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Research article

Mobile and wearable technologies for the analysis of Ten Meter Walk Test: A concise systematic review

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ABSTRACT

Physical issues started to receive more attention due to the sedentary lifestyle prevalent in modern culture. The Ten Meter Walk Test allows measuring the person's capacity to walk along 10 m and analyzing the advancement of various medical procedures for ailments, including stroke. This systematic review is related to the use of mobile or wearable devices to measure physical parameters while administering the Ten Meter Walk Test for the analysis of the performance of the test. We applied the PRISMA methodology for searching the papers related to the Ten Meter Walk Test. Natural Language Processing (NLP) algorithms were used to automate the screening process. Various papers published in two decades from multiple scientific databases, including IEEE Xplore, Elsevier, Springer, EMBASE, SCOPUS, Multidisciplinary Digital Publishing Institute (MDPI), and PubMed Central were analyzed, focusing on various diseases, devices, features, and methods. The study reveals that chronometer and accelerometer sensors measuring spatiotemporal features are the most pertinent in the Gait characterization of most diseases. Likewise, all studies emphasized the close relation between the quality of the sensor's data obtained and the system's ultimate accuracy. In other words, calibration procedures are needed because of the body part where the sensor is worn and the type of sensor. In addition, using ambient sensors providing kinematic and kinetic features in conjunction with wearable sensors and consistently acquiring walking signals can enhance the system's performance. The most common weaknesses in the analyzed studies are the sample size and the unavailability of continuous monitoring devices for measuring the Ten Meter Walk Test.

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1. Introduction

Ten Meter Walk Test is a performance metric to evaluate functional mobility, vestibular function, and gait [1,2]. The primary outcome of this test is to assess walking speed and the steps number performed during the 10-m distance [3]. This test plays a vital role in various neurodegenerative disorders such as traumatic brain injury or damage, multiple sclerosis, Parkinson's disease, spinal cord injury, acquired cerebral palsy, hip fracture, geriatrics, lower limb amputation, and other movement disorders. It is used to assess function and identify clinical issues in preschoolers, kids, adults, and seniors, demonstrating outstanding reliability [4–6]. Regular and ongoing assessment of people's movement abilities may aid in identifying and evaluating the severity of neurological problems. The test can be performed with or without assistive devices, but its performance must be documented [7]. In general, two consecutive trials are administered with a comfortable walking speed and at least a chronometer/stopwatch to count the performance test time [8,9].

Products designed for mobile phones, tablets, wearable technology, and other portable electronic devices are referred to as mobile technologies [10,11]. With the rapid advancement and adoption of mobile technologies, there is a rising need for improved performance from ever-smaller devices and a requirement for a more comprehensive safety margin and stricter compliance standards due to direct human connection [12]. Any gadget worn on the body is commonly called a wearable device, including fitness trackers, smart glasses, and smartwatches [10,11]. These devices include sensors that allow the measurement of inertial, imaging, medical data, or a simple chronometer [13–15]. These data are helpful for accurately measuring the Ten Meter Walk Test results [16,17]. However, deploying sensors, i.e., their location and attachment method, for optimal analysis and data filtering and their analysis are also challenging.

Regarding validating the Ten Meter Walk Test, the authors of [18] implemented the test with Multiple Sclerosis patients, revealing a high correlation related to the self-care at a comfortable speed. They also presented an adequate to excellent correlation with support in mobility at a comfortable speed and with addiction in domestic life at a comfortable speed. Additionally, the authors of [19] implemented the test with stroke patients, demonstrating a high correlation with instrumented activities of daily living and the Barthel Index. Finally, with the analysis of healthy adults, the authors of [20] revealed a poor correlation between the Box and Block Test and a good correlation with the Functional Reach Test. However, the impact of various standardizations of its conduct on test outcomes is unknown.

Several review articles [19,21,22] in the literature have discussed the use of sensors for gait analysis. However, their focus was limited to either specific sensors or diseases. More comprehensive reviews were presented using wearable or both wearable and non-wearable sensors [23,24]. The Ten Meter Walk Test is very popular for clinical review studies, such as [25–27]. However, to the best of the authors' knowledge, no existing comprehensive study reviews the Ten Meter Walk Test from the perspective of Mobile and Wearable technologies.

The main distinction between our paper and these review papers is that our paper presents an analysis of wearable sensors covering all disease monitoring regarding a specific physical functional test. This systematic review performs a search of scientific works related to the Ten Meter Walk Test implementation with wearable and mobile devices, published between January 2010 and October 2022 in the following scientific databases: IEEE Xplore, Springer, Elsevier, EMBASE, SCOPUS, Multidisciplinary Digital Publishing Institute (MDPI), and PubMed Central. The studies found to reveal many clinical conditions. However, our focus was on using technological devices for measuring performance during the test, performing its relationship with the specific population. Through this analysis, we determined the correlation of the most used features with the most used methods and the benefits and limitations of its study, opening further implementation of a system to minimize the limitations found and help medical doctors and patients with a personalized solution.

The main contributions of this systematic review are the clarification of the use of wearable and mobile devices to automate the diagnosis of the physical problems related to the test with reduced human intervention with different methods. Also, identifying the different technological methods is important for further developing a new methodology for the analysis of the results, where this paper presents the most used methods and features extracted. Furthermore, the classifications of the sensors, methods, and features found in the literature were proposed for the comparative analysis. Finally, the overview of a future solution to be developed is presented. These contributions can provide an overview of the previous studies on measuring the test results.

Solutions for remote monitoring and therapy are required for many medical diseases. Automatic data analysis can aid in detecting several diseases because sensors are included in widely used mobile devices, and different physical tests can be carried out independently. Automated detection uses technology, statistical analysis, and artificial intelligence approaches to discover patterns related to different physical movements. The accuracy of these measures is crucial for treating some disorders, such as stroke, for the early disease's diagnosis, such as Parkinson's disease, or ongoing monitoring of specific populations, such as older adults.

2. Methodology

This systematic review is based on the methodological framework of the "Preferred Reporting Items for Systematic Reviews and Meta-Analyses" (PRISMA), employing specific inclusion and exclusion criteria and well-defined search phrases to find and gather pertinent articles. Then, duplicates, additional unrelated or incomplete articles, and papers that go through a thorough screening process are removed from the results. Next, a qualitative analysis of manually chosen, high-quality articles is carried out [28]. As a result, this study assesses the most recent developments in the literature related to implementing the specified test with wearable or mobile devices. To facilitate an effective search of the literature databases, a natural language processing (NLP) toolbox was automatically employed [29]. Other articles follow a similar methodology in automating the PRISMA flow [30,31].

2.1. Research questions

The following were the primary inquiries of this systematic review: (RQ1) Which are the most used systems for measuring the Ten Meter Walk Test results? (RQ2) What are the advantages of measuring the Ten Meter Walk Test with wearable devices? (RQ3) How do the features extracted by the sensors improve the monitoring of the evaluation of the Ten Meter Walk Test results for different diseases?

2.2. Search strategy

The search approach used in this paper follows the PRISMA technique to find and analyze the Ten Meter Walk Test-related material published between January 2010 and October 2022. First, we used an automatic approach to search for papers published by and following publishers in their respective digital libraries: IEEE Xplore, Elsevier, Springer, and Multidisciplinary Digital Publishing Institute (MDPI), as well as the paper repository PubMed Central. Processing of these publishers is automated through a tool that performs an exhaustive search in these libraries based on the provided search phrases. Then all articles returned by the respective systems are analyzed by the NLP toolkit, and irrelevant ones are automatically eliminated. The reader is referred to the work of Zdravevski et al. [29] for further in-depth information regarding the elements of the NLP toolbox. Additionally, we manually searched two additional databases, such as SCOPUS and EMBASE, to identify other papers not found in the former list that was automatically processed.

The input parameters of the NLP framework are represented as a set of keywords (i.e., phrases) used to find relevant articles and a list of requirements that the identified articles must meet. The search phrases used in this study are: "Ten Meter Walk Test with wearables" OR "Ten Meter Walk Test with mobile devices" OR "Ten Meter Walk Test". Therefore, the search was performed three times separately with these phrases in all digital libraries, and then, based on the identifiers, the software removed the duplicates. Additionally, the remaining publications were analyzed per the inclusion criteria defined in the following subsection.

2.3. Inclusion criteria

The main scope of articles of interest was about ones that utilize wearable technology to analyze the Ten Meter Walk Test. The authors of this systematic review independently assessed each potentially relevant paper to see if it met the search's eligibility requirements. This multidisciplinary research involves computer, electrotechnical, and health sciences. For extracting pertinent information about the many research analyzed and connecting it to the medical industry, the studies were analyzed, the sensors were classified, and the information was mapped. The search was conducted on October 24, 2022.

The following criteria were considered when selecting studies for this systematic review: (1) studies that utilize wearables to measure the test results; (2) studies that employ mobile devices to measure the test results; (3) studies that clearly articulate their objectives; (4) studies that describe the population's characteristics; (5) studies that provide specific findings related to the test; (6) original research studies published between 2010 and 2022; (7) studies published in English language.

2.4. Ten Meter Walk Test protocol

Ten Meter Walk Test is a commonly used test and recommended method for assessing gait speed in Parkinson's disease patients [32]. It helps detect gait speed changes in response to treatment therapies due to its satisfactory measuring qualities. Traditionally, a chronometer measures only the average velocity and time during 10 m. Typically, this test is conducted on a 14-m path, with the first 2 m representing the acceleration stage and the last 2 m considered the deceleration stage, with the data from these stages discarded. The assessment is often conducted using tools such as a timer, a measuring wheel to track the distance traveled, and two markers (e.g., cones) to indicate the remaining distance. Patients are usually instructed to walk in the designated pathway at their maximum possible velocity. The use of technology will allow for the more accurate measurement of instant walking speed and walking time. Other sensors can also measure health indicators like heart rate, blood pressure, and other medical parameters.

Table 1
Sensor's categories.

Categories	Sensors
Time	Chronometer
Motion	ActTrust® device; Accelerometer; 3D-Gait Analysis; Platform robot; ActiMyo® device; Optotrak Certus; Nintendo® Wii; Shoe lift; GAITRite; COSMED h/p/cosmos T170 treadmill; Mobile device; REDCap; Lokomat gait rehabilitation robot; M5 device; BTS G-WALK device
Environment	Temperature; Light sensor
Vision	Camera; Microsoft Xbox360 Kinect camera; 4-camera system
Force	Force platform
Medical	ECG sensors; EMG sensors; BioStampRC sensor; EEG sensors; Trigno™ Wireless EMG
Magnetic	Magnetometer
Inertial	Gyroscope

2.5. Extraction of study characteristics

Different mappings were performed, including the sensors categories (Table 1), methods categories (Table 2), features categories (Table 3), and disease categories (Table 4) to support the analysis and extraction of the study characteristics.

Table 5 then includes the following data that was gleaned from the studies: the year the article was published, the location, the research's population, the study's goals, the types of sensors employed in the study, the sensors themselves, and the illnesses present in the population under investigation. Finally, Table 6 lists the methodologies used, including statistical analyses of the data, mapping of the types of methods used, features drawn from technological devices and other features, and mapping of the various features, as the focus of this review is on the methodologies used for the measurement of the results of the Ten Meter Walk Test. Unfortunately, the source code and datasets used in the research under consideration are not accessible to the public.

3. Results

The NLP toolkit automatically selected 9251 research studies from the various databases, as shown in Fig. 1. From the previously mentioned additional sources, 281 studies were added to further analysis. From the total 9532 studies, 7018 papers were kept after removing 2514 duplicate data found via the Digital Object Identifier (DOI). A title analysis resulted in the exclusion of 143 publications. After, the remaining 6875 papers underwent an abstract examination, and 6739 articles were eliminated. In addition, 101 research studies unrelated to the Ten Meter Walk Test or do not employ devices or are literature reviews that were not immediately excluded by the framework were excluded after the remaining 136 studies were examined. Finally, the quantitative synthesis and meta-analysis incorporated the final 35 studies.

The selected studies were examined to extract the relevant data. The query performed in this study retrieved papers published between January 2011 and October 2022. As reported in Table 5, two studies (6%) were published in 2022, eleven studies (31%) in 2021, six studies (17%) in 2020, three studies (9%) in 2019, three studies (9%) in 2018, three studies (9%) in 2017, three studies (9%) in 2014, and the remaining four studies were published each one (3%) per year in 2011, 2013, 2015 and 2017. Regarding the sensors, eighteen studies (23%) used Chronometer, four studies (11%) used ECG sensors, two studies (6%) used a Force Platform, two studies (6%) used a Lokomat gait rehabilitation robot, four studies (11%) used Accelerometer, and two studies (6%) used Microsoft Xbox360 Kinect camera. Other sensors are distributed by one study (3%) each, such as 3D-Gait analysis, 4-camera system, ActiMyo® device, ActTrust® device, BioStampRC sensor, BTS G-WALK device, COSMED h/p/cosmos T170 treadmill, EMG sensors, GAITRite, M5 device, Nintendo® Wii, Optotrak Certus, Platform robot, Mobile device/Smartphone, REDCap, Shoe lift, Trigno™ Wireless EMG, Gyroscope, Magnetometer, temperature sensor, and light sensor. The categorization of the sensors shows that twenty studies (57%) used time sensors, fourteen studies (40%) used motion sensors, six studies (17%) used medical sensors, four studies (11%) used vision sensors, two studies (6%) used force sensors, two studies (6%) used magnetic sensors, one study (3%) used environmental sensors, and one study (3%) used inertial sensors.

Based on Table 6, the studies revealed that thirty-three studies (94%) used statistical methods, twelve studies (34%) used predictive methods, and only one study (3%) refers the use of data processing techniques. Regarding the features measured, twenty-seven studies (77%) include features related to movement, twenty-one studies (60%) to time, eight studies (23%) to metric characteristics, four studies (11%) to countable characteristics, two studies (6%) to angular characteristics, two studies (6%) to medical, and four studies (11%) to other characteristics.

Regarding Table 7, further analysis shows that only two studies (6%) are from Conference Proceedings, and the remaining thirty-three (94%) are Journal publications. Regarding the latter, thirteen (37%) were published in Q1 journals, twelve (34%) in Q2 journals, four (11%) in Q3 journals, and two (6%) in Q4 journals. These publications presented a 5.6 ± 2.4 number of authors and 14.8 ± 21.8 number of citations. Regarding the location of the different studies, seven studies (20%) were performed in the USA, four (11%) in Brazil, three studies (9%) in China, three studies (9%) in Australia, two studies (6%) in South Korea, two studies (6%) in Turkey, two studies (6%) in Italy, and the remaining nine studies were each one (3%) in Belgium, Netherlands, Israel, Ireland, Jordan, Spain, Switzerland, Germany, Pakistan, and Philippines.

