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Review

Measurement of Results of Functional Reach Test with Sensors: A Systematic Review

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Abstract: The test of physical conditions is important to treat and presents several diseases related to the movement. These diseases are mainly related to the physiotherapy and orthopedy, but it can be applied in a wide range of medical specialties. The Functional Reach Test is one of the most common physical tests used to measure the limit of stability that is highly important for older adults because their stability is reduced with aging. Thus, older adults are part of the population more exposed to stroke. This test may help in the measurement of the conditions related to post-stroke and stroke treatment. The movements related to this test may be recorded and recognized with the inertial sensors available in off-the-shelf mobile devices. This systematic review aims to determine how to determine the conditions related to this test, which can be detected, and which of the sensors are used for this purpose. The main contribution of this paper is to present the research on the state-of-the-art use of sensors available on off-the-shelf mobile devices to measure Functional Reach Test results. This research shows that the sensors that are used in the literature studies are inertial sensors and force sensors. The features extracted from the different studies are categorized as dynamic balance, quantitative, and raw statistics. These features are mainly used to recognize the different parameters of the test, and several accidents, including falling. The execution of this test may allow the early detection of different diseases.

Keywords: older adults; inertial sensors; force sensors; physiotherapy; systematic review; Functional Reach Test measurement

1. Introduction

The term "older adults" usually refers to people aged 65 years old or more [1], who have health, social, and economic problems [2]. The percentage of older adults is increasing in the European Union. Thus, the rate of older adults increased by 2.5% between 2018 and 2018 [1]. In 2018, the elderly population in the European Union was stated as 19% of the population [1]. Around the world, currently, 1 in 10 individuals are aged 60 years old or more [3]. However, in 2050, this ratio will increase to 1 in 5 individuals [3].

Due to the high prevalence of different diseases in older adults, the most common health problems available in the literature are presented in Table 1. It is verified that one of the most present and studied health problems are cardiac problems, cognitive impairment, visual impairment, and depression. However, chronic physical illness and tobacco are the health problems with a high percentage of prevalence in the population. These research studies are included in the research on Ambient Assisted Living and Enhanced Living Environments [4–7].

Table 1. Percentage of population with different health problems in the various studies.

Study:	Health Problem:	Average of the Percentage of Population:	Number of Studies:
[8–10]	Cardiac problems	29.2%	3
[3,9,11]	Cognitive impairment	16.0%	3
[8,10]	Visual impairment	45.4%	2
[3,11]	Depression	13.7%	2
[11]	Sedentary	93.5%	1
[3]	Chronic physical illness	60.1%	1
[8]	Tobacco	58.97%	1
[8]	Dental problems	32.6%	1
[9]	Arthritis	26.5%	1
[10]	Proteinuria	22.2%	1
[12]	Falling prevalence	21.1%	1
[10]	Pulmonary tuberculosis	16%	1
[3]	Functional dependence	15.7%	1
[8]	Diabetes	12%	1
[10]	Glycosuria	7.6%	1
[10]	Asthma	4.5%	1
[10]	Urinary tract infection	1.5%	1

Different tests can be used for the measurement of the physical ability of older adults. This study analyses the Functional Reach Test to assess dynamic balance in a simple task (Figure 1) [13]. Mainly, the maximum distance related to arm's length with the remaining parts of the body in a standing position is used to measure the limit of stability [14]. It will be useful to measure the fall risk [15].

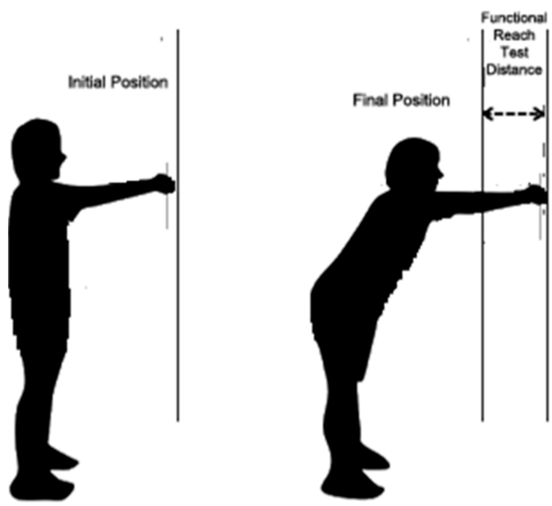

Figure 1. Functional Reach Test execution.

Following the research on the development of technological solutions to support healthy lifestyles, this team already developed systems for the recognition of activities of daily living [16–20], and measurement of jump flight time [21], energy expenditure [22], and other physical functional tests, including the heel rise test [23] and Timed Up and Go test [20,24].

