of Gerontology. 1992;47:93–8.
Gómez (2008)	-	fixed BS	1 trial	-
Queiroz et al. (2009)	-	-	-	Original
Campos et al. (2013)	-	-	3 tests trials mean over 3 trials	-
PROSPECTIVE COHORT STUDIES				
Duncan et al. (1992)	fisted hand dominant upper limb (one arm)	comfortable BS fixed BS	5 tests trials mean over the last 3 trials	-
Brauer et al. (2000)	-	-	-	Original
Murphy et al. (2003)	-	-	2 tests trials mean over 2 trials	Original
Lin et al. (2004)	hand and fingers extended (one arm)	-	2 tests trials mean over 2 trials	-
Morita et al. (2005)	fisted hand (one arm)	-	-	-
Sugihara et al. (2006)	hand and fingers extended right upper limb (one arm)	-	-	Original + Duncan PW, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. Journal of Gerontology.1992; 47: 93-8

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Fujimoto et al. (2015)	hand and fingers extended (one arm)	-	-	Original + Duncan PW, Studenski S, Chandler J, Prescott B. Functional reach: predictive validity in a sample of elderly male veterans. Journal of Gerontology.1992; 47: 93-8.
Haines et al. (2008)	-	-	1 test trial	Original + Duncan PW, Studenski S, Chandler J, et al. Functional reach: predictive validity in a sample of elderly male veterans. Journal of Gerontology. 1992;47:93-8. + Billek-Sawhney B, Gay J. The Functional Reach Test: are three trials necessary? Topics in Geriatric Rehabilitation. 2005;21:144-8.

BS: Base of Support; SD: Standard Deviation.
Gray cell: followed the description of the original format.
Dark gray cell: did not follow the description of the original format.
- : not evaluated/ no reference.

when presenting the FRT but did not describe how the test was administered.

The main changes made to the FRT were the use of extended hand (n = 8 studies (Almeida et al., 2012; Fujimoto et al., 2015; Gabbard & Cordova, 2013; Hageman et al., 1995; Isles et al., 2004; Lin et al., 2004; Robinovitch & Cronin, 1999; Sugihara et al., 2006)) and the number of trials (n = 21 studies (Almeida et al., 2012; Aslan et al., 2008; Campos et al., 2013; Cho & Kamen, 1998; Costarella et al., 2010; Franzen et al., 1999; Gabbard & Cordova, 2013; Gómez, 2008; Haines et al., 2008; Isles et al., 2004; Jonsson et al., 2003; Lin et al., 2004; Lindemann et al., 2003; Murphy et al., 2003; Newton, 2001; Robinovitch & Cronin, 1999; Rockwood et al., 2000; Silveira et al., 2006; Tantisuwat et al., 2014; Teixeira et al., 2011; Thapa et al., 1994)). The problems found in FRT assessment method were lack of description of hand position (n = 19 studies (Balasubramanian et al., 2015; Brauer et al., 2000; Campos et al., 2013; Gai et al., 2010; Gómez, 2008; Haines et al., 2008; Lindemann et al., 2003; Lobo, 2012; Murphy et al., 2003; Newton, 1997, 2001; Nolan et al., 2010; Queiroz et al., 2009; Rockwood et al., 2000; Takahashi et al., 2006; Tantisuwat et al., 2014; Teixeira et al., 2011; Thapa et al., 1994; Uritani et al., 2016)), of the base of support (n = 17 studies (Balasubramanian et al., 2015; Brauer et al., 2000; Campos et al., 2013; Cho & Kamen, 1998; Franzen et al., 1999; Fujimoto et al., 2015; Gai et al., 2010; Haines et al., 2008; Lin et al., 2004; Morita et al., 2005; Murphy et al., 2003; Newton, 1997, 2001; Nolan et al., 2010; Queiroz et al., 2009; Rockwood et al., 2000; Sugihara et al., 2006)), and of the number of trials (n = 12 studies (Balasubramanian et al., 2015; Brauer et al., 2000; Fujimoto et al., 2015; Gai et al., 2010; Lobo, 2012; Morita et al., 2005; Newton, 1997; Nolan et al., 2010; Queiroz et al., 2009; Sugihara et al., 2006; Takahashi et al., 2006; Uritani et al., 2016)).

3.4. FRT explanatory variables

Age was analyzed by 21 studies (Almeida et al., 2012; Aslan et al., 2008; Costarella et al., 2010; Duncan et al., 1990; Franzen et al., 1999; Gabbard & Cordova, 2013; Hageman et al., 1995; Hosek & Sackett, 1997; Isles et al., 2004; Jonsson et al., 2003; Lin et al., 2004; Lindemann et al., 2003; Morita et al., 2005; Murphy et al., 2003; Nolan et al., 2010; Norris & Medley, 2011; Silveira et al., 2006; Tantisuwat et al., 2014; Thapa et al., 1994; Uritani et al., 2016; Wallmann, 2001) as an explanatory variable in FRT performance. Among these, 18 studies (Almeida et al., 2012; Aslan et al., 2008; Duncan et al., 1990; Franzen et al., 1999; Gabbard & Cordova, 2013; Hageman et al., 1995; Hosek & Sackett, 1997; Isles et al., 2004; Lin et al., 2004; Lindemann et al., 2003; Morita et al., 2005; Murphy et al., 2003; Nolan et al., 2010; Norris & Medley, 2011; Silveira et al., 2006; Tantisuwat et al., 2014; Thapa et al., 1994; Uritani et al., 2016) verified an association or correlation between age and the FRT, with test performance being inversely proportional to age. Nine studies (Almeida et al., 2012; Aslan et al., 2008; Costarella et al., 2010; Duncan et al., 1990; Hageman et al., 1995; Lindemann et al., 2003; Silveira et al., 2006; Takahashi et al., 2006; Thapa et al., 1994) assessed the association between sex and the FRT. Only 3 studies (Aslan et al., 2008; Costarella et al., 2010; Silveira et al., 2006) found statistically significant differences between sexes, with higher FRT values among men. Anthropometric variables were assessed in relation to the FRT by 7 studies (Duncan et al., 1990; Franzen et al., 1999; Isles et al., 2004; Jonsson et al., 2003; Silveira et al., 2006; Thapa et al., 1994; Uritani et al., 2016). Height interfered in FRT performance according to 6 studies (Isles et al., 2004, Duncan et al., 1990; Franzen et al., 1999; Silveira et al., 2006; Thapa et al., 1994; Uritani et al., 2016) in which taller individuals presented greater FRT distances. Weight was analyzed in 3 studies (Silveira et al., 2006; Thapa et al., 1994; Uritani et al., 2016), and of these, only 1 study (Uritani et al., 2016) identified an association with the FRT (Table A3).

Fifteen studies (Almeida et al., 2012; Costarella et al., 2010; Duncan et al., 1990, 1992; Hosek & Sackett, 1997; Lin et al., 2004; Morita et al., 2005; Murphy et al., 2003; Newton, 1997, 2001; Rockwood et al., 2000; Takahashi et al., 2006; Thapa et al., 1994; Uritani et al., 2016; Wallmann, 2001) assessed the association or correlation between FRT performance and physical-functional variables. Diverging results were found relative to center of pressure (Costarella et al., 2010; Duncan et al., 1990) and activities of daily living (Lin et al., 2004; Rockwood et al., 2000; Takahashi et al., 2006). Balance, mobility, and gait tests were associated/correlated with the FRT (Almeida et al., 2012; Duncan et al., 1992; Hosek & Sackett, 1997; Lin et al., 2004; Murphy et al., 2003; Newton, 1997, 2001; Thapa et al., 1994; Uritani et al., 2016). The Timed Up and Go test was assessed by 3 studies (Almeida et al., 2012; Hosek & Sackett, 1997; Newton, 2001) and presented weak to moderate negative correlation with the FRT ($r = -0.15$ (Almeida et al., 2012); $r = -0.51$ (Hosek & Sackett, 1997)). Laboratory balance tests such as Limits of Stability and the Sensory Organization Test were assessed by only 1 study (Wallmann, 2001), which did not find any association between these variables and the FRT (Table A3).