Finally, regarding the population analyzed, the participants had different diseases, including stroke analysis in sixteen studies (46%), Spinal cord injury in nine studies (26%), Parkinson's disease in three studies (9%), knee problems in two studies (6%). The remaining studies contained participants with different diseases, each one (3%), including Cerebral Palsy, coronary artery disease, diabetes mellitus, Brain problems, Hip problems, Hypertension, hypothyroidism, Lung transplantation, neck cancer, Unilateral Lower Limb Prostheses, and other orthopedic or neurologic diseases. Regarding the diseases previously mapped in Table 4, thirty-one studies

Table 2
Methods categories.

Categories	Methods
Statistical methods	Descriptive analysis; Proportional Integral Mode algorithm; Shapiro-Wilk test; Kolmogorov–Smirnov test; Analysis of Covariance (ANCOVA); Analysis of Variance (ANOVA); Wilcoxon signed rank test; Mann–Whitney *U* test; Student's t-test; Levene's test; Fisher's exact tests; Chi-square test; Kruskal–Wallis H test; Friedman test
Predictive methods	Multivariate regressions; Pearson's correlation; Bonferroni correction; Intraclass Correlation; Spearman's rank correlation; Hierarchical multiple regression; Multidimensional Scaling; Dimensionality reduction
Data processing	Fourth-order Butterworth low-pass filter; Continuous wavelets transform

Table 3
Features categories.

Categories	Features
Movement	Walking speed; Stride velocity; Step velocity
Metric	Walking distance; Step length; Stride length
Angular	Angles
Time	Walking time; Stance time; Swing duration; Step time; Gait cycle duration
Count	Number of steps; Number of repetitions
Medical	Heart rate; Median of the EMG metric; Maximum EMG value
Others	Actigraphy parameters; MoCA[1] score; Walking adaptability; WISCI-II[2] scores; Cadence

[1] Montreal Cognitive Assessment.
[2] Walking Index for Spinal Cord Injury II.

Table 4
Diseases categories.

Categories	Pathologies
Brain diseases	Cerebral Palsy; Brain problems; Neck cancer, Other neurologic diseases
Physical problems	Hip problems; Knee problems; Lung transplantation; Parkinson's disease; Spinal cord injury; Stroke; Unilateral Lower Limb Prostheses; Other orthopedic diseases
Cardiovascular diseases	Coronary artery disease; Hypertension
Endocrine diseases	Diabetes mellitus; hypothyroidism

(89%) comprehended the analysis of physical problems, four studies (11%) comprehended the analysis of brain diseases, one study (3%) comprehended the analysis of brain diseases, and one study (3%) comprehended the analysis of cardiovascular diseases. The following sections organize the results by studies that present physical problems (section 3.1) and studies that show only other diseases or healthy subjects (section 3.2).

3.1. Physical problems

Priyaranjan et al. [33] present a study with 51 patients (40 males and 11 females), mostly between 21 and 50 years old, separated into 29 walking and 22 non-walking individuals, and conducted for 2 years in a tertiary-level hospital. The purpose is to correlate the amount of neurological impairment to the walking abilities of individuals with spinal cord injury using the Ten Meter Walk Test and Walking Index for Spinal Cord impairment II scale. In addition, the authors assessed the average velocity for the performance of the test. The authors described and analyzed the categorical variables in number and percentage and the continuous variables as mean ± standard deviation and median using the IBM SPSS Statistics (IBM Corp., Armonk, NY). In conclusion, the individuals with lower thoracic and lumbar injury degrees had greater walking abilities. The study also shows that in individuals with traumatic spinal cord injuries, the neurological level of impairment and injury severity are predictive indicators of walking capacity.

The authors of [34] identified the different movements performed during the walking activity related to the Ten Meter Walk Test with the data acquired from the ActTrust® device composed of an accelerometer sensor, two temperature sensors, and one light sensor. The five participants in the study are two males and three females aged 56.4 ± 11.2 years old after recovering from a stroke at least 45 months ago. The features acquired during the test performance were actigraphy parameters, MoCA score, walking speed, and walking distance for applying the Proportional Integral Mode (PIM) algorithm. In addition, the data were statistically evaluated with IBM SPSS Statistics (IBM Corp., Armonk, NY), using the Shapiro-Wilk test and a Pearson correlation. The results revealed that the walking speed obtained by the participants was 0.84 ± 0.26 m/s^2, demonstrating a high correlation with the circadian parameters. Also, it was verified that the continuous measurement of sleep and activity cycles in assessing stroke survivors is essential.

Azharuddin et al. [35] used a chronometer to compare the results of five times sit-to-stand scores with the gait speed measured during the Ten Meter Walk Test. The sixteen stroke patients in the study are aged between 45 and 65 (56.19 ± 7.98) and can walk for 10 m with or without a walking aid. They also had other diseases, such as Hypertension, diabetes mellitus, coronary artery disease, and hypothyroidism. The data were also statistically evaluated with IBM SPSS Statistics (IBM Corp., Armonk, NY) with Pearson's correlation coefficient with a significance level of $p < 0.05$. The results showed a moderately strong negative relationship between five times sit-to-stand scores and gait speed.

In [36], twenty post-stroke patients (10 females and 10 males) aged 53.9 ± 11.2 years old were analyzed with the 3D-Gait analysis composed by six cameras (VICON, Oxford Metrics Ltd, Oxford, UK) set at 100 Hz as sample rate, and two force platforms (Kistler, Winterthur, CH; acquisition frequency 500 Hz). For kinematic assessment, passive reflecting markers and force platforms were also utilized. The authors used clinical-functional measures to characterize the functional limitations of post-stroke hemiparetic patients. When the time to complete the Ten Meter Walking Test was analyzed, it showed 18.52 ± 10 s. After the Kolmogorov-Smirnov test, the findings were statistically assessed using Statista software (Statsoft, College Station, Texas, USA). Additionally, the paretic lower limb and the non-paretic lower limb were compared using a one-way analysis of variance (ANOVA). According to Pearson's correlation coefficients and multivariate regressions, the Gait Profile Score demonstrated a decent relationship with the Functional Ambulation

Table 5
Study analysis.

Paper	Year	Population	Purpose of Study	Sensors categories	Sensors Used	Diseases categories	Diseases
Priyaranjan et al. [33]	2022	51 patients	The research is aimed at how persons with spinal cord injuries recover their natural ability to walk to develop rehabilitation programs.	Time	Chronometer	Physical problems	Spinal Cord Injury
Umemura et al. [34]	2022	3 females and 2 males	The authors examine how a sample of chronic stroke survivors' levels of cognitive impairment, walking ability, sleep patterns, and circadian characteristics.	Motion; Environment	ActTrust® device; Accelerometer; Temperature; Light sensor	Physical problems	Stroke
Azharuddin et al. [35]	2021	16 patients	The authors identified potential relationships between the gait speed measured by the Ten Meter Walk Test, and quality of life.	Time	Chronometer	Physical problems; Brain diseases; Endocrine diseases; Cardiovascular diseases	Stroke; Hypertension; diabetes mellitus; coronary artery disease; hypothyroidism
Bigoni et al. [36]	2021	10 females and 10 males	The authors sought to determine whether there was a link between the Gait Profile Score and the clinical-based outcome measures to evaluate functional restriction in post-stroke hemiparetic patients.	Motion; Vision; Force	3D-Gait Analysis; Cameras; Force platforms	Physical problems	Stroke
Calabro et al. [37]	2021	9 females and 11 males	The authors wanted to evaluate the neurophysiological bases of robot-assisted ankle rehabilitation (using a platform robot) and its effectiveness in enhancing gait performance and balance in patients with incomplete spinal cord damage.	Motion; Medical	Platform robot; Accelerometer; ECG sensors; EMG sensors	Physical problems	Spinal cord injury
Chang et al. [38]	2021	5 females and 11 males	The authors examined the effects on the balance of walking backward on a treadmill, walking speed, and cardio-pulmonary fitness in persons with chronic strokes.	Time	Chronometer	Physical problems	Stroke
Davis et al. [39]	2021	100 females and 151 males	The study aims to evaluate how Parkinson's syndromes affect individuals with normal pressure hydrocephalus diagnosis.	Time	Chronometer	Physical problems	Parkinson's disease
Eymir et al. [40]	2021	42 females and 14 males	The study aimed to evaluate the Step Test's concurrent validity, reliability, and little discernible change in individuals who had undergone total knee arthroplasty.	Time	Chronometer	Physical problems	Total knee arthroplasty
Karunakaran et al. [41]	2021	4 females and 10 males	The study assesses a robotic exoskeleton's capacity for high-dose gait training. It also quantifies the therapeutic impact on functional ambulation.	Time; Motion	Chronometer; Accelerometer	Physical problems	Stroke
Poleur et al. [42]	2021	46 females and 36 males	The authors want to gather normative information on spontaneous stride length	Motion; Magnetic	ActiMyo® device; Accelerometer; Magnetometer	N/A	N/A

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Table 5 (*continued*)

Paper	Year	Population	Purpose of Study	Sensors categories	Sensors Used	Diseases categories	Diseases
			and velocity in an uncontrolled context and its changes over 12 months.				
Tan et al. [43]	2021	2 females and 9 males	The authors examined how much daily acute intermittent hypoxia and walking exercise improved intralimb motor coordination and overground walking performance.	Time; Motion	Optotrak Certus; Chronometer	Physical problems	Spinal cord injury
Valenzuela et al. [44]	2021	1 female and 3 males	The authors worked with teenagers with cerebral palsy who were categorized as having level II gross motor function in a two-week, 1.5-h per day intense treatment using a non-immersive virtual reality exercise game.	Motion	Nintendo® Wii	Brain diseases	Cerebral Palsy
Zieriacks et al. [45]	2021	21 females and 89 males	The study aimed to determine the functional and motor recovery in the post-acute phases of neurorehabilitation in participants with acute and chronic Spinal Cord Injury.	Time	Chronometer	Physical problems	Spinal Cord Injury
Ali et al. [46]	2020	9 females and 13 males	The study aimed to evaluate the effects of a task-oriented circuit class training program on the capacity to walk and balance in subacute stroke patients.	Time	Chronometer	Physical problems	Stroke
Fortes et al. [47]	2020	23 females and 19 males	The authors compared the effects of a 1.5 cm shoe elevation on the unaffected lower limb with and without a shoe lift on the immediate post-stroke alterations in gait speed and functional mobility.	Time; Medical	Shoe lift; Chronometer	Physical problems	Stroke
Pehlivan et al. [48]	2020	20 females and 43 males	Instead of using the 6-min walk test to determine exercise capacity after lung transplantation, the authors used the 10-m walk test instead.	Time	Chronometer	Physical problems	Lung transplantation
Sawers & Hafner [49]	2020	7 females and 13 males	This study aimed to describe the impact of practice on three performance-based assessments often given to Lower Limb Prostheses users. Additionally, it was predicted that in the case of unilateral Lower Limb Prostheses users, practice effects would show up on the Ten Meter Walk Test.	Time	Chronometer	Physical problems	Unilateral Lower Limb Prostheses
Timmermans et al. [50]	2020	14 females and 19 males	The normal overground FALLS program and a treadmill-based treatment called C-Mill therapy were compared	Vision	Microsoft Xbox360 Kinect camera	Physical problems	Stroke
Vieira de Moraes Filho et al. [51]	2020	10 females and 30 males	To provide new parameters for a better understanding of its effects and a good and progressive resistance training use as a	Time	Chronometer	Physical problems	Parkinson's disease

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Table 5 (*continued*)

Paper	Year	Population	Purpose of Study	Sensors categories	Sensors Used	Diseases categories	Diseases
			supplemental therapy, the authors evaluated the short-term effects of advanced resistance training on Parkinson's disease patients.				
Lunar et al. [52]	2019	108 females and 72 males	The research aimed to determine whether mobility test results varied between participants who lived in urban and rural areas and to report the initial reference numbers for the test.	Time	Chronometer	Physical problems	Stroke
O'Brien et al. [53]	2019	25 females and 25 males	The study analyzed variations in sensor-derived measures with age, sex, height, and weight. During regular clinical outcome testing, it was tested and confirmed using a single inertial measurement unit to quantify gait and balance.	Medical; Motion	BioStampRC sensor; GAITRite	Physical problems	Stroke
Ofran et al. [54]	2019	24 females and 46 males	The authors examined the correlation between spatiotemporal gait parameters, clinical gait test results, and predicted standard clinical measures in stroke patients.	Vision	4-camera system	Physical problems	Stroke
Broderick et al. [55]	2018	6 females and 25 males	The authors determined the effectiveness and viability of mirror therapy and treadmill training for post-stroke lower-limb.	Motion	COSMED h/p/cosmos T170 treadmill	Physical problems	Stroke
Bui et al. [56]	2018	12 females and 8 males	The study aimed to determine if adding an app-based supplemental fitness program to orthopedic therapy would be practical, participant-acceptable, raise activity levels, and enhance functional results.	Motion	Mobile device	Physical problems	Hip diseases; knee diseases; other orthopedic diseases
Hadoush et al. [57]	2018	5 females and 13 males	The authors examined how treating Parkinson's disease patients with bilateral anodal transcranial direct current stimulation affects their balance and fear of falling.	Time; Medical	EEG sensors; Chronometer	Physical problems	Parkinson's disease
Éden et al. [58]	2017	8 females and 34 males	The authors wanted to determine the test-retest reliability of key physical function measures and their correlations in individuals receiving head and neck cancer therapy.	Motion	REDCap	Brain diseases	Head cancer; neck cancer
In et al. [59]	2017	13 females and 17 males	The research sought to determine how treadmill training with a Thera-Band affected stroke patients' motor function, gait, and balance.	Time	Chronometer	Physical problems	Stroke
Swank et al. [60]	2017	148 patients	The authors correlated the primary neurologic diagnosis with the Ten Meter Walk Test and activities-specific balance confidence scale.	Time	Chronometer	Brain diseases	Neurologic disorders

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Table 5 (*continued*)

Paper	Year	Population	Purpose of Study	Sensors categories	Sensors Used	Diseases categories	Diseases
Kumru et al. [61]	2016	7 females and 24 males	The authors found that adding repetitive transcranial magnetic stimulation to physical therapy improved the functional result during the initial stages of gait rehabilitation in spinal cord injury.	Motion	Lokomat gait rehabilitation robot	Physical problems	Spinal cord injury
Han et al. [62]	2015	4 males	The authors created a robotic gadget to help older adults and those with impairments, such as stroke victims and those who have suffered spinal cord injuries.	Medical; Motion; Magnetic; Inertial	Trigno™ Wireless EMG; M5 device; BTS G-WALK device; Accelerometer; Magnetometer; Gyroscope	Physical problems	Stroke; Spinal cord injury
Clark et al. [63]	2014	9 females and 21 males	The research examined Kinect's accuracy and extra data while instrumenting a gait evaluation in stroke survivors.	Vision	Microsoft Xbox360 Kinect camera	Physical problems	Stroke
Poncumhak et al. [64]	2014	11 females and 19 males	The study looked at the Ten Meter Walk Test to assess the capacity to walk without a walking aid, examining the inter-tester reliability to evaluate individuals with Spinal Cord Injury functional capacity.	Time	Chronometer	Physical problems	Spinal Cord Injury
Saensook et al. [65]	2014	26 females and 59 males	The authors used the Ten Meter Walk Test to assess independent ambulatory individuals who used a cane, walker, crutches, or another non-ambulatory assistive device.	Time	Chronometer	Physical problems	Spinal Cord Injury
Scrivener et al. [66]	2013	93 females and 97 males	The authors evaluated the Ten Meter Walk Test, Step Test, and lower limb items of the Motor Assessment Scale for responsiveness and floor/ceiling effects.	Time	Chronometer	Physical problems	Stroke
Schuck et al. [67]	2011	1 female and 3 males	The authors examined the viability of using patient-cooperative robot-assisted gait rehabilitation for incomplete spinal cord damage and stroke during a four-week treatment period.	Motion; Medical; Force	Lokomat gait rehabilitation robot; EMG sensors; ECG sensors; force sensors	Physical problems	Spinal Cord Injury

Category, Trunk Impairment Scale, and Ten Meter Walk Test.