The main contribution of this study is the presentation of a systematic review centered on the research on the use of sensors for the measurement of the different results of the Functional Reach Test using the sensors available over the world with a focus on inertial and force sensors. Inertial sensors are affordable and embedded in most of today's phones and smart watches. Likewise, the data they produce usually can be processed with algorithms that are simpler regarding computational and memory requirements, compared with camera and audio sensors. For these reasons, such algorithms are also more portable and can be executed directly on the devices that have battery constraints [25,26].

The scope of this study consists of the research of different scientific articles, published between 2011 and 2020, in ACM Digital Library, IEEE Xplore, PubMed, and ScienceDirect, about the implementation and analysis of the Functional Reach Test with inertial or force sensors with the correct description of the population involved and results obtained in the English language.

Following our review, we verified that the mean speed, the mean acceleration, the distance, and the different angles are the most extracted features for the identification of the results of the Functional Reach Test. The various experiments in the selected studies are mainly related to stroke disease, proving its reliability.

This paper's continuation is organized as follows: Section 2 presents the methodology of this review, sharing the research questions, inclusion criteria, search strategy, and the different study characteristics extracted. The results and a summary description of each selected study are presented in Section 3. Section 4 offers a discussion of the results. This paper is finalized with the conclusions of the study, presented in Section 5.

2. Materials and Methods

2.1. Research Questions

The main research questions of this review were as follows: (RQ1) How can sensors improve the measurement of the Functional Reach Test results? (RQ2) Which features extracted from the different sensors may be used in the analysis of the Functional Reach Test? (RQ3) How are sensors combined with the Functional Reach Test to allow improvements in the assessment of stroke patients? (RQ4) What are the limitations on the use of sensors in this type of study?

2.2. Inclusion Criteria

The methods available in the literature for the measurement of the results of the Functional Reach Test, and the inclusion criteria of the searched studies were: (1) studies that measure the results of the Functional Reach Test using sensors; (2) studies that contain different analysis related to the Functional Reach Test; (3) studies that use inertial or force sensors; (4) studies that were published between 2009 and 2020; (5) studies that present the population involved and results obtained; and (6) studies available in the English language.

2.3. Search Strategy

There are different scientific libraries available electronically that were used for this research. The team used the following electronic databases: ACM Digital Library, IEEE Xplore, PubMed, and ScienceDirect. The keywords used for the research for this systematic review were: "Functional Reach Test", and "sensors". Each scientific article found in the study was independently analyzed, included, and excluded by the agreement of three reviewers. This research intends to explain the different papers related to the measurement of analysis performed with the Functional Reach Test using various sensors. This research was conducted on May 11, 2020. The preliminary screening for eligibility, deduplication, and relevance assessment of identified papers was done using the natural language processing (NLP)-based framework to search and identify the relevant papers [27]. As a result, the authors were required to read only relevant papers and perform qualitative synthesis.

2.4. Extraction of Study Characteristics

The studies were analyzed, and the data available in Table 2 were extracted: year of publication, the population of the study, purpose, sensors used, and diseases present in the studied population. As most of the studies only performed the statistical analysis of different variables extracted during the Functional Reach Test's performance, there was no source code available, and the raw data were not publicly available. Thus, we contacted the corresponding author of the selected studies by email, asking for more details about each study. The sensors used in the articles are forked in two types:

"Inertial sensors" and "Force sensors". Primarily, the inertial sensors are a group of sensors that includes the accelerometer, magnetometer, and gyroscope sensors, which may be embedded on mobile devices or not. Finally, the force sensors include a set of pressure sensors, force platforms, or other force devices.

Table 2. Study analysis.

Study	Year of Publication	Population	Purpose	Sensors Used	Diseases
Fell et al. [28]	2019	35 patients (21 males, and 14 female)	Mobile health system for a support management system for patients with exercise plans or clinical measurement tools for healthcare providers	Accelerometer, gyroscope, and magnetometer	Stroke
Mengarelli et al. [29]	2018	48 subjects aged between 21 and 26 years old	Comparison of the center of pressure data	Force sensors in Nintendo Wii Balance Board	Healthy patients
Arai et al. [30]	2017	204 older adults aged between 73 and 85 years old	Examination of the utilities of maximum angular velocity assessment during knee extension	Gyroscope	Healthy patients
D'Anna et al. [31]	2017	4 male subjects aged between 27 and 40 years old	Assessment of the validity of a measurement method for Functional Reach Test implementation	Cameras	Healthy patients
Williams et al. [32]	2017	23 individuals (15 females and eight males) with an average age of 25.3 years old	Monitoring of the fall risk with Functional Reach Test	Accelerometer, gyroscope, and magnetometer	Stroke
Harris et al. [33]	2016	14 subjects (7 males and seven females) aged between 22 to 50 years old	Measurement of fall risk	Gyroscope, and accelerometer	Stroke
Lin et al. [34]	2016	309 individuals (178 females and 131 males) aged over 65 years old	Monitoring of the impact of the aging of elderly people	Pressure sensor	Healthy patients
Ruiz-Muñoz et al. [35]	2016	28 participants (14 stroke survivors and 14 healthy) subjects) over 65 years old	Analysis of the relationship between electromyographic variables, tibialis anterior architecture, and functional variables during maximal isometric and isotonic foot dorsiflexion	Accelerometer and electromyography sensors	Balance impairment
Scena et al. [36]	2016	80 patients, where 38 are males, and 42 are females	Measurement of distance, velocity, time length, arm direction and girdles translation during Functional Reach Test	Cameras	Neurological disorders
Merchán-Baeza et al. [37]	2015	Seven subjects over 65 years old	Analysis of the reliability in the Functional Reach Test parameters with mobile sensors	Accelerometer, gyroscope, and magnetometer	Stroke
Merchán-Baeza et al. [38]	2015	Ten subjects (6 females and four males) aged between 68 and 77 years old	Comparison of kinematic variables and analysis of the reliability of the kinematic measurements	Accelerometer	Stroke