Nine studies (Billek-Sawhney & Gay, 2005; Duncan et al., 1990; Gabbard & Cordova, 2013; Isles et al., 2004; Jonsson et al., 2003; Newton, 1997, 2001; Norris & Medley, 2011; Robinovitch & Cronin, 1999) analyzed FRT performance while modifying the assessment method, such as by biomechanical tools, comparison of sides (right vs. left upper limbs), estimated reach, and number of trials. The results of the actual FRT diverged when compared to estimates (Gabbard & Cordova, 2013; Robinovitch & Cronin, 1999). Other variables that can interfere with the FRT, such as dizziness (Teixeira et al., 2011), vision deficits (Almeida et al., 2012; Thapa et al., 1994), postural hypotension (Thapa et al., 1994), depression (Takahashi et al., 2006; Thapa et al.,

Table A3
Relationship of Forward Functional Reach Test with age, sex, body composition, physical, functional and other variables.

Study	Age	Sex	Body Composition Variables	Physical and Functional Variables	Other Variables
CROSS-SECTIONAL STUDIES					
Duncan et al. (1990)	✓	X	✓ height X right foot length X base of support	✓ center of pressure	✓ Yardstick Reach and Electronic FRT ($r = 0.69$)
Hageman et al. (1995)	✓	X	–	–	–
Hosek and Sackett (1997)	✓ ($r = -0.40$)	–	–	✓ Timed Up and Go ($r = -0.51$) ✓ 10-foot walk ($r = -0.53$)	–
Jonsson et al. (2003)	X	–	X height	–	✓ FRT clinical and FRT experimental
Lindemann et al. (2003)	✓	X	–	–	–
Isles et al. (2004)	✓	–	✓ height (each 10 cm of height increased FR in 3.3 cm)	–	✓ FRT right and left arm (no difference)
Billek-Sawhney and Gay (2005)	–	–	–	–	✓ all comparisons (mean of 3 trial, first trial, second trial and mean of 2 trials) resulted in similar measures of FRT
Silveira et al. (2006)	✓	✓	✓ height ✓ foot length X arm length X weight X base of support	–	–
Takahashi et al. (2006)	–	X	–	X ADL	X depression
Costarella et al. (2010)	X	✓	–	X center of pressure	–
Nolan et al. (2010)	✓	–	–	–	–
Norris and Medley (2011)	✓ ($r = -0.72$)	–	–	–	✓ object-present contexts (touch or grasp) resulted in greater reach ability than the traditional FRT condition. FRT < FR Grasp = Object FR
Almeida et al. (2012)	✓ age ≥ 70 yrs X age in years	X	–	✓ Timed Up and Go ($r = -0.15$)	✓ vision (regular/bad) ✓ house (home) ✓ income (low income) X hearing X health perception X fractures
Gabbard and Cordova (2013)	✓	–	–	–	X reach estimation
Tantisuwat et al. (2014)	✓	–	–	–	–
Uritani et al. (2016)	✓ (women only $r = -0.16$)	–	✓ height (men $r = 0.39$ and women $r = 0.34$) ✓ weight (men $r = 0.15$)	✓ isometric knee extension strength (men $r = 0.21$; women $r = 0.31$) ✓ Timed Up and Go (women only $r = -0.19$) ✓ toe grip strength (women only $r = 0.13$)	–
Newton (1997) Newton (2001)	–	–	–	✓ activity level ✓ Berg Balance Test ($r = 0.47$) ✓ Timed Up and Go ($r = -0.44$) ✓ comfort in activities without fear of falling ✓ frequency of performing activities	✓ fear of falling ✓ significant difference between the two trials for reach in the forward direction. ✓ health status
Cho and Kamen (1998)	–	–	–	–	–
Franzen et al. (1999)	✓ ($r = -0.47$)	–	✓ weight ($r = 0.38$)	–	–
Wallmann (2001)	X	–	–	*X Limits of Stability* X Sensory Organization Test	–
Gai et al. (2010)	–	–	–	–	–
Teixeira et al. (2011)	–	–	–	–	X dizziness
Balasubramanian et al. (2015)	–	–	–	–	–
Thapa et al. (1994)	✓	X	✓ height X weight	✓ lower extremity weakness ✓ chair stand ($r = 0.39$) ✓ time walk ($r = 0.35$) ✓ mobility ($r = 0.38$) ✓ mean velocity ($r = 0.15$) X ambulation X upper extremity weakness	X mental status X depression X near vision X postural hypotension X hearing X needs assistance
Lobo (2012)	–	–	–	–	X setting
Rockwood et al. (2000)	–	–	–	✓ OARS: ADL ($r = 0.40$) ✓ OARS: IADL ($r = 0.44$)	✓ Cumulative Illness Rating scale ($r = -0.14$) ✓ Frailty scale ($r = -0.38$)
Aslan et al. (2008)	✓	✓	–	–	–
Robinovitch and Cronin (1999)	–	–	–	–	✓ reach estimates
Gómez (2008)	–	–	–	–	–
Queiroz et al. (2009)	–	–	–	–	–

(*continued on next page*)

Table A3 (*continued*)

Study	Age	Sex	Body Composition Variables	Physical and Functional Variables	Other Variables
Campos et al. (2013)	–	–	–	–	–
PROSPECTIVE COHORT STUDIES					
Duncan et al. (1992)	–	–	–	✓ Mobility	✓ neurological diagnoses ✓ orthopedic/ rheumatologic diagnoses
Brauer et al. (2000)	–	–	–	–	–
Murphy et al. (2003)	✓ ($r = -0.52$)	–	–	✓ floor transference ($r = -0.49$) ✓ 5-step test ($r = -0.57$) ✓ Performance-Oriented Mobility Assessment ($r = 0.40$) ✓ Penny pick-up ($r = -0.51$) ✓ turns ($r = -0.47$) ✓ 50-ft walk ($r = -0.54$) ✓ 5-min walk ($r = 0.65$) X tandem ($r = 0.36$)	–
Lin et al. (2004)	✓	–	–	✓ Tinetti balance ($r = 0.48$) ✓ walking aid ✓ ADL disability ✓ ADL improvement	–
Morita et al. (2005)	✓ ($r = -0.33$)	–	–	✓ physical activity ($r = 0.12$)	–
Sugihara et al. (2006)	–	–	–	–	–
Fujimoto et al. (2015)	–	–	–	–	–
Haines et al. (2008)	–	–	–	–	X sample sets

✓: association or correlation between the variable and the Functional Reach Test.
X: no association or correlation between the variable and the Functional Reach Test.
-: not evaluated.
ADL = Activities of Daily Living; AADL = Advanced Activities of Daily Living; IADL = Instrumental Activities of Daily Living; OARS = Older American Resources and Services.

1994), and fear of falling (Newton, 1997, 2001), were poorly investigated in the studies.