The authors of [37] used a platform robot composed of an accelerometer, Electrocardiography, and Electromyography sensors to analyze six males and four females aged 39 ± 13 years old with incomplete spinal cord injury. The authors evaluated the gait speed during the Ten Meter Walk Test performance with statistical analysis, including the Kolmogorov–Smirnov test, analysis of covariance (ANCOVA), and Pearson's correlation coefficient. The results reported a gait speed of 0.43 ± 0.11 to 0.51 ± 0.09 m/s for the experimental group and from 0.4 ± 0.13 to 0.45 ± 0.12 m/s for the control group. It shows a clinically significant improvement in gait performance with robot-aided ankle rehabilitation (using a platform robot).

Chang et al. [38] examined the effects of chronic stroke patients' balance, walking speed, and cardiopulmonary fitness by walking backward on a treadmill. Sixteen individuals participated in the study, where 8 were included in the control group (3 females and 5 males) aged 54.38 ± 14.05 years, and 8 in the experimental group (2 females and 6 males) aged 52.39 ± 6.06 years. The Ten Meter Walk Test was used to evaluate the walking speed and time with a frequency of three times a week for four weeks. The data were analyzed with IBM SPSS Statistics (IBM Corp., Armonk, NY) to implement the Mann–Whitney *U* test, Wilcoxon signed-rank test, and the Student's t-test to determine the differences in all variables between the control and experimental groups. The results showed significant differences between the start and end of the study, and the walking speed increased by 8 m/min in the experimental group.

Davis et al. [39] used a chronometer to analyze 251 patients (151 males and 100 females) aged 73.83 ± 8.67 years old with

Table 6
Study methods and features.

Paper	Type of Methods	Methods	Type of Features	Features
Priyaranjan et al. [33]	Statistical analysis	Descriptive analysis	Movement	Walking speed
Umemura et al. [34]	Statistical analysis; Predictive methods	Proportional Integral Mode algorithm; Shapiro-Wilk test; Pearson's correlation	Movement; Metric; Others	Actigraphy parameters; MoCA[3] score; Walking speed; Walking distance
Azharuddin et al. [35]	Predictive methods	Pearson's correlation	Movement	Walking speed
Bigoni et al. [36]	Statistical analysis; Predictive methods	Kolmogorov–Smirnov test; Analysis of Variance (ANOVA); Pearson's correlation; Multivariate regressions	Angular; Time	Angles; Walking time
Calabro et al. [37]	Statistical analysis; Predictive methods	Kolmogorov–Smirnov test; Analysis of Covariance (ANCOVA); Bonferroni correction; Pearson's correlation	Movement; Time	Walking speed; Walking distance
Chang et al. [38]	Statistical analysis	Mann–Whitney *U* test; Wilcoxon signed rank test	Movement; Time	Walking speed; Walking time
Davis et al. [39]	Statistical analysis	Descriptive analysis; ANCOVA; Wilcoxon signed rank test; Student's t-test	Time	Walking time
Eymir et al. [40]	Statistical analysis; Predictive methods	Kolmogorov–Smirnov test; Intraclass Correlation	Movement	Walking speed
Karunakaran et al. [41]	Statistical analysis; Predictive methods	Spearman's rank correlation; Shapiro-Wilk test	Count; Time; Movement	Number of steps; Walking time; Walking speed
Poleur et al. [42]	Statistical analysis	Mann–Whitney *U* test; Wilcoxon signed rank test	Metric; Movement	Stride length; Stride velocity
Tan et al. [43]	Statistical analysis	Shapiro-Wilk test; Levene's test; ANOVA; Mann–Whitney *U* test	Movement; Time	Walking speed; Walking time
Valenzuela et al. [44]	Statistical analysis	Descriptive analysis	Metric; Movement	Walking speed; Walking distance
Zieriacks et al. [45]	Statistical analysis	ANOVA; Shapiro-Wilk test; Wilcoxon signed rank test	Movement; Time	Walking speed; Walking time
Ali et al. [46]	Statistical analysis	Mann–Whitney *U* test; Student's t-test	Time	Walking time
Fortes et al. [47]	Statistical analysis	Shapiro-Wilk test; Wilcoxon signed rank test	Metric; Movement	Walking speed; Walking time
Pehlivan et al. [48]	Statistical analysis	Pearson's correlation	Time	Walking time
Sawers & Hafner [49]	Statistical analysis	Descriptive analysis	Movement; Time	Walking speed; Walking time
Timmermans et al. [50]	Statistical analysis	Mann–Whitney *U* test; Fisher's exact tests; ANCOVA; Student's t-test; Wilcoxon signed rank test	Movement; Others	Walking speed; Walking adaptability
Vieira de Moraes Filho et al. [51]	Statistical analysis	Chi-square test; Shapiro Wilk test; Wilcoxon signed rank test; ANOVA	Movement; Time	Walking speed; Walking time
Lunar et al. [52]	Statistical analysis	Kolmogorov–Smirnov test; Levene's test; Shapiro–Wilk test	Time	Walking time
O'Brien et al. [53]	Data processing; Predictive methods; Statistical analysis	Fourth-order Butterworth low-pass filter; Continuous wavelets transform; Intraclass Correlation; Hierarchical multiple regression; ANOVA	Angular; Time; Metric; Movement; Count	Angles; Stance time; Swing duration; Step time; Step length; Step velocity; Number of steps
Ofran et al. [54]	Predictive methods	Spearman's rank correlation	Time; Metric; Movement; Others	Step time; Stance time; Swing duration; Stride length; Step length; Stride velocity; Cadence
Broderick et al. [55]	Statistical analysis	Intraclass Correlation	Movement	Walking speed
Bui et al. [56]	Statistical analysis; Predictive methods	Student's t-test; Multidimensional Scaling; Dimensionality reduction	Time; Count	Walking time; Number of repetitions
Hadoush et al. [57]	Statistical analysis	Intraclass Correlation; Student's t-test	Movement	Walking speed
Éden et al. [58]	Statistical analysis; Predictive methods	Descriptive analysis; Intraclass Correlation; Pearson's correlation; Spearman's rank correlation	Movement	Walking speed
In et al. [59]	Statistical analysis	Shapiro-Wilk test; Student's t-test; Chi-square test	Time	Walking time
Swank et al. [60]	Statistical analysis	Student's t-test	Movement; Time	Walking speed; Walking time
Kumru et al. [61]	Statistical analysis	Chi-square test; Mann–Whitney *U* test	Movement; Metric; Others	Walking speed; Cadence; Stride length; WISCI-II[4] scores
Han et al. [62]	Statistical analysis	Descriptive analysis	Movement; Metric; Others; Time; Medical	Walking speed; Cadence; Stride length; Gait cycle duration; Heart rate
Clark et al. [63]	Statistical analysis; Predictive methods	Intraclass Correlation; ANOVA; Multivariate regression	Movement; Time; Count	Walking speed; Walking time; Number of steps
Poncumhak et al. [64]	Statistical analysis	Mann–Whitney *U* test	Time	Walking time
Saensook et al. [65]	Statistical analysis	Kruskal–Wallis H test; Mann–Whitney *U* test; Chi-square test	Movement; Time	Walking speed; Walking time

(*continued on next page*)

Table 6 (*continued*)

Paper	Type of Methods	Methods	Type of Features	Features
Scrivener et al. [66]	Statistical analysis	Descriptive analysis	Movement	Walking speed
Schuck et al. [67]	Statistical analysis; Predictive methods	Friedman test; Bonferroni correction; Student's t-test	Medical; Movement	Heart Rate; Median of the EMG metric; Maximum EMG value; Walking speed

[3] Montreal Cognitive Assessment.
[4] Walking Index for Spinal Cord Injury II.

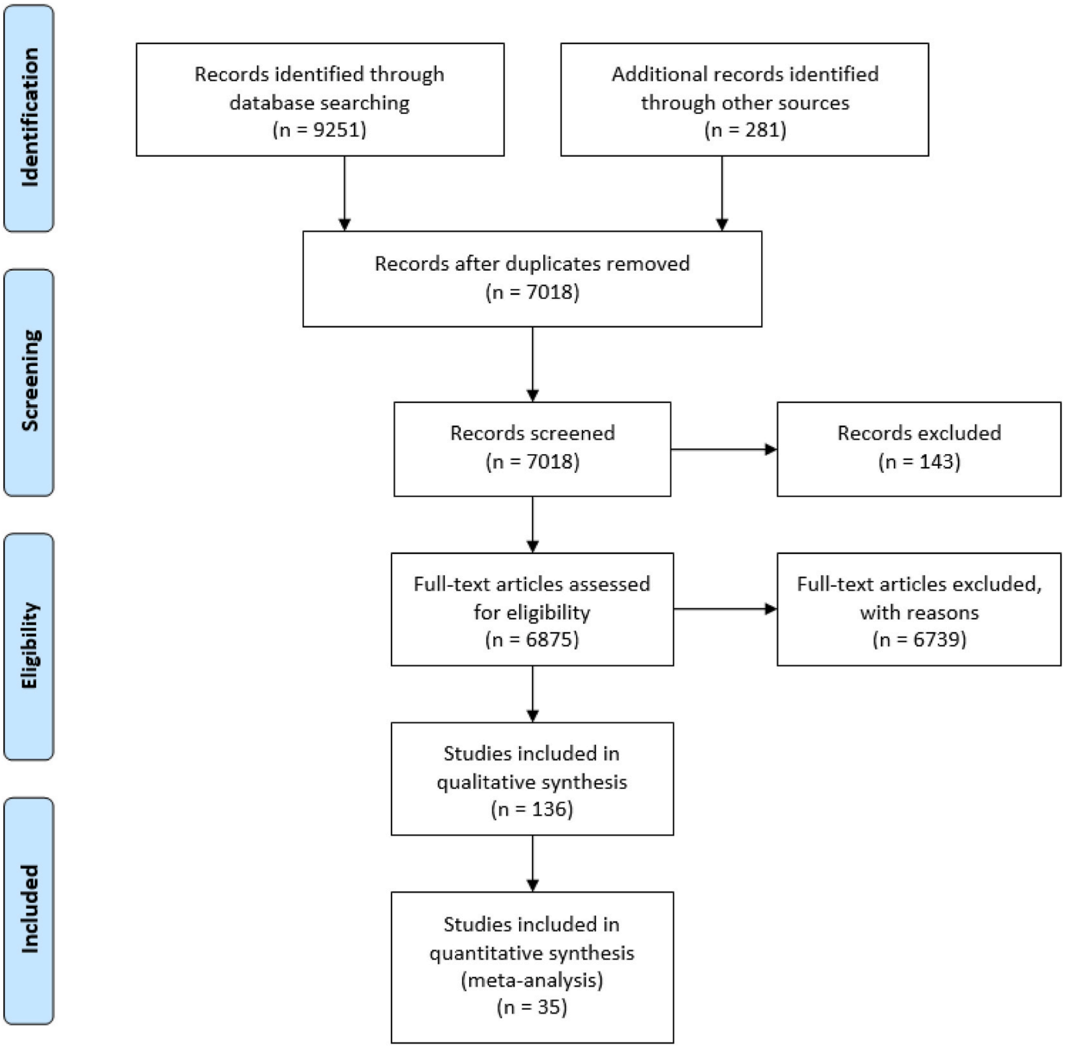

Fig. 1. Flow diagram of the selection of the relevant studies.

Parkinson's Disease, where 101 patients were included in a control group (55 males and 46 females) aged 72.61 ± 9.74 years old. To analyze the Ten Meter Walk Test performance, the authors extracted the gait time that reported 14.77 ± 10.32 s for all participants and 13.02 ± 8.73 s for the control group. The results were analyzed with descriptive statistics and ANCOVA for age, sex, an assistive device used, and past medical history affecting gait, reporting no significant difference in response between groups.

In [40], the authors used a chronometer to analyze the Ten Meter Walk Test performance with 56 patients (42 females and 14 males) with total knee arthroplasty, aged 63.51 ± 13.72 years old. The feature extracted was the test time to determine the concurrent validity, reliability, and minimal detectable change. Thus, the data were statistically analyzed with the IBM SPSS Statistics (IBM Corp., Armonk, NY), implementing the Kolmogorov–Smirnov test, exploring the intraclass correlation coefficients and reporting a significant moderate correlation.

Table 7
Publications ranking (retrieved on 28 March 2023).