Table 2. *Cont.*

Study	Year of Publication	Population	Purpose	Sensors Used	Diseases
Carmeli et al. [39]	2014	73 subjects aged between 20 and 95 years old	Description of the difference in Functional Reach Test distance and velocity during different velocities, and description of the age-related differences associated distance and velocity	Cameras	Healthy patients
Merchán-Baeza et al. [40]	2014	4 participants aged between 69 and 92 years old	Analysis of the reliability, sensitivity, and specificity	Accelerometer	Stroke
van den Heuvel et al. [41]	2014	33 individuals with unknown age	Investigation of the effects of the balance training program	Accelerometer	Parkinson's disease
Yalla et al. [42]	2014	30 patients with an average age of 73 years old	Improvement of postural stability in older adults	Accelerometer, gyroscope, and magnetometer	Healthy patients
Allen et al. [43]	2013	Physical therapy students and stroke patients from Siskin Hospital	Measurement of fall risk	Accelerometer, gyroscope, and magnetometer	Stroke
Allen et al. [44]	2013	One patient with unknown age	Measurement of fall risk	Gyroscope, and accelerometer	Ischemic stroke
Shin et al. [45]	2013	36 persons aged between 19 and 26 years old	Comparison of seated postural control in persons with spinal cord injury with age-related people	Force platform	Spinal Cord Injury
Itoh et al. [46]	2012	30 subjects (9 males and 21 females with a minimum age of 63 years old	Calculation of the characteristics of the average acceleration of elderly people	Accelerometer	Healthy patients
Pertille et al. [47]	2012	32 subjects aged between 65 and 80 years old	Monitoring of the effects of the treatment of bilateral grade III mobilization of the talocrural joint	Pressure platform	Bilateral grade III mobilization of the talocrural joint
Rajaratnam et al. [48]	2011	12 individuals aged over 45 years old	Identification the effects of the use of the Wii Fit with conventional stroke rehabilitation	Force sensors in Nintendo Wii Balance Board	Hemiparetic stroke
Yamada et al. [49]	2011	45 persons aged between 73 and 89 years old	Assessment of the fall risk with the Nintendo Wii Fit program	Pressure sensors	Parkinson's disease or stroke
Costarella et al. [50]	2010	50 subjects divided aged over 55 years old	Assessment of the physical and cognitive conditions	Pressure sensors	Healthy patients
Katz-Leurer et al. [51]	2009	10 post-stroke patients with unknown age	Evaluation of the reliability of sitting balance, and the ability to change in reaching while sitting, and comparison of results from modified functional reach test and the Balance Master	Pressure sensors	Stroke

3. Results

As referred to in Figure 2, our review identified 63 scientific articles that included one duplicate, which was removed. The remaining 62 research studies were evaluated by title, abstract, and keywords, where 18 papers were excluded. The main reason for the exclusion of the 18 articles is that they are not directly implementing the measurement of the Functional Reach Test with sensors. Following the inclusion criteria, we evaluated the full text of the remaining 44 papers, which resulted in the exclusion of 20 scientific studies. The remaining 24 studies were analyzed and included in the qualitative synthesis and quantitative synthesis. Thus, we extensively examined 24 papers.