3.5. Meta-analysis

3.5.1. FRT normative data (community vs. non-community)

Of the 40 studies included in this systematic review, 25 studies (Almeida et al., 2012; Balasubramanian et al., 2015; Billek-Sawhney & Gay, 2005; Costarella et al., 2010; Duncan et al., 1990; Franzen et al., 1999; Gómez, 2008; Hageman et al., 1995; Haines et al., 2008; Hosek & Sackett, 1997; Isles et al., 2004; Jonsson et al., 2003; Lin et al., 2004; Lobo, 2012; Morita et al., 2005; Newton, 2001; Nolan et al., 2010; Norris & Medley, 2011; Robinovitch & Cronin, 1999; Silveira et al., 2006; Sugihara et al., 2006; Takahashi et al., 2006; Tantisuwat et al., 2014; Thapa et al., 1994; Uritani et al., 2016) were included in the meta-analysis of normative data by setting (community vs. non-community). Studies were not included in the meta-analysis if they presented: FRT values by history of falls (n = 10 studies (Brauer et al., 2000; Campos et al., 2013; Cho & Kamen, 1998; Duncan et al., 1992; Fujimoto et al., 2015; Gai et al., 2010; Murphy et al., 2003; Queiroz et al., 2009; Teixeira et al., 2011; Wallmann, 2001)); FRT median data (n = 1 study(Lindemann et al., 2003)); lacked standard deviation (n = 1 study (Gabbard & Cordova, 2013)); mixed data of community and non-community sample (n = 3 studies (Aslan et al., 2008; Robinovitch & Cronin, 1999; Rockwood et al., 2000)); and duplicate samples (n = 1 study (Newton, 1997)). Newton (1997, 2001) presented FRT values from the same sample; in order to avoid double data entry, only the 2001 study (Newton, 2001), which contained the larger sample, was included in the meta-analysis.

To conduct a meta-analysis of the normative data, 35 samples from 25 studies were included, with 29 samples (Almeida et al., 2012; Balasubramanian et al., 2015; Billek-Sawhney & Gay, 2005; Costarella et al., 2010; Duncan et al., 1990; Franzen et al., 1999; Hageman et al., 1995; Hosek & Sackett, 1997; Isles et al., 2004; Jonsson et al., 2003; Lin et al., 2004; Lobo, 2012; Morita et al., 2005; Newton, 2001; Nolan et al., 2010; Norris & Medley, 2011; Silveira et al., 2006; Sugihara et al., 2006; Takahashi et al., 2006; Tantisuwat et al., 2014; Uritani et al., 2016) composed of community-dwelling older adults, and 7 with older adults from other settings (Gómez, 2008; Haines et al., 2008; Lobo, 2012; Robinovitch & Cronin, 1999; Thapa et al., 1994). Statistical differences were found ($p < 0.0001$) between normative values of community-dwelling older adults, with 26.60 cm [95%CI: 25.14; 28.06], and non-community-dwelling older adults, 15.45 cm [95%CI: 13.47; 17.42] (Fig. A2).

3.5.2. FRT normative values in terms of sex (female, male, all) and age

Regarding normative data for sex of community-dwelling older adults, 8 samples (Duncan et al., 1990; Hosek & Sackett, 1997; Isles et al., 2004; Lobo, 2012; Morita et al., 2005; Silveira et al., 2006; Uritani et al., 2016) provided FRT data for women, 6 samples (Duncan et al., 1990; Lobo, 2012; Nolan et al., 2010; Silveira et al., 2006; Uritani et al., 2016) for men, and 15 samples (Almeida et al., 2012; Balasubramanian et al., 2015; Billek-Sawhney & Gay, 2005; Costarella et al., 2010; Franzen et al., 1999; Hageman et al., 1995; Jonsson et al., 2003; Lin et al., 2004; Newton, 2001; Norris & Medley, 2011; Sugihara et al., 2006; Takahashi et al., 2006; Tantisuwat et al., 2014) included general data (independent of sex). The highest FRT value was for men with 31.52 cm [95%CI: 28.37; 34.66], followed by women, with 28.69 cm [95%CI: 26.69; 30.70], and last, by the general sample, with 23.30 cm [95%CI: 20.21; 26.39]. No differences were found between sexes (male and female), with p = 0.138. Differences were found between sex (male and female) with the general data ($p < 0.001$) (Fig. A3).

Regarding the impact of age, meta-regression using a mixed model was applied, which showed high heterogeneity ($I^2 = 98.11\%$). Age did not explain this variation ($R^2 = 0.00\%$). Starting at 65 years of age (constant = 66.41- year 0; 65 years old 31.96), FRT performance decreased 0.53 cm per year [95%CI: -0.85;-0.21] (p = 0.0010).

3.5.3. FRT values in relation to history of falls

To assess FRT as a predictor of falling, 5 (Brauer et al., 2000; Duncan et al., 1992; Fujimoto et al., 2015; Morita et al., 2005; Murphy et al., 2003) of the 8 prospective studies were included in the meta-analysis. The studies by Haines et al. (2008), Lin et al. (2004) and Sugihara et al. (2006) were not included because the follow-up data regarding history of falls was not presented in terms of means and standard-deviation. The meta-analysis revealed that FRT was not capable of predicting falls ($p = 0.098$). The group of older adults who had not fallen presented values 2.30 cm greater [95%CI: -0.43; 5.04] than those who had fallen in the follow-up period (Fig. A4).

3.6. Assessing the methodological quality of the studies

Using the Newcastle-Ottawa scale, the methodological quality of the prospective studies ranged between 4 and 8 points (median = 5 points; mean = 5.2 points), demonstrating low to moderate risk of bias. Duncan et al. (1992) obtained the highest score (8 points), and Murphy et al. (2003) and Sugihara et al. (2006), the lowest scores (4 points). The highest-scoring items in the prospective studies were "selection of the non-exposed cohort" and "ascertainment of exposure," from the "selection" category. The lowest-scoring items were "comparability of cohorts on baseline or analysis" from the "comparability" category, and "assessment of outcome," from the "outcome" category (Table A4).

Regarding cross-sectional studies, scores ranged between 1 and 5 points (median = 2 points, mean = 2.7 points), indicating high to moderate risk of bias. Duncan et al. (1990), Isles et al. (2004) and Thapa et al. (1994) received the highest score of 5 points. Four studies (Gabbard & Cordova, 2013; Gómez, 2008; Lobo, 2012; Queiroz et al., 2009) received 1 point. The lowest-scoring item was "ascertainment of the exposure" from the "selection" category. "Representativeness of the sample" from the "selection" category had the lowest score (Table A5).

4. Discussion

The present review provides an important perspective on the FRT normative values of older adults with no specific health condition. The search found a high number of publications and data about the use of the FRT to assess balance control, but few studies used the test to determine risk of falling. Moreover, the studies varied greatly in FRT data and assessment method.

The meta-analysis resulted in normative data of 26.6 cm among community-dwelling older adults, which corroborates to the values proposed in the Berg Balance Scale (Berg et al., 1989), but does not corroborate to the Balance Evaluation Systems Test (Horak et al., 2009). In the Berg Scale, reach is considered normal and safe at 25 cm or greater, while the Balance Evaluation Systems Test (Horak et al., 2009) sets normal limits for maximum reach at greater than 32 cm. The results of this review is similar to the study of Bohannon, Wolfson, and White (2017) that carried out a meta-analysis with 20 studies with 7535 older adults including with specific health conditions in which the normative values of the FRT was 27.2 cm (CI 95% 25.5; –28.9 cm).