Paper	Study Location	Type of Study	Number of Authors	Citations	Quartile
Priyaranjan et al. [33]	New Deli, India	Journal paper	4	0	Q4
Umemura et al. [34]	São Paulo, Brazil	Conference Proceeding	4	1	N/D
Azharuddin et al. [35]	New Delhi, India	Journal paper	2	1	N/D
Bigoni et al. [36]	Verbania, Italy	Journal paper	8	6	Q1
Calabro et al. [37]	Messina, Italy	Journal paper	9	6	Q2
Chang et al. [38]	Kaohsiung, China	Journal paper	6	9	Q1
Davis et al. [39]	Maryland, USA	Journal paper	6	2	Q2
Eymir et al. [40]	Erzurum, Turkey	Journal paper	4	1	Q3
Karunakaran et al. [41]	New Jersey, USA	Journal paper	6	4	Q2
Poleur et al. [42]	Liège, Belgium	Journal paper	10	4	Q1
Tan et al. [43]	Colorado, USA	Journal paper	4	8	Q1
Valenzuela et al. [44]	Juiz de Fora, Brazil	Journal paper	7	1	Q1
Zieriacks et al. [45]	Bochum, Germany	Journal paper	6	6	Q2
Ali et al. [46]	Islamabad, Pakistan	Journal paper	3	1	Q4
Fortes et al. [47]	Brasília, Brazil	Journal paper	5	3	Q2
Pehlivan et al. [48]	İstanbul, Turkey	Journal paper	4	0	Q3
Sawers & Hafner [49]	Chicago, USA	Journal paper	2	1	N/D
Timmermans et al. [50]	Amsterdam, Netherlands	Journal paper	5	5	Q1
Vieira de Moraes Filho et al. [51]	Brasilia, Brazil	Journal paper	13	24	Q1
Lunar et al. [52]	Manila, Philippines	Journal paper	8	2	Q3
O'Brien et al. [53]	Chicago, USA	Journal paper	8	15	Q1
Ofran et al. [54]	Jerusalem, Israel	Journal paper	5	6	Q2
Broderick et al. [55]	Sligo, Ireland	Journal paper	6	21	Q1
Bui et al. [56]	New South Wales, Australia	Journal paper	8	4	Q2
Hadoush et al. [57]	Irbid, Jordan	Journal paper	5	27	Q2
Éden et al. [58]	Arizona, USA	Journal paper	3	46	Q2
In et al. [59]	Gimcheon, South Korea	Journal paper	4	14	Q1
Swank et al. [60]	Texas, USA	Journal paper	3	4	Q3
Kumru et al. [61]	Barcelona, Spain	Journal paper	7	54	Q2
Han et al. [62]	Seoul, Korea	Conference Proceeding	5	2	N/D
Clark et al. [63]	Melbourne, Australia	Journal paper	8	103	Q1
Poncumhak et al. [64]	Khon Kaen, Thailand	Journal paper	3	22	Q2
Saensook et al. [65]	Khon Kaen, Thailand	Journal paper	6	24	Q2
Scrivener et al. [66]	New South Wales, Australia	Journal paper	3	29	Q1
Schuck et al. [67]	Zurich, Switzerland	Journal paper	5	61	Q1

The authors of [41] used chronometers and accelerometers to analyze a robotic exoskeleton's capacity to deliver high-intensity gait training and quantify the therapeutic impact on functional ambulation in persons with acute stroke based on the Ten Meter Walk Test. The study measured the number of steps, walking speed, and walking time with 14 participants with stroke aged 61.24 ± 1.98 years. For the analysis of the data, Wilcoxson Signed Rank test, spearman's rank correlation, and Shapiro-Wilk showed that the data is not normally distributed for the variables measured, but it shows a positive correlation between sessions with an improvement of the ability to perform the test.

The authors of [43] used the Optotrak Certus (Northern Digital, Waterloo, Ontario, Canada) to track the movements with infrared light-emitting rigid body sensors at 0.1 mm accuracy. The sensors were placed in the pelvis, thigh, leg, and foot. The acquired data was processed with MATLAB scripts (The MathWorks, Inc., Natick, MA). The study included 11 participants (2 females and 9 males) aged between 20 and 68 years old with spinal cord injury, reporting a walking speed between 0.09 and 1.20 m/s during the Ten Meter Walk Test. The acquired data were statistically analyzed with IBM SPSS Statistics (IBM Corp., Armonk, NY), applying the Shapiro-Wilk and Levene's tests to assess the data's normality and homogeneity. Finally, the ANOVA was performed, and the Mann-Whitney *U* test was used, reporting that the overground walking performance decreased during the Ten Meter Walk Test.

The authors of [45] assessed the outcome of acute and chronic participants with spinal cord injury after 12 weeks of bodyweight-supported treadmill training with a hybrid assistive limb exoskeleton. The study included 110 participants (89 males and 21 females), with an average age of 44.3 years, ranging from 16 to 74 years. Ten Meter Walk Test was used to examine the gait performance without an exoskeleton. The Shapiro-Wilk test and distribution plots for the three time periods determined whether all results were usually distributed. In addition, the total time measurements for the Ten Meter Walk Test were measured, revealing no differences between the results of acute and chronic individuals. After 12 weeks, the chronic participants' outcomes showed and high improvement, but the acute participants showed a lower improvement. In general, all participants accelerated from 70.1 ± 66.0 s to 36.5 ± 43.4 s. Remarkably, the acute participants improved from 63.6 ± 47.2 s to 26.3 ± 37.5 s, and the chronic participants improved from 68.7 ± 59.3 s to 34.5 ± 30.2 s, but the analysis shows no differences between groups.

In [46], the effects of a task-oriented circuit class training program on walking ability and balance in subacute stroke patients were evaluated using a chronometer. The authors analyzed 22 stroke survivors (13 males and 9 females) aged 52–72 years. The data acquired measured the walking endurance, speed, balance and ambulation based on the time during the Ten Meter Walk Test performance. It was analyzed with IBM SPSS Statistics (IBM Corp., Armonk, NY), implementing the Mann–Whitney *U* test and Student's t-test. The patients were randomly distributed by a control group and an experimental group, and the test was performed in 2 stages. It was revealed that, in the experimental group, the time decreased from 48.18 ± 6.62 s to 36.18 ± 8.53 s, and in the control group, the time decreased from 47.45 ± 4.59 s to 35.27 ± 5.47 s.

Fortes et al. [47] extracted the walking speed and walking time with a shoe lift and a chronometer to evaluate the immediate changes in post-stroke gait speed and functional mobility in post-stroke gait. The analysis comprised the data of 42 subjects (23 females and 19 males) aged 52.8 ± 11.1 years old. The data were statistically analyzed with MATLAB software (The MathWorks, Inc., Natick, MA), applying the Shapiro-Wilk, and Wilcoxon signed-rank tests, revealing a significant increase in walking speed in the Ten Meter Walk Test.

In [48], the authors used a chronometer to research the use of the Ten Meter Walk Test to determine exercise capacity in 63 individuals aged between 18 and 68 years old, with an average of 41.42 years old, that suffer from lung transplantation. The Ten Meter Walk Test average was 8.45 s, ranging between 4.44 and 21.03 s. The data were statistically analyzed with IBM SPSS Statistics (IBM Corp., Armonk, NY), applying Pearson's correlation. The results reported a negative and moderate correlation between Six-Minute Walk Test and Ten Meter Walk Test, but there is a strong relationship between the five-times sit-to-stand test and the Ten Meter Walk Test.

In [49], a chronometer was utilized to evaluate the incidence, time-course, and size of practice effects in the commonly given Ten Meter Walk Test to people wearing lower limb prostheses. There are 20 participants (13 males and 7 females) with 55.7 ± 19.1 years old and used Unilateral Lower Limb Prostheses. In addition, the authors performed descriptive statistics of the walking velocity and time, revealing that the participants performed a median number of 3.5 trials to reach a consistent level of performance. Finally, the practice effects were observed in 45%–76% of participants. The performance test median velocity is around 1.3 m/s in the first session and 1.2 m/s in the second session for all participants.

The authors of [50] performed two analyses, C-Mill therapy and the FALLS program, with stroke patients monitored by Microsoft Xbox360 Kinect camera. First, the C-Mill therapy recruited 16 patients (9 females and 7 males) aged 52 ± 13 years old. Secondly, the FALLS program recruited 17 patients (5 females and 12 males) aged 59 ± 10 years old. The analysis consisted of comparing the efficacy of the different treatments using the Kinect device to measure the Ten Meter Walk Test. For that purpose, the statistical analysis was performed with Mann-Whitney U tests, Fisher's exact tests, ANCOVA, Student's t-test, and Wilcoxon signed rank test. The results compared walking speed and Walking adaptability, reporting no significant differences between groups.

Vieira de Moraes Filho et al. [51] analyzed 40 subjects (10 females and 30 males) with Parkinson's disease, distributed by a control group with 15 patients (5 females and 10 males) aged 64.4 ± 3.7 years old and a training group with 25 patients (5 females and 20 males) aged 64.7 ± 1.8 years old. For the test, a chronometer was used to measure the time and gait speed during the Ten Meter Walk Test performance. The training group reported a gait speed of 1.7 ± 0.2 m/s in the pre-training stage and 2.0 ± 0.3 m/s in the post-training stage. Also, the control group reported a gait speed of 1.7 ± 0.4 m/s in the pre-training stage and 1.7 ± 0.3 m/s in the post-training stage. The statistical analysis was performed with IBM SPSS Statistics (IBM Corp., Armonk, NY), using the Chi-square test, Shapiro-Wilk test, Wilcoxon signed rank test, and ANOVA. These tests reported significant time between the different stages, showing substantial improvement after the 9-week training.

Lunar et al. [52] sought to investigate the performance of the Ten Meter Walk Test among people who resided in urban and rural areas and to present early reference values for the Ten Meter Walk Test by residential setting. They used a chronometer to measure the test time based on 180 individuals aged 67.58 ± 5.41 years, where 55 (15 males and 30 females) were from rural environments aged 67.16 ± 5.30 years, and 125 (57 males and 68 females) were from urban environments aged 67.76 ± 5.46 years. The Ten Meter Walk Test was performed in two different manners, including comfortable gait velocity and fast gait velocity. The data were analyzed with IBM SPSS Statistics (IBM Corp., Armonk, NY), implementing Kolmogorov–Smirnov, Levene, and Shapiro–Wilk tests. The average time of the test performance was. The results reported that urban scores are better than rural scores. The study was an excellent starting point for follow-up studies. A representative sample to examine how factors specific to residential settings affect differences in mobility performance, illustrate differences in mobility performance according to a residential setting, and determine the extent to which clinicians should take into account an older person's residential setting when interpreting mobility test results.

In [53], the authors used the GAITRite device (GAITRite; CIR Systems, Inc., Franklin, NJ, USA) to quantify gait and balance features during the performance of the Ten Meter Walk Test, also evaluating the changes in sensor-derived measurements with age, sex, height, and weight. They recruited 50 individuals (25 females and 25 males) aged between 20 and 70 years old, and one male patient had a stroke. After the experiments, 184 features were extracted from the acceleration and angular velocity signals, including Angles, Stance time, Swing duration, Step time, Step length, Step velocity, and Step count. Before the feature extraction, a Fourth-order Butterworth low-pass filter was applied, and the features were extracted with a Continuous wavelets transform using MATLAB software (The MathWorks, Inc., Natick, MA). The Intraclass Correlation Coefficient, the Hierarchical multiple regression, and the ANOVA were applied for the statistical analysis of the data. They reported an excellent correlation between stance time, step time, gait velocity, and step count. In contrast, a high correlation is observed for swing duration and a moderate correlation for step length, providing higher resolution information about balance, gait, and mobility than the clinical test scores alone.

The authors of [54] used a 4-camera system (Basler Scout, Basler AG, Ahrensburg, Germany) to forecast typical clinical outcomes in stroke patients using spatiotemporal gait parameters. They determined the relationship between spatiotemporal gait metrics and frequently used clinical gait test results to test the performance of the Ten Meter Walk Test. The authors measured the Step time, Stance duration, Swing duration, Stride length, Step length, Base width, Stride velocity, and Cadence. The 70 stroke patients (24 females and 46 males) that collaborated in the study are 59.2 ± 11.4 years old, where 16 have a hemorrhagic stroke, and the remaining 54 have an ischemic stroke. The results reported high correlations between diverse spatiotemporal parameters significantly predicting the Ten Meter Walk Test.

Broderick et al. [55] used a COSMED h/p/cosmos T170 treadmill to determine the effectiveness and feasibility of combining treadmill training with mirror therapy for post-stroke lower-limb rehabilitation in comparison to a control strategy. The experiments were performed by two groups: mirror therapy and placebo groups. First, the mirror therapy group comprises 16 individuals (5 females and 11 males) aged 61.2 ± 9.5 years old. Next, the placebo group is formed by 15 individuals (1 female and 14 males) aged 67.06 ± 19.47 years old. The Ten Meter Walk Test assessed the comfortable walking velocity, which reported 0.87 ± 0.41 m/s for the mirror therapy group and 0.74 ± 0.46 for the placebo group. The authors only used the Intraclass Correlation Coefficient. The results reported no significant between-group differences for the post-training or 3-month follow-up assessment of the Ten Meter Walk Test.

In [56], a mobile device with the PTPal™ mobile application was used to promote independent living and provide tests with the mobile application. There are 20 participants equally distributed by the intervention and the control groups. The 10 participants in the intervention group are aged 65 ± 20.3 years old, and the remaining 10 participants in the control group are 66.3 ± 11.8 years old. It was intended to investigate the feasibility and acceptance of an app-based supplemental exercise program in orthopedic rehabilitation. The authors analyzed the walking time and the number of repetitions in patients with hip, knee, and other orthopedic diseases. The results reported 23.2 ± 30 s for intervention groups and 17.3 ± 8.1 s for the control group during the Ten Meter Walk Test. In addition, the results were analyzed with Student's t-test, Multidimensional Scaling, and Dimensionality reduction, verifying that a realistic, safe, and activity-increasing app-based fitness program has the potential to enhance functional results.

The authors of [57] used Electroencephalography sensors and a chronometer to evaluate the treatment of Parkinson's disease patients with bilateral anodal transcranial direct current stimulation and if it affects their balance and fear of falling. In addition, an Intraclass Correlation Coefficient and Student's t-test were calculated to evaluate the walking speed during the Ten Meter Walk Test performance. The study comprised 18 participants (5 females and 13 males), where the female participants were aged 61.8 ± 10.5 years old, and the male participants were 62.4 ± 8.4 years old. The results reported a slight decrease in the Ten Meter Walk Test duration.