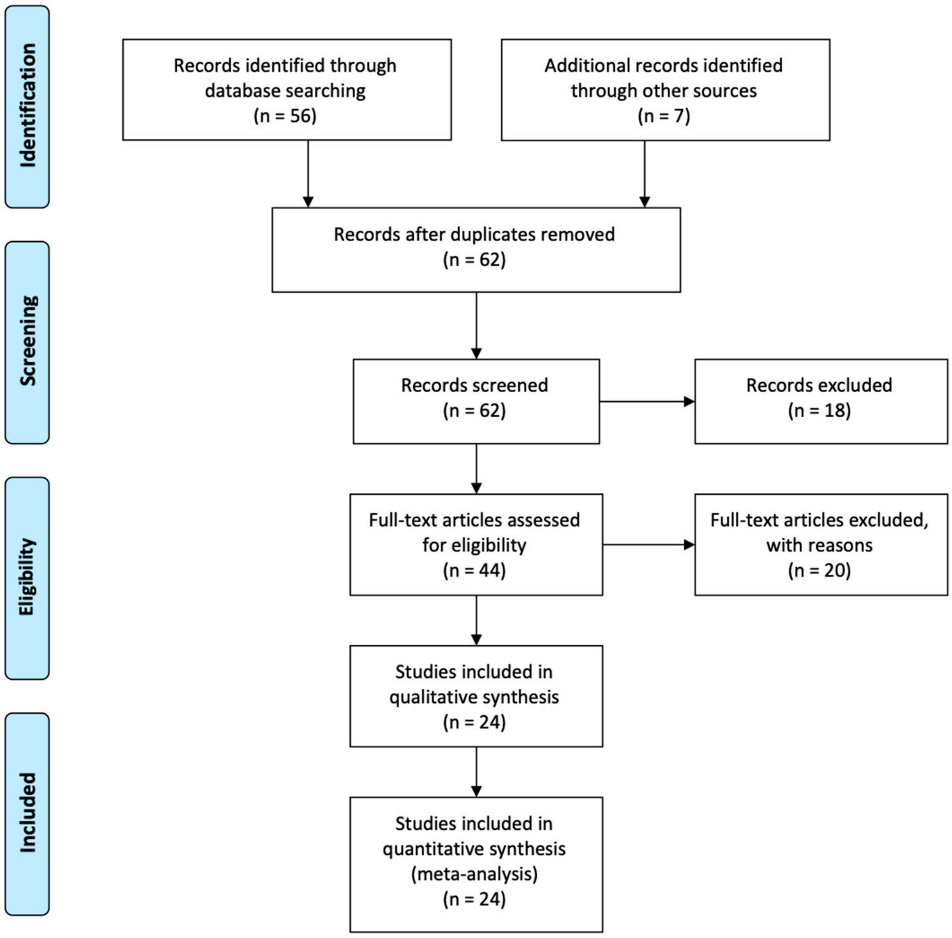

Figure 2. PRISMA flow diagram of the selection of the papers.

Our analysis performed the extraction of relevant information from the different studies, and extraction also of the different metadata. However, the interested readers may find other relevant information in the original cited works related to the measurement of the Functional Reach Test results. As presented in Table 1, the analyzed studies were published between 2009 and 2020, where one study (4%) was published in 2009, one study (4%) was published in 2010, two studies (8%) were published in 2011, two studies (8%) were published in 2012, three studies (13%) were published in 2013, four studies (17%) were published in 2014, two studies (8%) were published in 2015, four studies (17%) were published in 2016, three studies (13%) were published in 2017, one study (4%) was published in 2018, and one study (4%) was published in 2019. Following the sensors used, 12 studies (50%) used the accelerometer, 8 studies (33%) used the gyroscope, 5 studies (21%) used the magnetometer, 3 studies (13%) used force sensors, 5 studies (21%) used pressure sensors, 3 studies (13%) used cameras, and 1 study (4%) used electromyography sensors. Finally, there are different diseases available in the analyzed studies, where different types of strokes were analyzed in 11 studies (44%). The remaining diseases are balance impairment in one study (4%), Parkinson's disease in two studies (8%), spinal cord injury in one study (4%), grade III mobilization of the talocrural joint in one study (4%), and neurological disorders in one study (4%).

Different diseases found in the population were categorized as healthy people, stroke disease, and other diseases. The following sections present the results categorized by the three groups of diseases listed in Table 1.

3.1. Healthy People

The authors of [29] performed tests related to the Functional Reach Test with people with non-mentioned diseases with the Nintendo Wii Balance Board for the measurement of the center-of-pressure path deviation. It was used to recognize three activities, such as reaching down, reaching up, and walking, and five types of fall, such as backward-fall, left-fall, right-fall, forward-fall, and non-fall. The different measurements showed that the Nintendo Wii Balance Board has limited noise influence with low average noise-driven error in spatial parameters, and, when compared with other devices, it shows that this device may obtain reliable results. The results presented a correlation coefficient higher than 0.950.

Statistical methods were implemented by the authors of [30] with the maximum angular velocity to validate the exercises during knee extension in older adults, reporting a functional reach distance with an average of 28.6 cm and a standard deviation of 6.0 cm. The results obtained by the authors shown a low correlation coefficient.

The authors of [34] used pressure sensors to monitor the impact of aging with reaction time, balance, functional reach, physical weakness, and slowness of movement. After the extraction of different features, the authors implemented a Pearson correlation, reporting a high correlation in the Functional Reach Test with gold standards. The authors of [34] reported significant results at $P < 0.001$ with a Spearman Rho equal to 0.929.