In this meta-analysis, a difference of approximately 10 cm was observed between the normative data for community-dwelling older adults and those in other settings. This difference can be explained by the assumption that non-community-dwelling older adults are older (Ellis et al., 2017), suffer more from balance problems and are at high risk of falls than community-dwelling individuals (Becker & Rapp, 2010; Lopez-Soto et al., 2015). Therefore, such differences among samples must be considered when interpreting the studies. The FRT is quick and easy to apply, and since it requires few materials, it is considered an appropriate and ideal test to assess balance control among the population of non-community-dwelling older adults.

The results of the present review corroborated that body balance control is hindered with advanced age (Borel & Alescio-Lautier, 2014), i.e., the higher the age, the lower the FRT performance (Almeida et al.,

Table A4
Evaluation of the methodological quality of the prospective studies by the Newcastle-Ottawa Scale.

Study	Selection				Comparability	Outcome			Total 9*
Cohort	Representativeness of exposed cohort	Selection of the non-exposed cohort	Ascertainment of exposure	Outcome of interest was not present at start of study	Comparability of cohorts on baseline or analysis	Assessment of outcome	Follow-up long enough for outcome to occur	Adequacy of follow-up of cohorts	
Duncan et al. (1992)	*	*	*	*	**	—	*	*	8
Brauer et al. (2000)	*	*	*	*	—	—	*	*	6
Murphy et al. (2003)	—	*	*	—	—	—	*	*	4
Lin et al. (2004)	*	*	*	*	—	—	*	—	5
Morita et al. (2005)	*	*	*	—	**	—	*	—	6
Sugihara et al. (2006)	—	*	*	*	—	—	—	*	4
Fujimoto et al. (2015)	—	*	*	*	—	—	*	*	5
Haines et al. (2008)	*	*	*	*	—	*	—	—	5

Table A5
Evaluation of the methodological quality of the cross-sectional studies by the Newcastle-Ottawa Scale adapted.

Study	Selection			Comparability	Outcome		Total 7*
Cross-Sectional	Representativeness of the sample	Non-respondents	Ascertainment of the exposure	Subjects are comparable. Confounding factors are controlled	Assessment of the outcome	Statistical test	
Duncan et al. (1990)	_____	*	*	**	NA	*	5
Hageman et al. (1995)	_____	*	*	*	NA	*	4
Hosek and Sackett (1997)	_____	_____	*	_____	NA	*	2
Jonsson et al. (2003)	_____	*	*	_____	NA	*	3
Lindemann et al. (2003)	_____	_____	*	*	NA	*	3
Isles et al. (2004)	*	_____	*	**	NA	*	5
Billek-Sawhney and Gay (2005)	_____	_____	*	_____	NA	*	2
Silveira et al. (2006)	_____	_____	*	_____	NA	*	2
Takahashi et al. (2006)	_____	_____	*	_____	_____	*	2
Costarella et al. (2010)	_____	_____	*	_____	NA	*	2
Nolan et al. (2010)	_____	*	*	*	NA	*	4
Norris and Medley (2011)	_____	_____	*	_____	NA	*	2
Almeida et al. (2012)	*	*	*	_____	NA	*	4
Gabbard and Cordova (2013)	_____	_____	*	_____	NA	_____	1
Tantisuwat et al. (2014)	_____	_____	*	_____	NA	*	2
Uritani et al. (2016)	*	_____	*	_____	NA	*	3
Newton (1997)	_____	_____	*	_____	_____	*	2
Newton (2001)	_____	_____	*	_____	_____	*	2
Cho and Kamen (1998)	_____	_____	*	_____	_____	*	2
Franzen et al. (1999)	_____	_____	*	_____	_____	*	2
Wallmann (2001)	_____	*	*	_____	_____	*	3
Gai et al. (2010)	_____	_____	*	_____	_____	*	2
Teixeira et al. (2011)	_____	_____	*	_____	_____	*	2
Balasubramanian et al. (2015)	_____	*	*	*	_____	*	4
Thapa et al. (1994)	*	_____	*	**	NA	*	5
Lobo (2012)	_____	_____	*	_____	_____	_____	1
Rockwood et al. (2000)	*	_____	*	_____	NA	*	3
Aslan et al. (2008)	_____	*	*	_____	_____	*	3
Robinovitch and Cronin (1999)	_____	_____	*	**	NA	*	4
Gómez (2008)	_____	_____	*	_____	_____	_____	1
Queiroz et al. (2009)	_____	_____	*	_____	NA	_____	1
Campos et al. (2013)	_____	_____	*	_____	_____	*	2

NA: Not Applicable.

2012; Duncan et al., 1990; Franzen et al., 1999; Gabbard & Cordova, 2013; Hageman et al., 1995; Hosek & Sackett, 1997; Isles et al., 2004; Lin et al., 2004; Lindemann et al., 2003; Morita et al., 2005; Murphy et al., 2003; Nolan et al., 2010; Silveira et al., 2006; Tantisuwat et al., 2014; Thapa et al., 1994; Uritani et al., 2016). This was confirmed by the results of the present meta-analysis, which allows for the adjustment of normative values according to individual patient age. Other tools to assess balance (Berg Balance Scale and Lateral Reach test) (Downs, Marquez, & Chiarelli, 2014; Isles et al., 2004) have also shown that scores tend to decrease with age. Thus, age has become one of the main predictors of imbalance among older adults.

About sex, no difference was found between the normative values for men and women. This finding confirms the original FRT validation study (Duncan et al., 1990). Perhaps the difference found in FRT values for populations from different countries is more related to anthropometric aspects than sex-related. Duncan et al. (1990) conducted a study in the United States, and found values 5 cm higher than those found by Silveira et al. (2006) with Brazilian community-dwelling older adults.

Regarding anthropometrics, height appeared to be correlated to the FRT, which may explain the difference between the measurements obtained by some studies. However, few authors (Duncan et al., 1990; Franzen et al., 1999; Isles et al., 2004; Jonsson et al., 2003; Silveira et al., 2006; Thapa et al., 1994; Uritani et al., 2016) present this important data and the statistics adjustments made for this variable. More studies are needed to gather data such as arm size, foot size, and height for future adjustments-corrections of FRT values.

Most of the studies included in the present review did not fully describe or report FRT assessment method. There was also lack of standardization in how to carry out the test. This can modify FRT performance and, consequently, could result in divergences among normative values. Only one study (Billek-Sawhney & Gay, 2005) verified the influence of the number of FRT trials in community-dwelling older adults, suggesting that the use of one or two trials and the averaged value of two trials was not statistically different from the results of the average of three trials. The FRT validation study (Duncan et al., 1990) proposed two practice trials and three “test” trials, and the last three values are averaged to obtain the score. Multiple trials before the actual trial can result in learning and, consequently, improved test performance. Thus, describing FRT methodology can help both researchers who wish to study this tool and clinicians who wish to use it in their practice. Future studies should provide detailed information about the assessment method used to apply the FRT.

Another factor that can influence FRT performance is the strategies used during the test. Lin et al. (2004) and Wernick-Robinson et al. (1999) verified with community-dwelling older adults changes in patterns of movement, with the use of the hip strategy during the FRT. Another study (Jonsson et al., 2003) observed that subjects used ankle strategy and trunk rotation during the test performance. A laboratory study demonstrated that during the FRT performance older adults use pelvic translation to prevent forward imbalance (de Waroquier-Leroy et al., 2014). It is important to highlight that glenohumeral joint also deserves researchers and health care providers attention while performing the FRT. A good range of motion of the upper limb is required for the test start position and for the reaching task. The studies included in the present review did not clarify which movement or strategies are allowed when assessing the FRT. Identifying the strategies used can be useful for both FRT assessment and treatment plans.