The authors of [59] examined stroke patients' motor function, gait, and balancing abilities in relation to the effects of treadmill training with Thera-Band during the performance of the Ten Meter Walk Test. The authors used a chronometer to measure the test time with 30 patients distributed by the control ground and the experimental group. The control group comprises 15 patients aged 53.53 ± 12.12 years, where 9 are males, and 6 are females. The experimental group includes the other 15 participants aged 53.20 ± 9.32 years, where 8 are males, and 7 are females. The data were analyzed with IBM SPSS Statistics (IBM Corp., Armonk, NY), implementing the Shapiro-Wilk, Student's t-test, and Chi-square tests. The results revealed that there were improvements in both groups after the intervention, wherein, in the control group, the test time reduced from 21.76 ± 8.30 s to 20.73 ± 8.29 s, and, in the experimental group, the test time reduced from 22.24 ± 6.77 s to 18.80 ± 6.46 s.

Kumru et al. [61] used Lokomat gait rehabilitation to enhance the robot's functional outcome during the earliest phases of gait rehabilitation in spinal cord injury by adding repeated transcranial magnetic stimulation to physical therapy. The 31 participants were 7 females and 24 males between 19 and 69 years. The authors analyzed walking speed, Cadence, Stride length, and WISCIII score features using the Chi-square test and Mann–Whitney *U* test and reported that 71.4% of the subjects after real repeated transcranial magnetic stimulation and 40% of the subjects after shamming repeated transcranial magnetic stimulation could perform Ten Meter Walk Test without significant differences in gait velocity, Cadence, step length and WISCI-II

In [62], the authors developed a robotic device to make moving about easier for older adults and those with disabilities, such as stroke sufferers and spinal cord injuries. It was composed of Trigno™ Wireless EMG, M5 device, BTS G-WALK device, Accelerometer, Magnetometer, and Gyroscope to acquire speed, Cadence, stride length, gait cycle duration, and heart rate during the performance of Ten Meter Walk Test. The study was implemented in 4 male subjects aged 75.3 ± 1.7 years old. Due to the commercial walker's modest weight, it performed better than the created device in flat and uphill conditions. In addition, the developed system can manage speed on a terrain with a downhill slope.

The authors of [63] used a Microsoft Xbox360 Kinect camera to assess the accuracy and additional information while doing a gait analysis on stroke survivors. The study counted the participation of 30 individuals (21 males and 9 females) aged 68 ± 15 years old. The features extracted from the experiments were step length, step length asymmetry, foot swing velocity, foot swing velocity asymmetry, peak gait speed, mean gait speed, and the percentage difference between the peak and mean gait speed. The authors analyzed the extracted features using the Intraclass Correlation Coefficient, ANOVA, minimum detectable change score, and Multivariate regression. They proved that system with reliable features offers a minimally invasive way to look at potentially significant gait traits in stroke survivors.

In [64], the study examined the performance of the Ten Meter Walk Test to determine the ability to walk without a walking device and the inter-tester reliability of the tests to assess functional ability in patients with spinal cord injuries. The test time was measured with a chronometer for further analysis with the IBM SPSS Statistics (IBM Corp., Armonk, NY), implementing the Mann–Whitney *U* test. The experiments included 60 participants with spinal cord injuries distributed by two groups, including the 30 participants with walking independency and the 30 that needed walking aids. The individuals with walking devices are aged 49.30 ± 14.31 years, taking 12.10 ± 5.77 s to perform the test. The individuals with walking independency are aged 50.60 ± 9.68 years, taking 4.47 ± 1.16 s to perform the test. The results showed a high correlation coefficient.

Scrivener et al. [66] used a chronometer to evaluate the Ten Meter Walk Test's responsiveness and floor/ceiling effects. The authors recruited 190 participants (93 females and 97 males) aged 76 ± 12.7 years old. The walking speed was analyzed with statistical methods, reporting that the Effect Size, Standardized Response Mean, and median-based Effect Size are 1.44, 0.93, and 0.45, respectively. It reported that walking speed could detect motor performance changes during inpatient stroke rehabilitation.

Saensook et al. [65] used a chronometer to measure the walking speed during the Ten Meter Walk Test performance in individuals with spinal cord injuries. The experiments consisted in 85 individuals, where 30 walked with a walker, 7 with crutches, 11 with a cane, and 37 without walking aids. The individuals with walkers were aged between 37.75 and 61.25 years old and achieved an average velocity of 0.31 m/s. The individuals with crutches were aged between 36 and 51 years old and achieved an average velocity of 0.45 m/s. The individuals with cane were aged between 50 and 63 years old and achieved an average velocity of 0.69 m/s. The individuals without walking aids were aged between 38.75 and 61 years old and achieved an average velocity of 0.86 m/s. The data were analyzed with IBM SPSS Statistics (IBM Corp., Armonk, NY), implementing the Kruskal–Wallis H, Mann–Whitney U, and Chi-square tests, revealing non-significant differences between subjects who used a walker and crutches.

In [67], the authors recruited 4 participants (3 males and 1 female), equally distributed between two groups, such as chronic incomplete spinal cord injury and chronic stroke. The participants, aged between 38 and 69 years old, used the Lokomat gait rehabilitation robot composed of Electromyography, Electrocardiography, and force sensors to examine the viability of using a four-week treatment to treat incomplete spinal cord injury and stroke with patient-cooperative robot-assisted gait rehabilitation. The features extracted by the device were Heart Rate, a median of the Electromyography metric, the maximal Electromyography value of the average stride under the free walking condition, and walking speed. In addition, they were analyzed with the Friedman test at the 5% significance level, Bonferroni adjustment, and Student's t-test, reporting one participant had a significant and pertinent increase in gait speed. In contrast, the other three patients did not demonstrate any appreciable changes.

3.2. *Other studies*

The authors of [42] used the ActiMyo® device (Sysnav, Vernon, France) composed of accelerometer and magnetometer sensors to gather normative information on the length and speed of spontaneous strides in an uncontrolled setting, as well as how they changed over a year. The study included 82 participants (46 females and 36 males) aged between 6 and 85 years old to evaluate the stride length and stride velocity during the Ten Meter Walk Test performance. For the statistical analysis, the individuals were divided into two groups, including a group with 65 participants (34 females and 31 males) aged between 5 and 17 years old and another group with 17 participants (12 females and 5 males) aged 18 or more years old. In addition, the authors used IBM SPSS Statistics (IBM Corp., Armonk, NY) to evaluate the results with the Mann–Whitney *U* test and Spearman's rank correlation, revealing a significant increase in the median stride length in children. Still, it is not differing significantly in the performance of the Ten Meter Walk Test.

Valenzuela et al. [44] analyzed four participants (1 female and 3 males) with cerebral palsy aged between 15 and 17. The authors measured the walking speed and distance during the Ten Meter Walk Test performance using twelve Nintendo® Wii games to assess the results of brief virtual reality therapy for cerebral palsy in teenagers. First, it measured the walking speed and distance. The final speed was the average of three repeats of each participant's evaluations, divided by the distance traveled and the time taken in seconds. The descriptive analysis was performed with IBM SPSS Statistics (IBM Corp., Armonk, NY), revealing that this kind of intervention may be an efficient therapy for these children, helping them regain some functionality.

In [58], the study comprised 42 participants (34 males and 8 females) aged 63.1 ± 9.3 years old with head or neck cancers. The study used a REDCap (Research Electronic Data Capture) device to determine the test-retest reliability of multiple physical function measures and correlations between them in a cohort of people in the early phases of therapy. The parameter evaluated was the walking speed, performing descriptive statistics, Intraclass Correlation Coefficient, Pearson's correlation, and Spearman's correlation with IBM

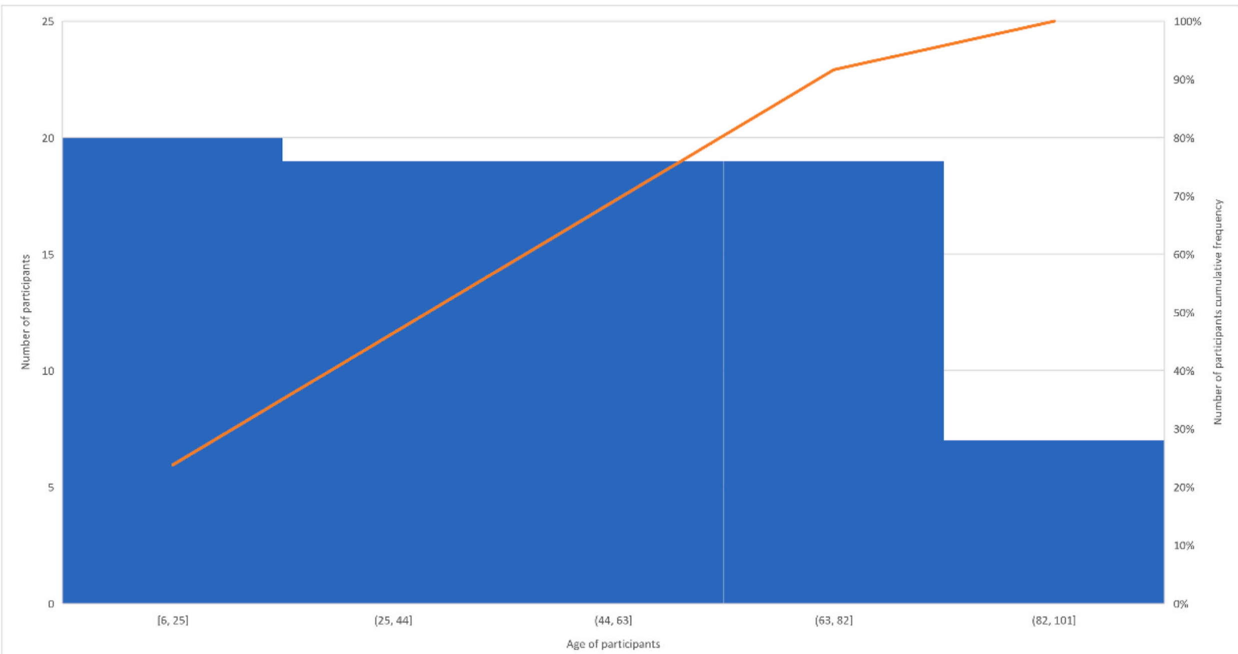

Fig. 2. Relation between age ranges and the number of participants.

SPSS Statistics (IBM Corp., Armonk, NY). The results revealed that the Ten Meter Walk Test has a strong correlation, indicating that it may be used to assess several aspects of physical function.

The authors of [60] examined 148 medical records for the significant neurologic diagnosis and the Ten Meter Walk Test results. The patients were 81 males and 88 females aged 63.12 ± 17.19 years. In addition, the data related to the walking speed were compared with Student's t-test with IBM SPSS Statistics (IBM Corp., Armonk, NY), revealing an increased walking speed between the baseline and the discharge.

4. Discussion

4.1. Interpretation of the results

The use of mobile devices can increase physical activity levels. It can also be used to monitor different parameters related to the Ten Meter Walk Test with the various embedded sensors, allowing the monitoring of patients remotely [56,68].

Previously, the authors performed a literature review on using sensors [21], including studies between 2009 and 2020. However, the study focused on identifying studies using sensors for the automated measurements of the Ten Meter Walk Test, and it was verified that it was inconsistent. Currently, the plans for the development of a system based on the use of wearables urged the research on the literature, and it was found that 13 of 35 studies were published after the previous review, verifying that the subject is becoming very researched, where the use of wearables is exploiting this research subject.

Regarding the wearables, shoe lifts were verified as helpful in increasing the gait speed of post-stroke patients [47], where they also proved the reducing fall risk. However, the most fundamental problem verified in the different studies was related to the reduced number of experiment participants in some studies [37,58,63,67]. However, the most studied disease is monitoring post-stroke patients and tracking the time for the test performance.

Based on the analysis of the 35 studies, Fig. 2 shows that, regarding the age ranges of the studies' participants, 90% of the studies are focused on persons younger than 82 years old. Also, up to 65% of the studies focus on persons younger than 63 years old.

Regarding the locations of the selected studies, Fig. 3 shows that the highest ratio of seven studies was found in the United States of America (20.0%), four studies found in Brazil (11.4%), three studies for each country (8.5%) were performed in China and Australia, and two studies for each country (5.7%) were done in Italy, India, South Korea, and Turkey. The remaining countries only placed one analysis.

Fig. 4 shows the type of sensors considered in the different studies. For example, time sensors were used in twenty studies (57%), motion sensors were considered in fourteen studies (40%), medical sensors were used in six studies (17%), vision sensors were used in four studies (11%), and the remaining sensors were distributed as force sensors (2 studies), magnetic sensors (2 studies), environmental sensors (1 study), and inertial sensors (1 study). Other works available in the literature work automatically extracted features from the accelerometer and camera sensors, proving allows the development of an automatic framework for this kind of test. In

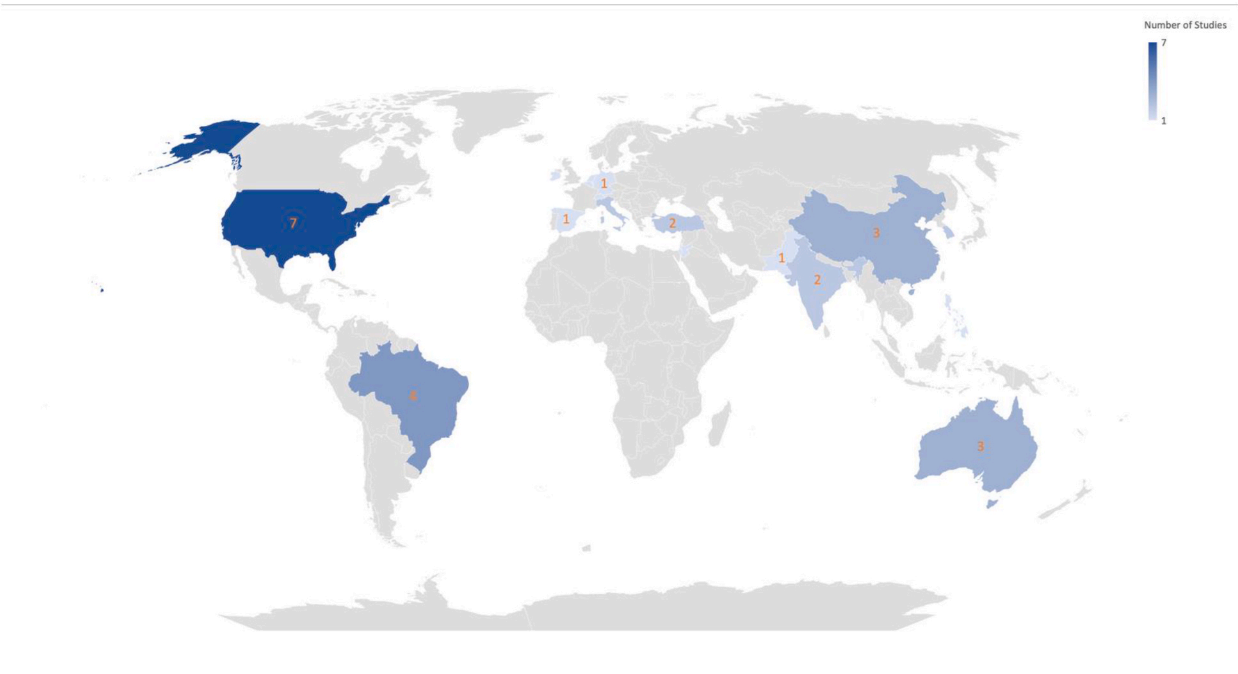

Fig. 3. Relation between the number of studies and locations.