In [42], accelerometer, magnetometer, and gyroscope sensors were used to quantify the ability of functional reach. For this purpose, the authors used the maximum reach distance with a slide ruler method. Further, the authors calculated the reciprocal compensatory index for the quantification of postural coordination. The Functional Reach Test shows low correlation values between 0.000 and 0.087.

The authors of [46] used the accelerometer to measure different features, including mean, the direction of accelerometer sensor, back-front, right-left, and up-down in different regions, such as lumbar, knee, ankle, and toe. The results obtained are not correlated with standard indices. However, the falls are more reliably detected with the average acceleration at the knee and lumbar positions. However, it is possible to discriminate the fall risk with the average acceleration.

In [31], two types of cameras, i.e., AXIS 210 Network Camera and SMART DX 6000, were used for the measurement of initial and final positions, distance, and time of the Functional Reach Test. The acquired data were processed by the Labview application, and BTS SMART-Analyzer to calculate the different features. It was verified that the results obtained depend on the processing methods used, verifying that the mean and standard deviation values decreased significantly in two subjects. As the results were not validated, the correlation is not available.

Carmeli et al. [39] calculated the distance and velocity of the Functional Reach Test from a camera. The data were analyzed with SPSS Software 19.0. The authors concluded that forward reach distance is, on average, 1.2 cm, but it is higher in young people. Next, the backward movement was 1.2 ± 4.9 cm. In continuation, the mean reach backward and backward movement was significantly higher in older adults, showing low correlation values.

The authors of [50] used a pressure sensor for the measurement of the time of the Functional Reach Test and variation in center-of-pressure and further application of Fisher statistics (F-test), and mini-mental state examination (MMSE), verifying that large differences exist between ages and gender, where the correlation coefficient is not very high, and the data distribution is spread out. However, the study is not correlated with the literature because a comparison is not performed.

3.2. Stroke Disease

The mobile application called mStroke [28] was used to calculate the Spearman Rho, and the correlation of the features. The features extracted were the motor arm and leg features. With the use of the mobile application, the Functional Reach Test results were disappointing because functional reach involves different variables, including various types of movement for knees, ankles, hips, shoulders, and trunk. With the use of them, the mobile application shows a high correlation of the results, but it is not reliable for clinical use. The study [28] reported significant results at $P < 0.01$ with a Spearman Rho equal to 0.630. The authors of [32] also used it to measure fall risk based on rotation angles. For this purpose, the authors measured the mean absolute error, and the correlation coefficient, reporting a correlation coefficient equal to 0.83.

The authors of [33] used accelerometer and gyroscope sensors to extract 54 statistical features, including the mean, range, absolute mean, zero-cross rate, mean cross rate, covariance, standard deviation, and mean trend. They implemented artificial intelligence methods, including k-nearest neighbors, linear support vector machine, random forest, and logistic regression for the recognition of three activities, such as reaching down, reaching up, and walking, and five types of falls, such as backward-fall, left-fall, right-fall, forward-fall, and non-fall. They were measured during the performance of the Functional Reach Test. They reported a minimum accuracy of 93.5% in the recognition of the activities related to Functional Reach Test, but this is not validated with other instruments.

Regarding the use of accelerometer, magnetometer, and gyroscope sensors for the analysis of the Functional Reach Test's reliability, the authors of [37] used the intraclass correlation coefficient. Different features were extracted and used, such as the distance of the Functional Reach Test, maximum angular lumbosacral/thoracic displacement, time of maximum angular lumbosacral/thoracic displacement of the Functional Reach Test, time for the return to starting position, the total time of the Functional Reach Test, the average speed of the Functional Reach Test, maximum angular lumbosacral/thoracic displacement speed of the Functional Reach Test, starting to return position speed, average acceleration of the Functional Reach Test, maximum angular lumbosacral/thoracic displacement average acceleration of the Functional Reach Test, and acceleration average return starting position of the Functional Reach Test. The results obtained always showed high correlation intrasubject and intersubject between 0.840 and 0.989.

With two inertial sensors, the authors of [38] measured the Functional Reach Test distance, and time, displacement, and acceleration from different instants based on kinematic variable differences. The results revealed that the angular displacement was higher in older adults, but they completed the test in similar times. Individuals with stroke disease showed higher acceleration values. The presented results showed high correlation values with a correlation coefficient between 0.987 and 0.990.

Merchán-Baeza et al. [40] measured several features, including different angles of the Functional Reach Test, the maximum time of lumbosacral/thoracic angular displacement, lumbosacral/thoracic maximum angular displacement, time return initial position, total time, resultant displacement, speed mean, maximum speed, minimum speed, maximum resultant speed, minimum resultant speed, mean acceleration, maximum acceleration, minimum acceleration, maximum resultant acceleration, and minimum resultant acceleration, with an accelerometer sensor. With these measurements, the authors compared the acquisition of the different data from different regions of the body, i.e., lumbar and trunk regions. The data were acquired with two inertial sensors, where the functional reach distance measured was 12.8 ± 2.1 cm, revealing a high correlation in intrasubject and intersubject reliability with a correlation coefficient between 0.983 and 0.987.