Ideally, prospective studies should be used to assess risk of falling. However, in the present review, most of the studies that assessed falls were retrospective and presented very diverse follow-up data with great potential for memory bias, which is characteristic of this particular study design. In the prospective studies, diverging fall follow-up data were found, with high heterogeneity. Our results suggest that there is no evidence regarding the appropriate FRT value to predict falls, and whether this tool can assess risk of falls in the older adult population.

Regarding methodological quality, all the studies presented limitations, regardless of methodology (cross-sectional or longitudinal). The studies scored poorly on the item “comparability of cohorts on baseline or analysis” from the “comparability” category, which could be improved by including possible FRT explanatory variables in the analyses. Most of the cross-sectional studies presented limitations relative to the item “representativeness of the sample,” from the “selection” category, because of the use of convenience samples. Compared to other types of sampling, convenience sampling is easier to use and incurs lower research costs; however, it often results in lower external validity of the data. Even though the search revealed many studies that addressed the topic of this review, few presented high methodological quality.

It is important to highlight that our search strategy it was not specific to find studies of fall risk. This is a limitation from this review, and this fact may have led to missing the inclusion of some studies on this topic. Other limitation of the present review is the exclusion of some studies because of the absence of FRT data. Before excluding these studies, emails were sent to the authors requesting such data on two different occasions, with a two-week interval between. This information should be considered when interpreting and generalizing the findings of this review.

5. Conclusion

The present systematic review with meta-analysis revealed great variation of normative data for the FRT and proposes different values for community- and non-community-dwelling older adults. The influence of the age of community-dwelling older adults must be considered in these values. Variations in FRT assessment method hamper the standardization of its use in both in research and in clinical practice. The findings show that there is evidence to support the use of the FRT to assess dynamic balance, but this evidence does not support its use to predict falls.

Conflict of interest statement

The authors declare no conflict of interest.

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Appendix A. Electronic search strategies

MEDLINE (Pubmed)

#1. ((((((((((((((((((epidemiologic[Title/Abstract]) OR "case control"[Title/Abstract]) OR "observational study"[Title/Abstract]) OR longitudinal [Title/Abstract]) OR retrospective[Title/Abstract]) OR prospective[Title/Abstract]) OR "cross sectional"[Title/Abstract]) OR prognosis[Title/Abstract]) OR "diagnostic accuracy"[Title/Abstract])OR "predictive value"[Title/Abstract])OR sensitivity [Title/Abstract])OR specificity [Title/Abstract])OR "correlational study" [Title/Abstract])OR "clinical study"[Title/Abstract])))))))))))))))))

#2. (((((((age*[Title/Abstract]) OR aging[Title/Abstract]) OR elder*[Title/Abstract]) OR senior*[Title/Abstract]) OR "old* people"[Title/Abstract]) OR "old* adult*"[Title/Abstract]) OR "old* person"[Title/Abstract]) OR "elderly people"[Title/Abstract])))))))))

#3.(((((((FR[Title/Abstract]) OR FRT[Title/Abstract]) OR "Functional Reach"[Title/Abstract]) OR "Forward Reach"[Title/Abstract]) OR Multi-directional reach test[Title/Abstract]) OR "Limits of stability"[Title/Abstract])))))))

#4. #1 AND #2 AND #3

ISI Web of Science

#1. TS = (age* OR aging OR elder* OR senior* OR "old* people" OR "old* adult*" OR “old* person" OR "elderly people")

#2. TS = (fr OR frt OR "Functional Reach" OR "Forward Reach" OR multi-directional reach test OR "Limits of stability")

#3. TS = (epidemiologic OR "case control" OR "observational study" OR longitudinal OR retrospective OR prospective OR "cross sectional" OR prognosis OR "diagnostic accuracy"OR "predictive value"OR sensitivity OR specificity OR "correlational study" OR "clinical study")

#4. #1 AND #2 AND #3

Embase

#1. (FR or FRT or "Functional Reach" or "Forward Reach" or "Limits of stability" or multi-directional reach test).ab.

#2. (epidemiologic or “case control” or “observation study” or longitudinal or retrospective or prospective or “cross sectional” or prognosis or “diagnostic accuracy” or “predictive value” or sensitivity or specificity or “correlational study” or “clinical study”).ab.

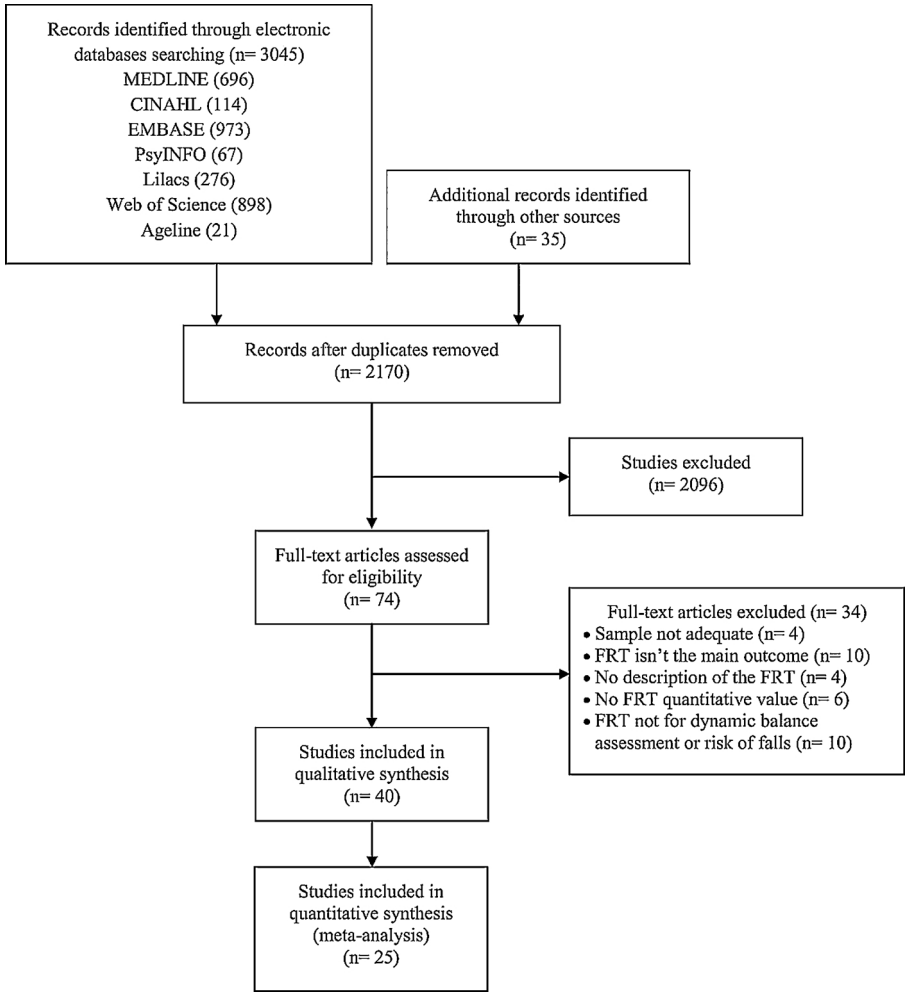

Fig. A1. Flow-chart of the selection process of the studies for the systematic review.