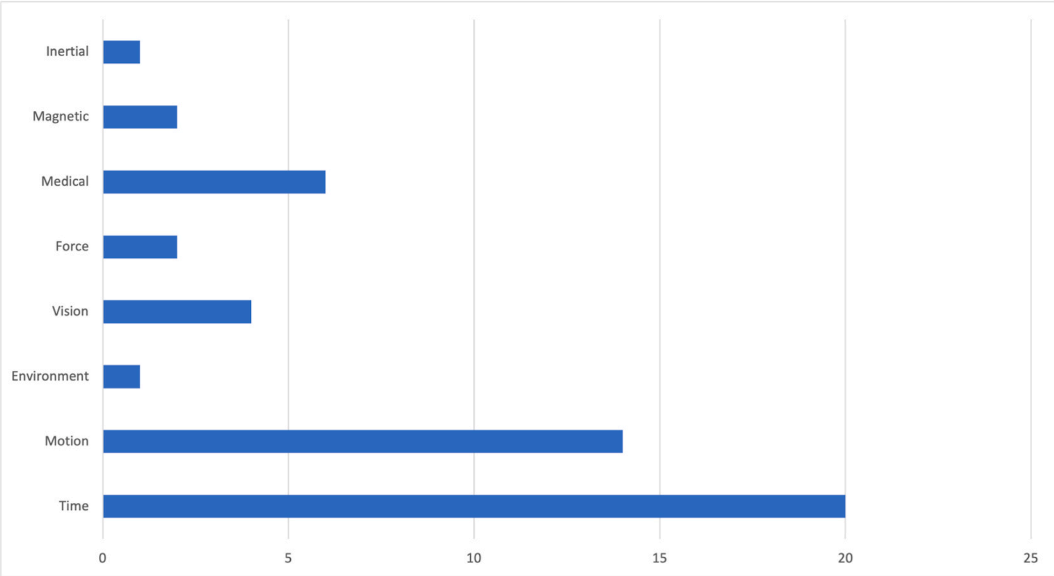

Fig. 4. Relation between the type of sensors and the number of studies.

Ref. [69], the author classified spatiotemporal features obtained from the accelerometer and achieved 70.42% accuracy. The addition of signal-based statistical features with the accelerometer features performed well, with a classification accuracy of 86.65%. In Ref. [70], infrared camera based sixteen features were analyzed. Further optimization of these features achieving a classification accuracy of 98%, suggested that step length, cadence, and swing speed features significantly impact gait analysis.

According to Fig. 5, regarding the diseases in the population studied by the different papers analyzed, different stages of stroke diseases were the most studied. Considering the categories of diseases, thirty-one studies (89%) are related to physical diseases. In addition, other residual diseases were presented in different studies, including brain, endocrine and cardiovascular diseases.

According to Fig. 6, regarding the categories of features extracted from the data acquired behind the different studies, the movement features are the most analyzed in twenty-seven studies (77%), followed by the time features in twenty-two studies (63%).

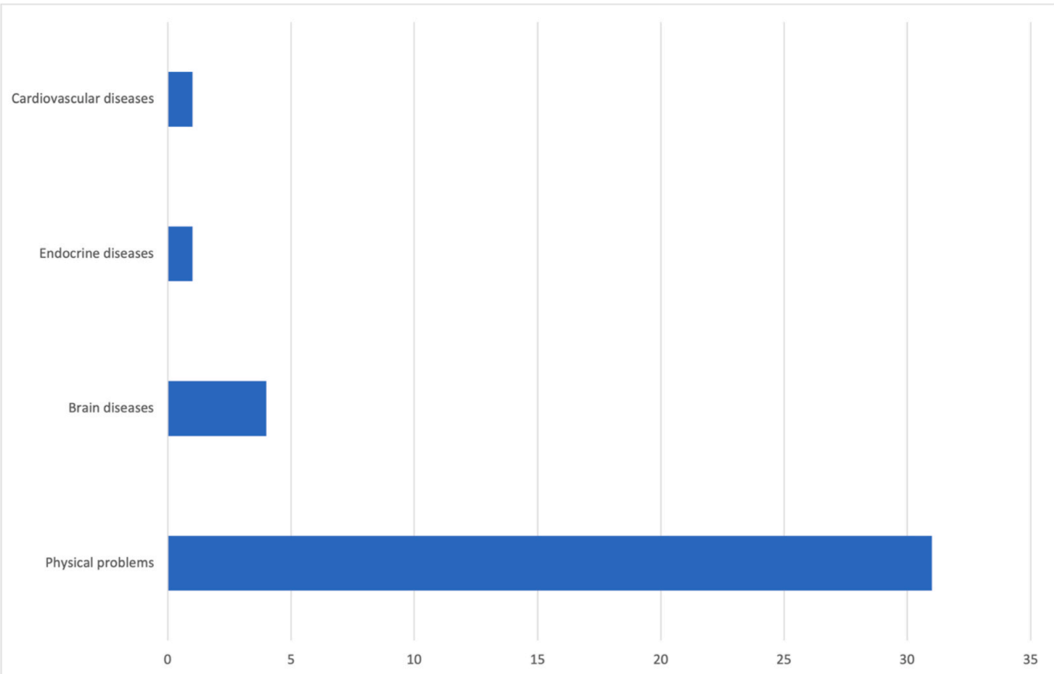

Fig. 5. Relation between categories of diseases and the number of studies.

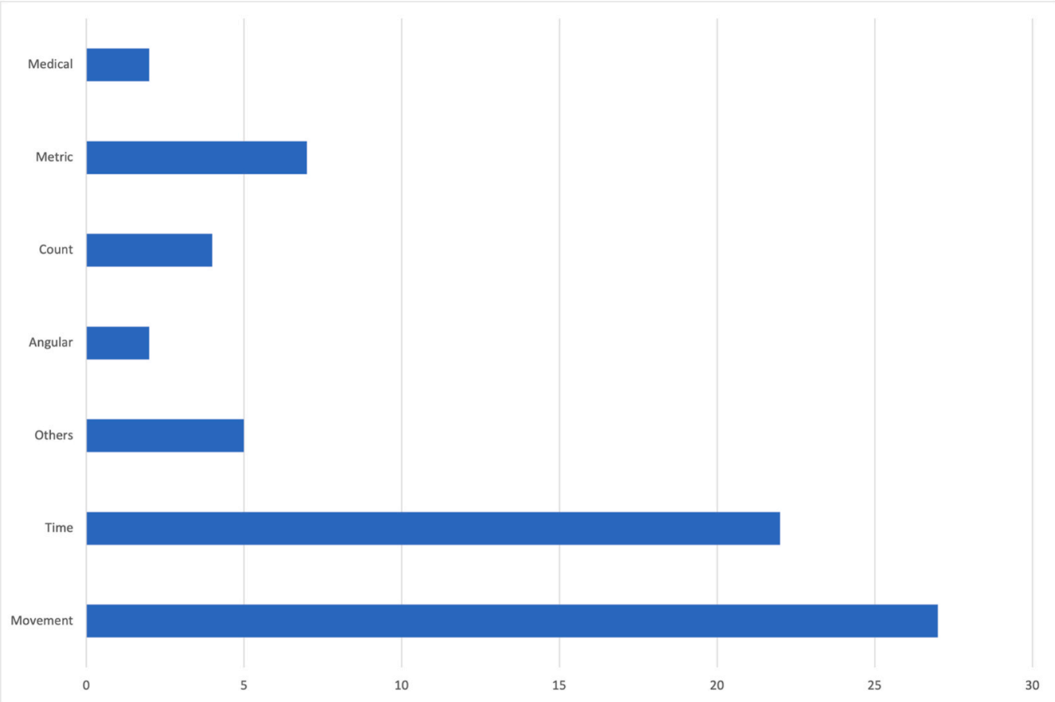

Fig. 6. Relation between categories of features considered and the number of studies.

Other mainly extracted feature categories were the metric in seven studies (20%) and the counting features in four studies (11%). In addition, other residual features were extracted in different studies.

According to Fig. 7, regarding the methodologies, all studies used statistical methods, followed by predictive methods in ten studies (29%), and data processing techniques in one study (3%), where the Student's t-test and Mann Whitney *U* test were used in eight studies (23%) each, the descriptive analysis in seven studies (20%), the Intraclass correlation and Person's correlation in six studies (17%) each, the Shapiro-Wilk test and ANOVA in five studies (14%) each, and the Chi-square test in four studies (11%). In addition, other residual methods were used.

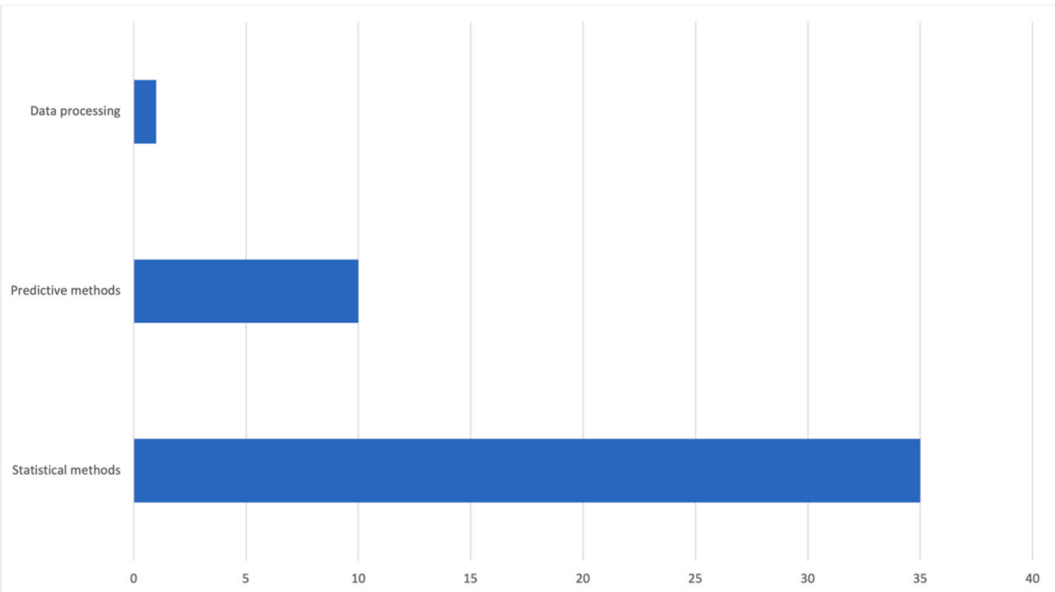

Fig. 7. Relation between implemented methods and the number of studies.

4.2. Comparison of the different studies analyzed

For the comparison of the different studies, Fig. 8 presents the relation between diseases and features extracted in the various studies, verifying that stroke and spinal cord injury are related to walking speed and time. It is also relevant that stroke is related to most features extracted, and walking speed is considered related to most diseases.

Also, Fig. 9 shows the relationship between diseases and implemented methods in the different studies, verifying that stroke is analyzed with most of the methods found in the studies. Also, Pearson's correlation method was considered to analyze most diseases.

Finally, Fig. 10 presented the relationship between features and implemented methods in the different studies, verifying that, as expected, the walking speed and walking time were considered with the most implemented methods.

As presented in Table 8, different available in the literature presented benefits and limitations related to Ten Meter Walk Test performance. It opens several possibilities for developing a new system for measuring the Ten Meter Walk Test results to facilitate medical measurements.

Based on the analysis of Table 8, we suggest employing mobile and wearable technology, together with the sensors built into these devices, to automatically assess the findings of the Ten Meter Walk Test and provide them to healthcare professionals and patients without a lot of manual labor. In addition, research investigations have shown that it may be feasible to put the analysis of many gait data into practice.

The Ten Meter Walk Test results cannot be automatically measured because no automated devices are on the market. But to assess anything correctly, this test is necessary and can help develop strategies for patient empowerment. The acquisition of walking signals must be better studied to build a reliable and functional system.

4.3. Final remarks

This systematic review opens the opportunity for developing a system for measuring the different parameters related to the Ten

	Stride length	Step length	Stride velocity	Maximum EMG value	Number of repetitions	Cadence	Walking distance	WISCI-II scores	Heart rate	Actigraphy parameters	Walking speed	Stance time	Step time	Number of steps	Walking adaptability	Swing duration	Heart Rate	Step velocity	Gait cycle duration	Median of the EMG metric	MoCA score	Walking time	Angles
Coronary artery disease	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Cerebral Palsy	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Head cancer	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Parkinson's disease	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	0
Diabetes mellitus	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Hypothyroidism	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Other orthopedic diseases	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Hypertension	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Unilateral Lower Limb Prostheses	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
Stroke	2	2	1	0	0	2	1	0	0	1	10	2	2	3	1	2	1	1	1	0	1	8	2
Hip diseases	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Neurologic disorders	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0
N/A	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total knee arthroplasty	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Lung transplantation	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Knee diseases	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Neck cancer	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Spinal Cord Injury	2	0	0	1	0	2	1	1	1	0	8	0	0	0	0	0	1	0	1	1	0	4	0

Fig. 8. Relation between diseases and features extracted.