In [43], different inertial sensors were used to measure different things, such as the recognition of chest pressure, arm posture, reach distance, and failed test, as well as the detection of falls. For this purpose, they measured the different angles with the accelerometer, combination of yaw, pitch, and roll, measurement of quaternion with accelerometer and gyroscope, and calculation of the length of the trunk and the different angles. The implemented algorithm consists of three steps, including the measurement of the angle between the gravitational vector and the chest, the calculation of the linear acceleration with the sensors on the chest, and the analysis of the rotational rate. The system measures the wrong body posture, taking steps during the test, falling, and twisting torso, as well as it measures the reach with errors less than 0.5 inches, but the study was not compared with others.

Allen et al. [44] also used gyroscope and accelerometer sensors to estimate fall risk with a Functional Reach Test based on the detection of steps and shuffles. They obtained different errors related to the measurement of distance reach and others related to the wrong body posture, falling, and steps during the test, but the results were not evaluated with other studies.

The authors of [48] used the Nintendo Wii Balance Board to determine the effects of the use of the Wii Fit for the evaluation of the balance of persons with sub-acute stroke. They used the data acquired from the different sensors, measuring the Mann–Whitney U, the dislocation in the Z-axis, the asymptotic significance, and the exact signification. For the evaluation of the Functional Reach Test, the authors implemented two statistical methods, such as Mann–Whitney U test and Wilcoxon sign ranked test, verifying that significant improvements were verified with the Wilcoxon sign ranked test. However, the results showed a low correlation value equal to 0.109.

Yamada et al. [49] implemented the Functional Reach Test with fallers, measuring the distance with an average of 20.3 cm and a standard deviation of 7.3 cm in all individuals with low correlation in this type of test. The results showed a low correlation value of 0.453.

In [51], the authors used a pressure sensor for the measurement of the maximum distance, mean of stroke activity scale, stroke assessment scale, and Functional Independence Measure, implementing Pearson correlations. Thus, the test presented high reliability and responsiveness to the paretic side, showing a high correlation coefficient between 0.900 and 0.970.

3.3. Other Diseases

In [35], statistical software (IBM SPSS 24.0) was used to implement different measurements related to the combination of different variables, including inertial and electromyography sensors, and a collection of functional variables during maximal isometric and isotonic foot dorsiflexion in patients with balance impairment. Various analyses were performed, such as the normality with the Kolmogorov–Smirnov harmonization test, the comparison between the two groups of normal distribution data with the T-test, the comparison of non-normal distribution data with the Mann–Whitney U test, the comparison of data for more than three groups with the Kruskal–Wallis test, pre-treatment and post-treatment comparisons with the Wilcoxon signed rank test and the comparison of categorical data with the chi-square test. The results reported a high correlation score between groups of persons between 0.651 and 0.719.

Patients with Parkinson's disease were evaluated in the performance of the Functional Reach Test, assessing the effects of a balance training program to improve postural control [41]. The authors extracted the Functional Reach Test distance between 27.1 and 16.4 cm, reporting a correlation coefficient between 0.054 and 0.899.

A group of individuals with spinal cord injury also performed the Functional Reach Test, where the analysis started with the measurement of the root mean square and velocity during the performance of the Functional Reach Test [45]. The authors also used the SPSS software for the implementation of Holm-modified Bonferroni correction and multiple comparisons, verifying a high correlation between the different variables, but the results were not compared with the literature.

In [47], the authors used a pressure platform for the evaluation of a single treatment of bilateral grade III mobilization of the talocrural joint on the balance of older women, measuring the distance of the Functional Reach Test for the comparison of the placebo group with the mobilization group. The chi-squared test was implemented with the data related to the two groups, and they reported an average distance between 28.4 and 30.4 cm with a correlation coefficient between 0.060 and 0.881.

The authors of [36] used the data acquired from cameras to measure the Tinetti score, distance, velocity, stop time, and lowering of the Functional Reach Test. The data were analyzed with SPSS

Version 17, calculating the P-values with Student's t-test, ANOVA, and Pearson's correlation coefficient during the performance of the Functional Reach Test. The correlations between the performance of the Functional Reach Test with velocity was 0.60, stop time was 0.05, and lowering was 0.14. The distance of the Functional Reach Test varied between 13.1 ± 4.7 cm, and 24.5 ± 10.3 cm. However, in some cases, there was high variability in the results.