#3. (age or aged or aging or elderly or "elderly people" or elders or "old people" or "elderly people" or "old adults" or "older adults" or "older person" or senior).ab.

limit 5 to (embase and yr="1990 - 2017")

#4. #1 AND #2 AND #3

Ageline

AB ((FR OR FRT OR "Functional Reach" OR "Forward Reach" OR "Limits of stability" OR multi-directional reach test)) AND AB ((epidemiologic OR "case control" OR "observational study" OR longitudinal OR retrospective OR prospective OR "cross sectional" OR prognosis OR "diagnostic accuracy" OR "predictive value" OR sensitivity OR specificity OR "correlational study" or "clinical study")) AND AB ((age OR aged OR aging OR elderly OR "elderly people" OR elders OR "old people" OR "elderly people" OR "old adults" OR "older adults" OR "older person" OR senior))

Lilacs

tw:(((tw:(age*)) OR (tw:(aging)) OR (tw:(elder*)) OR (tw:(senior*)) OR (tw:("old* people")) OR (tw:("old* adult*")) OR (tw:("old* person")) OR (tw:("elderly people"))) AND ((tw:(fr)) OR (tw:(frt)) OR (tw:("Functional Reach")) OR (tw:("Forward Reach")) OR (tw:(multi-directional reach test)) OR (tw:("Limits of stability")))) AND (instance:"regional") AND (db:("LILACS") AND year_cluster:("2013" OR "2012" OR "2010" OR "2009" OR "2007" OR "2015" OR "2006" OR "2011" OR "2004" OR "1997" OR "2014" OR "2008" OR "2016" OR "1996" OR "2005" OR "2001" OR "1993" OR "1998" OR "2000" OR "2003" OR "1994" OR "1990" OR "1995" OR "1999" OR "1991" OR "1992" OR "2002"))]

CINAHL

#1. (AB FR OR AB FRT OR AB "Functional Reach" OR AB "Forward Reach" OR AB "Limits of stability" OR AB multi-directional reach test)

#2. (AB epidemiologic OR AB "case control" OR AB "observational study" OR AB longitudinal OR AB retrospective OR AB prospective OR AB "cross sectional" OR AB prognosis OR AB "diagnostic accuracy" OR AB "predictive value" OR AB sensitivity OR AB specificity OR "correlational study" OR AB "clinical study")

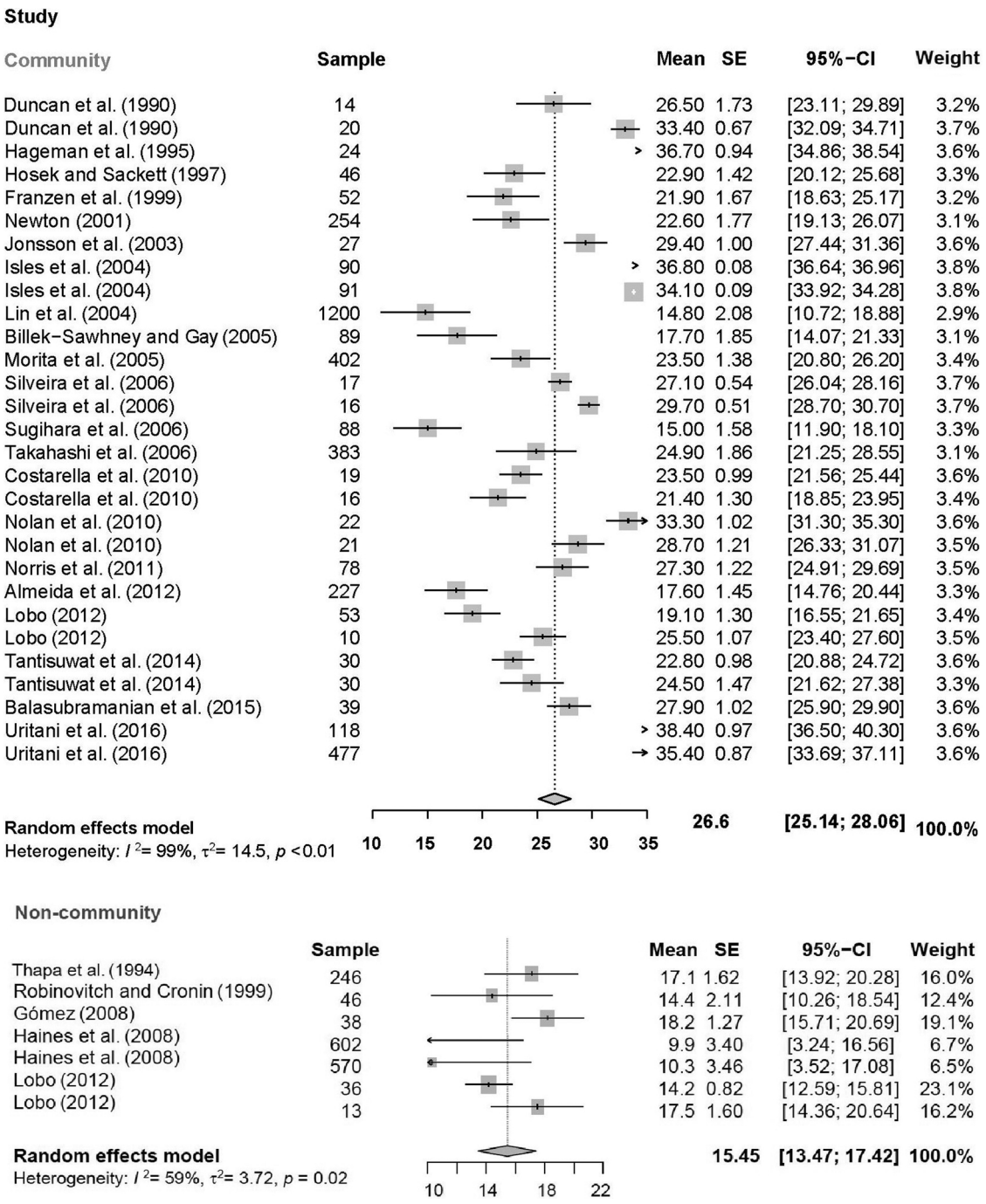

Fig. A2. Forest plot of normative values of the Functional Reach Test for community versus non-community older adults.

#3. (age AB OR AB aged OR AB aging OR AB elderly OR AB "elderly people" OR AB elders OR AB "old people" OR AB "elderly people" OR AB "old adults" OR AB "older adults" OR AB "older person" OR AB senior)

#4. (S1 AND S2 AND S3)

PsycINFO

(Abstract: FR OR Abstract: FRT OR Abstract: "Functional Reach" OR Abstract: "Forward Reach" OR Abstract: "Limits of stability" OR Abstract: multi-directional reach test AND Abstract: epidemiologic OR Abstract: "case control" OR Abstract: "observational study" OR Abstract: longitudinal OR Abstract: retrospective OR Abstract: prospective OR Abstract: "cross sectional" OR Abstract: prognosis OR Abstract: "diagnostic accuracy" OR Abstract: "predictive value" OR Abstract: sensitivity OR Abstract: specificity OR "correlational study" OR Abstract: "clinical study" AND Abstract: age Abstract: OR Abstract: aged OR Abstract: aging OR Abstract: elderly OR Abstract: "elderly people" OR Abstract: elders OR Abstract: "old people" OR Abstract: "elderly people" OR Abstract: "old adults" OR Abstract: "older adults" OR Abstract: "older person" OR Abstract: senior AND year: 1990–2017)