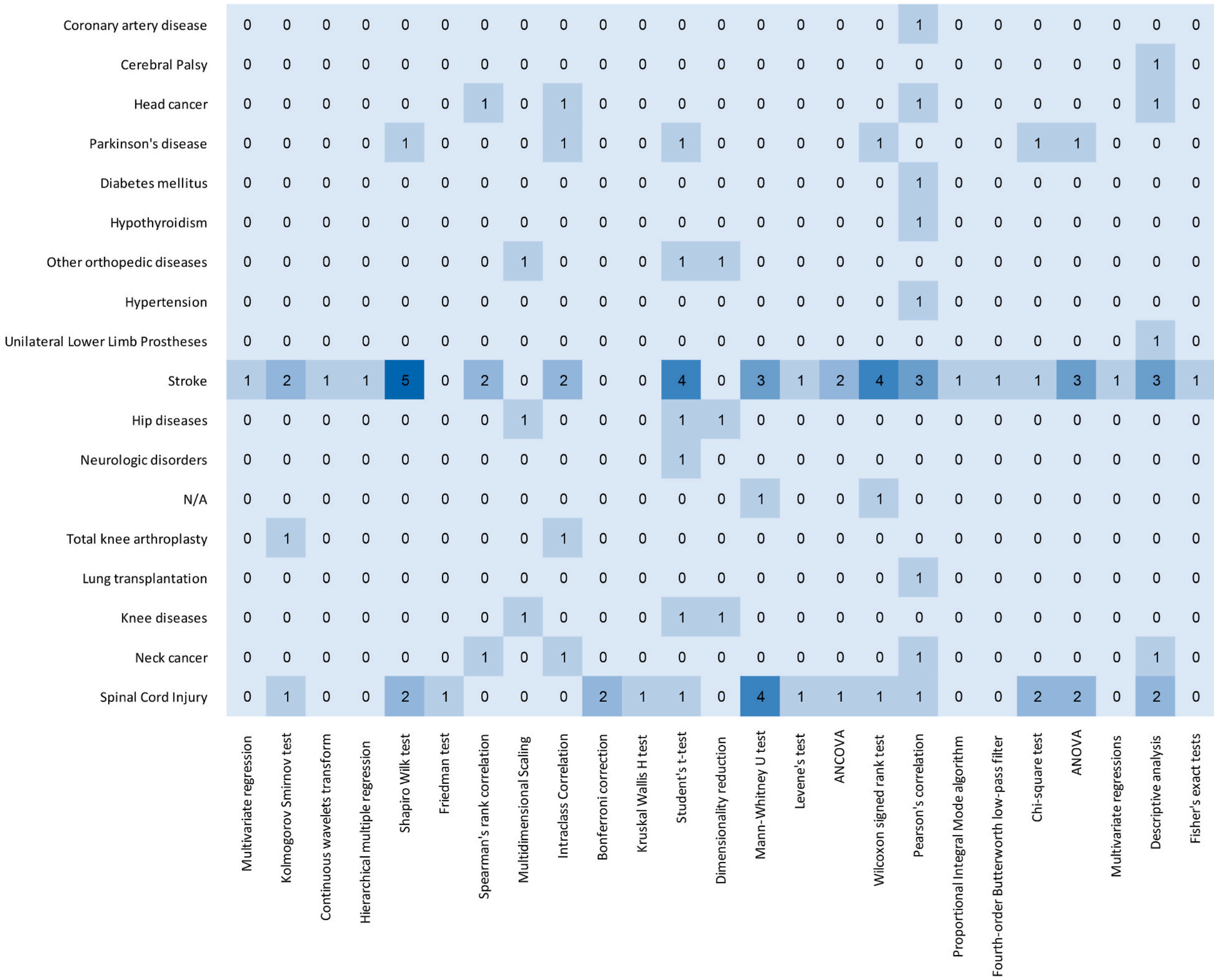

Fig. 9. Relation between diseases and implemented methods.

Meter Walk Test for promoting healthy living and treatments related to physical ability and specialty after stroke. In the future, we intend to develop a system for patient empowerment and personalized medicine for physical therapies. Using sensors widely embedded in commonly daily used devices is key to creating a reliable and useable solution.

The main findings related to the 35 studies analyzed in this systematic review are as follows. Regarding RQ1, "Which are the most used systems for measuring the Ten Meter Walk Test results?", we concluded that different devices are being used with relevance for the devices that embed a chronometer because the most critical parameter is related to the time spent in the performance of the test. Accelerometer sensors commonly embedded in a lot of devices were considered in several studies for the acquisition of data related to movements. The data acquisition and analysis techniques, number of wearables sensors and their placement, and other parameters affecting the accuracy of wearable technology utilized for a test assessment were usually inconsistent among the analyzed studies. Other relevant sensors are the vision and medical sensors used in some studies. As the population commonly holds the devices, creating a solution can be widespread. To gather biomechanical data, most of the research used just one wearable. Nonetheless, it's essential to consider the usefulness and comfort of various wearables in test performance. Although this will improve understanding of the ideal number and positioning of wearables to convey the essential data while enabling a natural running stride, more research is needed to examine the practicality and requirement of using several wearables or whether this can be condensed into one sensor.

Concerning RQ2, "Which are the advantages of measuring the Ten Meter Walk Test with wearable devices?", using different devices preliminarily to the medical appointment allows to speed up the diagnosis and personalized treatments. In addition, these devices will enable the acquisition of data that allows the measurement of different parameters more accurately than a simple visit to the doctor with the benefits of the scientific evaluation of the treatment and the various stages of the disease. However, a medical doctor must perform the later analysis, providing several warnings and proper diagnoses to the patients.

Finally, the RQ3, "How do the features extracted by the sensors improve the monitoring of the evaluation of the Ten Meter Walk Test results for different diseases?", is answered by the relation of different diseases and the features extracted, where the Gait cycle duration, Walking time, Walking distance, walking speed, repetitions, heart rate, stride velocity, stride length, and Cadence were

	Multivariate regression	Kolmogorov Smirnov test	Continuous wavelets transform	Hierarchical multiple regression	Shapiro Wilk test	Friedman test	Spearman's rank correlation	Multidimensional Scaling	Intraclass Correlation	Bonferroni correction	Kruskal Wallis H test	Student's t-test	Dimensionality reduction	Mann-Whitney U test	Levene's test	ANCOVA	Wilcoxon signed rank test	Pearson's correlation	Proportional Integral Mode algorithm	Fourth-order Butterworth low-pass filter	Chi-square test	ANOVA	Multivariate regressions	Descriptive analysis	Fisher's exact tests
Stride length	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0	1	0	0	0	1	0	0	1	0
Step length	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Stride velocity	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Maximum EMG value	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Number of repetitions	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
Cadence	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	1	0
Walking distance	0	1	0	0	1	0	0	0	0	1	0	0	0	0	0	1	0	2	1	0	0	0	0	1	0
WISCI-II scores	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
Heart rate	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Actigraphy parameters	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Walking speed	1	2	0	0	6	1	2	0	5	2	1	4	0	5	1	2	5	4	1	0	3	4	0	6	1
Stance time	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Step time	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Number of steps	1	0	1	1	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	1	0	2	0	0	0
Walking adaptability	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	0	0	0	0	0	1
Swing duration	0	0	1	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Heart Rate	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
Step velocity	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0
Gait cycle duration	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
Median of the EMG metric	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
MoCA score	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
Walking time	1	2	0	0	7	0	1	1	1	0	1	5	1	5	2	1	5	2	0	0	3	5	1	2	0
Angles	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	2	1	0	0

Fig. 10. Relation between extracted features and implemented methods.

considered relevant for different studies related to various diseases. Despite significant potential advantages, no technological application of automated techniques is available for continuous monitoring of the Ten Meter Walk Test and various medical problems, in-depth analysis of electronic medical data, and the linkage of the Ten Meter Walk Test findings. Furthermore, the direct comparison of the results across research was constrained by variations in study protocols, testing environments, and outcome measure definitions. In addition, the study suggests no validation of the outcomes with accepted and known laboratory standards.

Some gaps can be addressed in the retrieved studies, such as the need to develop publicly accessible systems that can foster patient autonomy and whose monitoring findings and results are accessible to the caregiver or physician. In addition, artificial intelligence (AI) techniques can be explored to further investigate and enhance the results of the measurements acquired from the Ten Meter Walk Test.

As a final remark, it is important to highlight the contributions delivered by this paper, not only in terms of data organization, extraction, and synthesis but also in terms of research opportunities and future directions related to the Ten Meter Walk Test.

Table 8
Study benefits and limitations.

Paper	Benefits	Limitations
Priyaranjan et al. [33]	The study emphasizes that the neurological degree of injury and severity were significant predictive factors for individuals with spinal cord injury's capacity to walk. Lower thoracic and lumbar spinal cord damage patients had superior walking abilities to individuals with more significant impairment. The patients' walking abilities improved with time. Some people who used orthoses were able to walk more easily. Knowing the characteristics that affect individuals with chronic spinal cord injuries' capacity to walk may help forecast walking ability and, in turn, aid in organizing the best possible rehabilitation strategies.	N/D
Umemura et al. [34]	The MoCA scores and the amount of sleep throughout the major episodes were correlated. For the proper interpretation of the findings, using a sleep diary and sleep quality questionnaires during the data collection of stroke survivors may be beneficial. In line with findings in patients with spinal cord injuries, it was revealed that participants who performed better on the Ten Meter Walk Test had reduced daily rhythm fragmentation and more synchronization with the 24-h light/dark cycle. The participants who performed better on the walking tests also had greater daily exercise levels and a more consistent circadian rhythm.	Stroke survivors tend to spend more time lying down, which might be mistaken for daytime sleep and lead to incorrect interpretations of the data. More reliable data are produced for the results' interpretation by examining circadian parameters from actimetry. For example, it might show decreased actogram activity levels, which leads to an incorrect understanding of sleep characteristics. Finally, more volunteers are required to enhance the sleep study using questionnaires and sleep logs.
Azharuddin et al. [35]	The Ten Meter Walk Test can be utilized to measure independence in stroke patients because of the significant association between its results and the five-times sit-to-stand performance. Therefore, therapeutic approaches emphasizing the "sit-to-stand" capacity may improve quality of life and dynamic balance.	Due to the tiny subject group, population-wide generalizations of the data are impossible. The participants' baseline features are inconsistent since the authors utilized practical sampling. Even though only ambulatory patients were included, the authors did not consider lower limb spasticity, which may impact performance.
Bigoni et al. [36]	A clinical link between overall gait performance, specific limb performance, balance, and trunk control was found in this study's multivariate linear modeling. A study of gait variable scores in the sagittal plane may aid physicians in understanding learned compensatory methods. The gait profile score is an independent linear predictor of balance performance in patients with chronic stroke.	Based on the patients' walking speed, specific data were eliminated. Because the associations with the clinical scales were considered without adjustment for walking speed, the conventional calculation of Gait Profile Score values was used. Deviations in the Gait Profile Score can quickly identify a gait impairment following a stroke and show the presence of compensatory mechanisms in the non-paretic limb, with generally positive clinical correlations and agreements that have not yet been fully explored.
Calabro et al. [37]	The paper demonstrates how a platform-based robot-assisted ankle rehabilitation might be a clinical rehab tool for people with partial spinal cord injuries. It may improve gait function, ankle dysfunction, and motor control measurements. The research also shows that individuals with spinal cord injuries can still have some degree of reorganization ability in their spinal cord, which allows them to produce and control rhythmic activity in their lower limbs. The evidence suggests that stepping retraining is essential for the gait rehabilitation of people with spinal cord injuries. Robot-assisted rehabilitation appears to entrain and enhance residual stepping-related spinal cord functions, influencing gait and postural control.	The study's primary shortcomings are its small sample size and lack of follow-up. But the study's main objective was to evaluate the effectiveness of platform robot-assisted ankle rehabilitation to traditional physiotherapy in enhancing gait function and balance in patients with partial spinal cord damage. Since almost 50% of the individuals relied on wheelchairs and had limited or no walking function, the authors may not have chosen the best clinical outcome measure for all people with spinal cord injuries. The authors strictly adhered to these results to assess the effectiveness of robot-assisted ankle rehab in enhancing gait stability and performance. In individuals with significantly reduced ambulation abilities, different scales could be employed.
Chang et al. [38]	This pilot study showed that Ten Meter Walk Test performance improved with an additional 30 min of backward walking on a treadmill thrice weekly for four weeks. In addition, this pilot research showed that practicing walking backward on a treadmill increased balance, walking speed, and cardiopulmonary fitness. The results imply that treadmill backward walking is a valuable adjunct to chronic stroke therapy.	These results cannot be extrapolated to a broader population of people with chronic stroke because of the trial's limited sample size. It's possible that using ordinal measures made it harder to spot important improvements. It is uncertain if walking backward on a treadmill improves lower limb strength. The electromyography and muscular strength of the lower extremity muscles were not employed to make this determination. The mild intensity of the exercise had no discernible impact on cardiopulmonary fitness. There was no improvement in cardiopulmonary fitness at this level of effort. Since the trial had no follow-up, the authors could not gather data on long-term outcomes.
Davis et al. [39]	Several gaits, balance, and endurance variables were measured quantitatively in detail for the study's many participants. In addition, the information for individuals having a CSF fluid tap examination includes extensive gait tests and dopamine transporter scans.	Because of its modest size, the study lacked the statistical power to distinguish between the dopamine transporter positive and control groups. Without a specialized examination, the authors cannot confidently say that a patient has Parkinson's syndrome. The authors could have overlooked some individuals since dopamine transporter scans were only given to patients suspected of having a movement condition. The authors do not know if patients in the control group who had no suspicion of having a movement issue had a positive dopamine transporter scan. Additionally, some movement diseases, such as vascular Parkinsonism, might have negative dopamine transporter scans, leading to a bias in misclassification.