4. Discussion

Mobile devices include several inertial sensors, such as accelerometer, magnetometer, and gyroscope sensors, and most of the studies found (72%) about the implementation of the automatic measurement of the Functional Reach Test used these types of sensors. Different features are extracted from the various studies, which are categorized in dynamic balance, quantitative, and raw statistics. The sensors available in mobile devices are commonly named as low-cost sensors. Another low-cost sensor that can be combined with mobile devices is the Bitalino device [52]. The study's efficiency is not commonly reported, but we contacted the various authors to obtain detailed information about the effectiveness of the implemented methods. This study only considered the studies that at least presented the methods used, the features extracted, and the population considered. The implementation of machine learning methods combined with the implemented statistical methods may be used to validate the different measurements.

The Functional Reach Test, created in 1990, is used to measure and assess dynamic balance in a simple task [13]. It is defined as the measurement of the maximum distance between the arm's length and the remaining parts of the body in a standing position [14]. It is mainly used to measure the limit of stability. This test may help to measure fall risk, where the individual should be able to reach more than 15 centimeters to avoid the different problems [15]. As presented in Table 2, various features are being used to measure the results of the Functional Reach Test, where the most used features are mean speed, mean acceleration, distance, and different angles. The most used features are highlighted in Table 3.

The extracted features from the studies analyzed were categorized as presented in the Interpretation column (Table 3). There are different proposed categories: dynamic balance, which mainly describes the dynamic balance of the person; quantitative, which explains some aspects of the Functional Reach Test or another physical characteristic; and raw statistic, which denotes features calculated with a statistical function directly on the raw sensory data.

The automatic and accurate measurement of the Functional Reach Test results and the different methods proposed in the literature proved that the use of sensors increased the accuracy or correlation of the analysis of the different results on the Functional Reach Test. Between the 24 studies analyzed (100%), 12 of these studies (50%) rely on the measurement of the distance measured by inertial or imaging sensors. The Functional reach Test is mainly related to the fall risk directly associated with strokes, mostly present in older adults. The data retrieved from the sensors can improve the measurement of the results of this test. This test is related to several subjects of medicine.

We extensively analyzed the different studies to verify the existence of the validation of the various studies, but none of them are clinically and rigorously validated. As these studies are related to humans, we also tried to verify the existence of the agreement of the human subject research ethics committee, but none of the studies referred to its existence.

There are different points of view for the analysis of the reliability of the use of sensors for the measurement of the results of the Functional Reach Test. Only one study (4%) reported the measurement accuracy on the recognition of the different movements, but 15 studies (62.5%) presented the correlation values, where only 2 studies (8%) showed low correlation in the results. Still, they showed that inertial sensors and cameras can be used with reasonable accuracy to measure the distance. The same sensors may be used for the measurements of mean speed and mean acceleration. Other more complicated parameters could not be measured accurately to a sufficient degree. As the mobile devices are ubiquitous, any developed solutions for them could be easily made available to a lot of people. However, these methods should be validated for acceptance in medical circumstances.

Table 3. Features relative to the Functional Reach Test.

Features:	Interpretation:	Number of Studies:
mean speed	Dynamic Balance	7
mean acceleration		4
maximum angular lumbosacral/thoracic displacement speed		2
maximum lumbosacral/thoracic angular displacement		2
maximum time of lumbosacral/thoracic angular displacement		2
resultant displacement		2
balance		1
bent angle		1
maximum acceleration		1
maximum angular lumbosacral/thoracic displacement average acceleration		1
maximum resultant acceleration		1
maximum resultant speed		1
maximum speed		1
minimum acceleration		1
minimum resultant acceleration		1
minimum resultant speed		1
initial position		1
final position		2
mean of stroke activity scale		1
minimum speed		1
distance	Quantitative	12
reaction time		2
total time		4
center-of-pressure path deviation		1
maximum distance		2
root mean square		1
shuffles		1
steps		1
time return initial position		1
trunk length		1
angle	Raw statistic	3
pitch		2
roll		2
yaw		2
absolute mean		1
covariance		1
mean		1
mean cross rate		1
mean trend		1
quaternion		1
range		1
standard deviation		1
variance		1
zero-cross rate		1

This review demonstrated that the Functional Reach Test's measurement can be performed with the sensors available on off-the-shelf mobile devices to measure the different parameters related to the test. As these devices have limited processing capabilities, and the measurement of this test may be performed with low resources, the constraints related to the network connections may be reduced, and only the restrictions related to the data processing locally are present [25,26]. This test is mainly associated with patients with stroke, where artificial intelligence methods may automatically detect the stage of the treatment. The different diseases found in the various studies are different types of stroke, balance impairment, Parkinson's disease, spinal cord injury, and bilateral grade III mobilization of the talocrural joint. With a mobile application, this test may be performed with low-cost devices, and the patients may execute his/her measurements without a healthcare professional's visit. Further, the performance of the tests with autonomy by the persons can help healthcare professionals to monitor patients' states anywhere at any time.