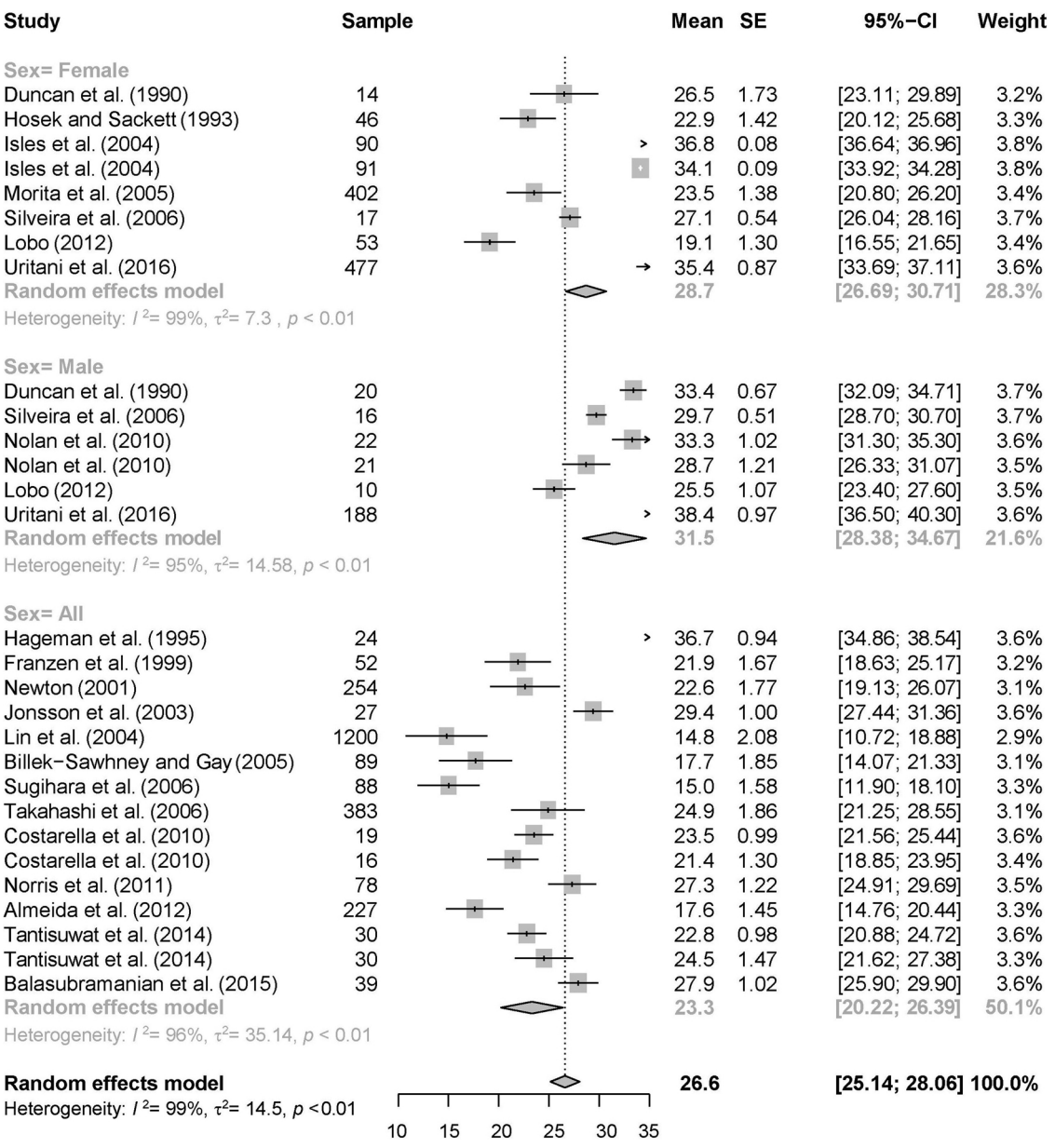

Fig. A3. Forest plot of normative values of the Functional Reach Test by sex for community-dwelling older adults.

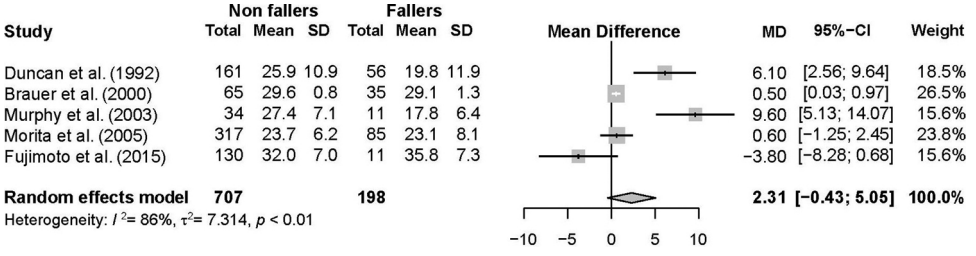

Fig. A4. Forest plot of Functional Reach Test values for prospective fall risk.

Appendix B. Excluded articles from the systematic review in the full text selection phase

References	Study type	Population	FRT main outcome measure	FRT description or reference	FRT Quantitative values	Evaluation of dynamic balance or risk of falls
Aoyama M, Suzuki Y, Onishi J, Kuzuya M.Physical and functional factors in activities of daily living that predict falls in community-dwelling older women. Geriatr Gerontol Int. 2011, 11(3):348-57.	✓	Older adults with fall risk	✓	✓	✓	✓
Bischoff HA, Conzelmann M, Lindemann D, Singer-Lindpaintner L, Stucki G, Vonthein R, Dick W, Theiler R, Stahelin HB. Self-reported exercise before age 40: influence on quantitative skeletal ultrasound and fall risk in the elderly. Arch Phys Med Rehabil. 2001, 82(6):801-806.	✓	✓	FRT isn't the main outcome measure	✓	✓	✓
*Bedient AM. A strategy utilizing simple clinical and laboratory tests to identify fallers among healthy independently-living older persons. Dissertation Abstracts International: Section B: The Sciences and Engineering. 2011, 71(10-B):6019.	✓	✓	✓	✓	Not described	✓
Bohannon, R.W., L.I. Wolfson, and W.B. White, Functional reach of older adults: normative reference values based on new and published data. Physiotherapy. 2017, 103(4):387-391.	✓	Specific disease: systemic arterial hypertension	✓	✓	✓	✓
Butler AA, Lord SR, Fitzpatrick RC. Reach distance but not judgment error is associated with falls in older people. J Gerontol A Biol Sci Med Sci. 2011, 66(8):896-903.			It is not the original FRT	No description or reference of the FRT assessment	Not described	The aim of the study was to evaluate reaching judgment error and maximal reach with a different assessment than the FRT.
Daubney ME, Culham EG. Lower-extremity muscle force and balance performance in adults aged 65 years and older. Phys Ther. 1999, 79(12):1177-85.	✓	✓	✓	✓	✓	The study aim was to evaluate lower-extremity muscle force.
Davis JW, Ross PD, Nevitt MC, Wasnich RD. Risk factors for falls and for serious injuries on falling among older Japanese women in Hawaii. J Am Geriatr Soc. 1999, 47(7):792-798.	✓	✓	✓	No description or reference of the FRT assessment	Not described	✓
Dennis RJ. Functional reach improvement in normal older women after Alexander Technique instruction. J Gerontol A Biol Sci Med Sci. 1999, 54(1):M8-11.	✓	✓	✓	✓	✓	The aim of the study was to investigate relationship between the performance of FRT and the Alexander technique.
Devinder KAS, Sharmila GKP, Sin Thien T, Chu Chiau T, Shahar S. Association between physiological falls risk and physical performance tests among community-dwelling older adults. Clin Interv Aging. 2015, 10:1319-1326.	✓	✓	FRT isn't the main outcome measure	✓	Not described	The study aim is to evaluate the Physiological Profile Assessment (PPA).
Duncan PW, Chandler J, Studenski S, Hughes M, Prescott B. How do physiological components of balance affect mobility in elderly men? Arch Phys Med Rehabil. 1993, 74(12)-:1343-1349.	✓	✓	FRT isn't the main outcome measure	✓	✓	The study aim is to evaluate the physical function
Feldman F, Robinovitch SN. Elderly nursing home and day care participants are less likely than young adults to approach imbalance during voluntary forward reaching. Exp Aging Res. 2004, 30(3):275-290.	✓	✓	It is not the original FRT	No description or reference of the FRT assessment	Not described	The study aim was to evaluate a forward reaching task with a different assessment than the FRT.
**Huang H-C. Risk assessment and interventions to prevent falls in older people in Taiwan. Doctoral Thesis University of Ulster: Northern Ireland, UK. 2000.	✓	✓	✓	✓	Not described	✓
Hughes MA, Duncan PW, Rose DK, Chandler JM, Studenski SA. The relationship of postural sway to sensorimotor function, functional performance, and disability in the elderly. Arch Phys Med Rehabil. 1996, 77(6):567-572.	✓	✓	FRT isn't the main outcome measure	✓	✓	✓
Jalali MM, Gerami H, Heidarzadeh A, Soleimani R. Balance performance in older adults and its relationship with falling. Aging Clin Exp Res. 2015, 27(3):287-296.	✓	✓	✓	✓	Not described	The study aim is to evaluate the disability.
Lin SI, Liao CF. Age-related changes in the performance of forward reach. Gait Posture. 2011, 33(1):18-22.	✓	✓	✓	✓	✓	The aim of the study was to evaluate biomechanics involved in the FRT.
Moreira MN, Bilton TL, Dias RC, Ferriolli E, Perracini MR. What are the main physical functioning factors associated with falls among older people with different perceived fall risk? Physiother Res Int. 2017,22(3).	✓	✓	FRT isn't the main outcome measure	✓	✓	✓