Each study used a different set of features, and there is no correlation between the purpose, the method used, and features extracted. Further, only the distance of the Functional Reach Test is available in most of the studies. Thus, these studies have different purposes, and it allows different types of measurements.

The main problem recognized by the Functional Reach Test is related to the different types of strokes, and, consequently, the detection of falling. Various things may affect the performance and detection with sensors, such as the involuntary movements during the performance of the test, the different persons taking different medications, and the discovery of the various parameters, which is always related to environmental conditions.

This review highlights the different related works about the measurement of the Functional Reach Test results using sensors. A lot of research studies are mainly related to the use of dynamic balance and quantitative features. However, these devices have limited capabilities, including limited memory, battery, and power processing. For the evaluation of these tests, more sophisticated techniques may be applied to detect the different types of movement instead of isolated features. The combination of features may increase the reliability of the measurement. These methods may be integrated with the system for the analysis of the different physical states or the electronic health records of patients, which will be automatically for the various healthcare professionals with the previous approval of the patient. It raises several challenges related to data privacy and security. However, it may be beneficial for different patients for the measurement of health states.

5. Conclusions

This systematic review researches the sensors that can be used to measure Functional Reach Test results to detect the different parameters related to the patient's stability. The use of these tests with physical functional tests may allow the performance of different conclusions related to the falling or strokes in older adults, and the development of solutions to minimize the various risks.

Different research studies proposed using technological equipment, e.g., mobile devices and low-cost sensors. Inertial sensors are available in the most commonly used mobile devices, and they allow the acquisition of different physical and physiological parameters efficiently. The mobile devices had low capabilities, but they have been recently increased. These devices are now capable of performing complex tasks and measuring the different results of physical functional tests. Finally, it was confirmed that this test's implementation does not require sophisticated equipment and monitoring from healthcare professionals. The measurements of the Functional Reach Test with inertial sensors may be available for all populations with autonomy.

Nineteen studies were analyzed, and the main findings are presented as follows:

(RQ1) *How can sensors improve the measurement of the Functional Reach Test results?* The use of embedded sensors in mobile devices is very convenient because it allows patients to autonomously perform the Functional Reach Test without the presence of a healthcare professional. The sensors are starting to be used in physiotherapy and medicine subjects widely. The data collected from the different sensors may allow the creation of accurate methods for the measurement of the results of this test. The main concern is that the accuracy often was not reported in the analyzed studies. However, the correlation coefficient in the different studies analyzed, when presented, shows high correlation values except for one study. More research is needed to measure different variables and increase the results;

(RQ2) Which features extracted from the different sensors may be used in the analysis of the Functional Reach Test? The most used features for the analysis of the results of the Functional Reach Test are mean speed, mean acceleration, distance, and different angles. However, the reliability can be evaluated with the correlation coefficient, verifying that the correlation with other instruments is commonly high for the different methods for the calculation and analysis of the different features;

(RQ3) How are sensors combined with the Functional Reach Test to allow improvements in the assessment of stroke patients? The combination of the Functional Reach Test with sensors allows the constant and autonomous monitoring of the state of stroke patients. It also enables the development of new technological systems for the remote control of people. Thus, ten studies are related to the treatment and recovery of different types of strokes, to the presence of strokes, and to the post-stroke treatment with the Functional Reach Test.

(RQ4) What are the limitations on the use of sensors in this type of study? There are different limitations on the use of sensors related to the accuracy and reliability of the sensors, but other challenges are related to the different diseases and capabilities of people. The positioning of the sensors is another limitation that can influence the data acquisition. However, the use of inertial sensors is expected to be more convenient than the use of traditional methods with medical personnel using rulers and measuring tapes because the measurements could be performed at real time, even at the expense of somewhat lower accuracy.

We identified several studies related to the implementation of the Functional Reach Test with sensors, but it can only be as a support to the healthcare professional. However, more studies may be performed for the identification of different diseases related to the test. This literature review highlighted that the sensors available on off-the-shelf mobile devices, i.e., accelerometer, magnetometer and gyroscope, can be explored to improve the accuracy of reports of the test's results as these sensors are able to help in the measurement of distances. The sensors used are mainly low-cost and commonly used devices that allow the development of tools for measuring the results of the Functional Reach Test.

As previously proposed [24], it allows the development of a personal digital file coach to evaluate individuals' different conditions with a commonly used off-the-shelf mobile device. Implementing efficient machine learning algorithms that increase the reliability of the various physical functional tests may benefit the development of different systems. However, a variety of devices available on the market, including smartphones, oximeters, thermometers, blood pressure monitors, and portable ECG devices, to name a few, have several limitations related to errors in data acquisition, and inconsistent device accuracy. Future research could focus on standardizing performance and accuracy ratings, providing transferability across studies leveraging different devices, and integration in Internet of Things (IoT) platforms, among others.

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