*Muir SW, Berg K, Chesworth B, Klar N, Speechley M. Balance impairment as a risk factor for falls in community-dwelling older adults who are high functioning: a prospective study. Phys Ther. 2010, 90(3):338-347.	✓	✓	✓	✓	Not described	✓
Portnoy S, Reif S, Mendelboim T, Rand D. Postural control of individuals with chronic stroke compared to healthy participants. Timed-Up-and-Go, Functional Reach Test and center of pressure movement. Eur J Phys Rehabil Med. 2017,53(5):685-693.	✓	✓	✓	✓	✓	The study aim is to compare FRT between groups with focus on stroke.
Riolo L. Attention contributes to functional reach test scores in older adults with history of falling. Phys Occup Ther Geriatr. 2003, 22(2):15-28.	✓	✓	✓	✓	✓	The study aim is to evaluate the attention on the FRT results.
Robinovitch SN. Perception of postural limits during reaching. J Mot Behav. 1998, 30(4):352-358.	✓	Middle age	✓	✓	✓	✓
Russell MA, Hill KD, Blackberry I, Day LL, Dharmage SC. Falls risk and functional decline in older fallers discharged directly from emergency departments. J Gerontol A Biol Sci Med Sci. 2006, 61 A(10):1090-1095.	✓	✓	✓	✓	✓	The study aim is to evaluate functional decline
Russell MA, Hill KD, Blackberry I, Day LM, Dharmage SC. Reliability and predictive accuracy of the Falls Risk for Older People in the Community assessment (FROP-Com) tool. Age Ageing. 2008, 37(6):634-639.	✓	✓	✓	✓	✓	The study aim is to evaluate the Falls Risk for Older People in the Community assessment (FROP-Com) tool
Saito T, Izawa KP, Watanabe S. Association between the functional independence and difficulty scale and physical functions in community-dwelling japanese older adults using long-term care services. J Geriatr Phys Ther. 2018, 41(1):28-34.	✓	✓	✓	Modified FRT using a telescoping rod	✓	The study aim is to evaluate the Functional Independence and Difficulty Scale
Sakamoto R, Okumiya K, Ishine M, et al. Predictors of difficulty in carrying out basic activities of daily living among the old-old: A 2-year community-based cohort study. Geriatr Gerontol Int. 2016, 16(2):214-222.	✓	✓	✓	✓	✓	The study aim is to evaluate functional decline
Spilg EG, Martin BJ, Mitchell SL, Aitchison TC. Falls risk following discharge from a geriatric day hospital. Clin Rehabil. 2003, 17(3):334-340.	✓	✓	✓	No description or reference of the FRT assessment	Not described	✓
*Stalenhoef PA, Diederiks JP, Knottnerus JA, Kester AD, Crebolder HF. A risk model for the prediction of recurrent falls in community-dwelling elderly: a prospective cohort study. J Clin Epidemiol. 2002, 55(11):1088-1094.	✓	✓	FRT isn't the main outcome measure	✓	Not described	✓
Thomas JI, Lane JV. A pilot study to explore the predictive validity of 4 measures of falls risk in frail elderly patients. Arch Phys Med Rehabil. 2005, 86(8):1636-1640.	✓	✓	✓	No description or reference of the FRT assessment	✓	✓
Tomita Y, Arima K, Kanagae M, Okabe T, Mizukami S, Nishimura T, et al. Association of physical performance and pain with fear of falling among community-dwelling japanese women aged 65 years and older. Medicine (Baltimore). 2015, 94(35):e1449	✓	✓	FRT isn't the main outcome measure	✓	✓	✓
Tsai YJ, Yang YC, Lu FH, Lee PY, Lee IT, Lin SI. Functional Balance and Its Determinants in Older People with Diabetes. PloS one. 2016, 11(7):e0159339.	✓	✓	✓	✓	Not described	The study aim is to compare FRT between groups with focus on diabetes.
Wang CY, Yeh CJ, Hu MH. Mobility-related performance tests to predict mobility disability at 2-year follow-up in community-dwelling older adults. Arch Gerontol Geriatr. 2011, 52-(1):1-4.	✓	✓	✓	✓	Not described	✓
Weiner DK, Bongiorni DR, Studenski SA, Duncan PW, Kochersberger GG. Does functional reach improve with rehabilitation? Arch Phys Med Rehabil. 1993, 74(8):796-800.	✓	No subgroups of individuals over 60 years old (age range 40 to 105 years)	✓	✓	✓	✓
Weiner DK, Duncan PW, Chandler J, Studenski SA. Functional Reach - a marker of physical frailty. J Am Geriatr Soc. 1992, 40(3):203-207.	✓	✓	✓	✓	✓	The study aim is to evaluate the physical frailty
Wernick-Robinson M, Krebs DE, Giorgetti MM. Functional reach. does it really measure dynamic balance? Arch Phys Med Rehabil. 1999, 80(3):262-269.	✓	✓	✓	✓	✓	The aim of the study was to evaluate biomechanics involved in the FRT
Yamada M, Ichihashi N. Predicting the probability of falls in community-dwelling elderly individuals using the trail-walking test. Environ Health Prev Med. 2010, 15(6):386-391.	✓	✓	FRT isn't the main outcome measure	✓	✓	✓

*The authors did not answer the email contact.

**Email contact was made with the authors who answerd that the thesis was not eletronic available.

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