(*continued on next page*)

Table 8 (*continued*)

Paper	Benefits	Limitations
Eymir et al. [40]	The study demonstrated that the Step Test is a valid and accurate assessment instrument to evaluate individuals with total knee arthroplasty for dynamic balancing ability and locomotor function. The Step Test has the advantages of being quick, easy, and requiring little staff and equipment. Thus, it may be used to evaluate balance and locomotor function in practically any clinical setting as part of a standard medical examination. In addition, the step test can measure minor, substantial improvements in balance and locomotor function due to treatments in patients with total knee arthroplasty by physicians in clinical settings because of the generally low minimal detectable change value.	This study's main drawback is that all the recruited patients came from the same university-based orthopedic surgery clinic, and only one surgeon performed all the operations.
Karunakaran et al. [41]	The Ten Meter Walk Test may have shown enhanced speed due to the increased walking distance brought on by training. Increased community involvement and ambulation are linked to enhanced functional ambulation, raising the quality of life. The findings suggest a more significant dose might enhance longer-term gait and balance recovery. The outcomes demonstrate that acute stroke patients undergoing inpatient rehabilitation can utilize RE to varying degrees of severity. There were no further problems or falls among the 14 individuals in the sample.	The lack of distinct groups for different times limited the study.
Poleur et al. [42]	The study shows that it is possible to collect normative data on stride length and velocity in a home-based setting using wearable sensors. With this normative data, the authors can determine which variables have significant confounding factors and represent a patient's data as a percentage of the anticipated value for age or height.	One of the drawbacks is the few controls per subgroup (age and gender), primarily due to the scarcity of recording equipment. In addition, given a large number of participants, the authors did not examine the seasonal effects on the parameters, which can have a more significant impact on walking behavior than the season and need continuous recording throughout the year, which may be laborious for controls. Another drawback is that the evolution of participants' body mass index tends to develop more gradually than those with Duchenne muscular dystrophy. Finally, due to the interference with movement caused by ambulation, the examination of upper limb movement in control patients is complicated.
Tan et al. [43]	People with partial spinal cord injuries can walk more easily after five days of acute intermittent hypoxia and walking drills. The group of people who used bilateral arm-driven walking aids to move above ground had the most change in performance. Training to walk faster and further after acute intermittent hypoxia, the more compromised leg's joint coordination or foot trajectory consistency were not affected, regardless of the use of walking aids. These functional improvements may not need the return of able-bodied walking patterns in individuals with partial spinal cord damage.	The intrinsic variety of spinal cord damage in people and the limited sample size prevents the generalization of the current findings, which is one of the study's shortcomings. In addition, the less affected lower limb or interlimb coordination was not evaluated by the authors, who instead concentrated on intralimb assessments of solely the more impaired lower limb. Along with neurophysiological measurements, more thorough lower-limb biomechanical measurements such as kinetic (lower-limb force measurements, joint torques, joint powers, etc.) and spatiotemporal (step-width, step-length asymmetry) parameters may shed light on the mechanisms underlying the effectiveness of this multimodal therapy.
Valenzuela et al. [44]	A Nintendo® Wii intense intervention for teenagers with various forms of cerebral palsy may be a practical, efficient, and secure tool that would improve the functioning of this group in several ways. First, it demonstrated the integration of motor skills into everyday life activities and trends to support gains in mobility.	The drawbacks were the unstable baseline evaluations and the inability to infer that the beneficial effects in the follow-up phase were solely attributable to the intervention phase. Additionally, the study's design does not allow for an acceptable inferential analysis, necessitating follow-up clinical studies to evaluate the posed theory.
Zieriacks et al. [45]	The Ten Meter Walk Test result, which measures ambulation speed, is more clinically applicable. In the Ten Meter Walk Test, acute and chronic subjects dramatically increased their test results. However, the Ten Meter Walk Test results and other treadmill-related data did not significantly differ between acute individuals and chronic participants.	The authors did not note the patients' further medical interventions or prescription drugs. Another drawback of this research is the absence of a control group.
Ali et al. [46]	The before and post-intervention data showed a significant change within the groups, but there was no significant difference between the groups in the end measures. The outcomes are also consistent with a study that employed task-oriented circuit training for stroke survivors in the form of a class, as they discovered a significant difference in the individuals' walking speed in the Ten Meter Walk Test compared to the control group. In addition, it was clear that more patients than others could walk independently at the program's completion and expressed greater satisfaction with their rehabilitation.	The participants in circuit class treatment had more time to perform the prescribed activity, which is frequently overlooked in standard physiotherapy.
Fortes et al. [47]	Shoe lifts significantly increased post-stroke walkers' gait speed and functional mobility. Additionally, the shoe lift helped post-stroke patients walk more naturally.	The study's weaknesses were heterogeneity, a lack of training time with the shoe lift, and a low or high shoe-lift height.

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Table 8 (*continued*)

Paper	Benefits	Limitations
Pehlivan et al. [48]	In candidates for lung transplants, the Ten Meter Walk Test can be employed instead of the 6-min walk test, particularly in those with highly constrained exercise tolerance. The findings showed that the Ten Meter and Six Minute Walk Tests are related. In addition, the Six Minute Walk Test and the Ten Meter Walk Test correlate significantly.	The paltry patient population brings on the principal drawback. Subgroups could not be created for the patients.
Sawers & Hafner [49]	The study's findings support the Ten Meter Walk Test's susceptibility to practice effects in the clinical population. In both sessions, the frequency of practice effects in each test group exceeded a 15% threshold. Additionally, the median amount of trials needed for individuals to perform at a level compatible with suggested administration and scoring protocols was higher.	The current findings come from an exploratory investigation that was only able to evaluate three performance-based measures in one clinical group and using small samples. The findings must thus be replicated and expanded to other performance-based exams and groups through additional research powered a priori. It might involve looking at how practice effects change depending on the level and reason for the amputation. Compared to more extensive national studies, the proportion of participants with transtibial and transfemoral amputations was skewed toward more people with transtibial amputation, potentially restricting the applicability of those findings to users of transfemoral prostheses. Numerous methodological decisions might have impacted the outcomes.
Timmermans et al. [50]	Regarding the significant end measure standard walking speed, the study found no changes between the innovative treadmill-based C-Mill treatment and a traditional overground FALLS program. However, the analyses of the secondary outcome measures suggested that the reported increase in perceived fitness and the observed increase in context-specific walking speed for the C-Mill group immediately following the intervention may be explained by the more significant amount of walking practice observed for the C-Mill group, a crucial component of successful intervention programs after stroke. Additionally, the "change-over-time" results demonstrated that while the standard walking speed of participants in both interventions did not improve, context-specific walking speed and walking adaptability did so and persisted after the interventions, demonstrating the significance of including walking adaptability in post-stroke rehabilitation.	The high dropout rate after ingestion (25%) is one issue. In addition, the absence of a control group, which prevents attributing all the observed effects to the treatments, was another drawback of this study. Finally, because of the nature of the intervention, neither the physical therapists, the participants, nor the assessors were blind to the participants' grouping.
Vieira de Moraes Filho et al. [51]	The study suggested a brief intervention of a few weeks would alleviate the disease's motor symptoms. It implies that the intervention encouraged short-term brain upgrades to increase functional performance significantly. The ability of dopamine-based antiparkinsonian medications to modify the three-phase muscle activation pattern consistent with a decrease in bradykinesia and an improvement in functional performance due to increased availability of the neurotransmitter in the affected regions is the final aspect of the functional performance it offers.	The authors did not keep track of the individuals being evaluated by muscle size and quality. Additionally, greater speed force performance was not tracked. The current situation indicates a broad field for therapeutic progress in disease and improving the quality of life for people with Parkinson's disease. More research should be done to fill in the gaps on the effects and uses of progressive resistance training on Parkinson's disease and its mechanisms, thereby consolidating it as a complementary treatment method.
Lunar et al. [52]	The study's findings provide a solid basis for follow-up studies that might give a clearer picture of the degree to which mobility test performance varies by residential situation. The results also serve as a foundation for studies highlighting the necessity to consider the residential environment and the proven anthropometric parameters of age, sex, and ethnicity. Clinicians could thus have a better knowledge of older persons' mobility and a more precise interpretation of the results of mobility assessment tools. In light of inter-regional variations in socio-cultural and environmental traits, looking into whether a comparable degree of rural-urban difference occurs in other regions might also be beneficial.	In this exploratory analysis, it was impossible to confirm if environmental, sociocultural, or health-related factors influence mobility. The results of this study may be a preliminary reflection of how older adults who live in urban and rural areas perform similarly on the mobility tests due to the easy sampling and the relatively small sample size. Similar to earlier studies that reported reference data for tests explicitly designed to assess older individuals' mobility, the study's technique for the 10-m walk test includes measuring time throughout the middle 6 m of the 10-m walkway. Therefore, the trends in this cohort's mobility test performance may not necessarily apply to other nations with different rural-urban setting features from the Philippines.
O'Brien et al. [53]	One benefit is the deployment based on the ease of employing only one sensor to measure the impact of aging on gait and balance during well-established clinical outcomes and confirming spatiotemporal gait characteristics with the smallest sampling rate known to exist in the literature. Sensor-based information derived from these clinical tests might be divided into several areas to evaluate balance, gait, and mobility. These characteristics go beyond the clinical outcome assessments' conventionally one-dimensional measurements. By identifying consistent differences between people and tasks, these sensor-derived traits reduce the influence of the floor and ceiling. Based on stroke patients as a proof-of-concept, it was demonstrated how sensor-derived characteristics from a single patient might be compared to normative data from age-ranged, healthy populations.	One drawback is that the study's maximum participant age was 70 among a cohort of older persons who were quite active, making the sample sizes for each age group relatively modest. An older or more diverse population can't foresee changes in sensor data caused by aging. After adjusting for weight and height, only one feature showed a moderate connection out of the 35 characteristics that showed a low correlation in the univariate sensor-based feature correlations. Individuals under 70 continue to do worse on the Ten Meter Walk Test. Age, gender, height, and weight were all included in the hierarchical multivariate regression model, which produced relatively low R^2 values.

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Table 8 (*continued*)

Paper	Benefits	Limitations
Ofran et al. [54]	The authors discovered substantial connections between computerized spatiotemporal gait characteristics and gait symmetry in post-stroke patients and their ability to predict typical clinical gait and functional mobility measures. For example, spatiotemporal factors predicted more significantly than 50% of the Ten Meter Walk Test scores. The objective computerized evaluation employing spatiotemporal and symmetry gait characteristics provide comparable information, like commonly used functional gait metrics. Using these metrics in the daily review of post-stroke patients may be favorably compared to the standard evaluation techniques regarding assessment time, progress tracking, and precision.	Different examiners carried out further functional evaluations. As a result, these tests also have high inter-rater reliability. However, the authors considered gait lab tests up to a year after the stroke. Thus, there may have been a significant lag in the timing of the tests.
Broderick et al. [55]	Patients with chronic stroke may experience decreased lower limb muscle tone because of the suggested treatments. The combined intervention has shown high feasibility for an adequately powered randomized-controlled study regarding participant retention and few adverse events.	The comparatively low dose of medicine may have reduced the efficacy of the treatment. The number of outcome evaluations allowed at each time point was one, and more assessments could increase the accuracy of participant rating. Participants had to look down while walking to look at the mirror treatment equipment. A participant's performance on the applicable outcome measures may have been impacted by the approach to gait, which deviates from standard posture when walking.
Bui et al. [56]	An appropriate and practical way to increase activity levels in orthopedic rehabilitation is through an app-based fitness regimen. It also shows how functional outcomes may perhaps be enhanced.	Because it was pilot research, it could not identify substantial changes in mobility. The considerable amount of time—on average 100 min per participant—those individuals in both groups spent in planned treatment reduced the functional importance of the supplemental exercise program. The individuals had shorter stays and, on average, excellent functioning, which reduced the potential benefits. After individuals were discharged, there was insufficient time for the follow-up to assess the longer-term effects of increasing independent exercise on function, confidence, and activity levels. Future research may also look at the financial viability of an additional app-based fitness program to help physicians use resources more effectively.
Hadoush et al. [57]	The research demonstrated that bilateral anodal transcranial direct current stimulation is an efficient, safe, and practical method for treating Parkinson's disease patients' balance and fear of falling issues.	There is inconsistent evidence against unilateral anodal transcranial direct current stimulation improving balance and postural stability.
Éden et al. [58]	The study shows that the Ten Meter Walk Test has excellent test-retest reliability. The research did show a statistically significant correlation between the several tests, which may indicate that each test measures a particular aspect of a larger construct of physical performance. In head and neck cancer survivors, the early use of functional performance measurements enables the development of a baseline level of function before the harmful effects of cancer therapies.	A small sample size that is relatively homogeneous in terms of ethnicity, place of residence, and cancer diagnosis was used in the study. This study's therapy technique and stage of treatment are further drawbacks. Based on the tight inclusion criteria relating to the existence of comorbidities that may impair the safe performance of the research-related tasks, a sizable number of individuals were judged unfit for participation in this study.
In et al. [59]	The researchers observed that treadmill training with Thera-Band considerably improved the function and balance of the lower limbs and gait skills in stroke patients.	It is difficult to generalize these results since the authors examined just a limited number of patients and did not study the impact on temporal gait symmetry. Future research may need to include a gait analyzer to explore the effects of gait training with Thera-Band on gait symmetry. It will also be important to assess muscle activity and muscular contraction onset time to understand the process that results in changes in gait patterns.
Swank et al. [60]	The authors created a composite measure to comprehensively represent the function of patients with deficiencies across several system domains because of neurological dysfunction. The clinical benefit might come from using a "mobility composite measure" for individuals with neurologic diseases.	The study has a retrospective design restricting our control over what data was gathered and reported resulting in missing data. Due to the small sample size and absence of a substantial dataset from which to derive z-scores for each patient, the authors could not produce results that could be trusted. The model values each measurement equally when characterizing a patient's functional condition.
Kumru et al. [61]	Early gait rehabilitation combined with high-frequency repetitive transcranial magnetic stimulation seems to be a practical therapeutic approach for improving motor function in the lower extremities and, in addition, can also improve motor function in the upper extremities in cervical spinal cord injury. Furthermore, it demonstrates the potential benefits of combining therapeutic methods with non-invasive brain stimulation approaches to enhance recovery in patients with motor-incomplete spinal cord injuries.	During active repetitive transcranial magnetic stimulation, a relatively low intensity was used for the leg muscles. The repeated transcranial magnetic stimulation group had greater lower extremity motor strength, which may have played a role in the improvement's significance. It is uncertain whether or if the natural trend of recovery in the first six months depends on the etiology of the spinal cord injury in the participants, which varies in severity. Because the study's premise and goals were to examine lower extremity and gait performance, the authors did not conduct any functional tests to assess upper extremity function.

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Table 8 (*continued*)

Paper	Benefits	Limitations
Han et al. [62]	Due to its slight weight and low inertia, the primary, non-motorized commercial walker helped the participants perform better on a level surface and with an upward grade. On the downhill slope, though, the smart mobile walker's speed control proved more beneficial. Walkers are primarily used to prevent falls while keeping good posture.	The system did not consider fall- and posture-related parameters.
Clark et al. [63]	The results showed the potential use of Kinect-instrumented gait analysis in a clinical environment, revealing more significant insights into a person's gait and dynamic balancing abilities that may be possible with the single, simple-to-use, and trustworthy examination. In addition, in both clinical and research contexts, variables collected from the evaluation may make it possible to effectively track gait performance changes over time and provide information for individualized treatment strategies.	The research sample was a small and diverse group of stroke survivors recruited from a single outpatient institution. Spatiotemporal variables were the only ones used as outcome measures. The authors did not look at potentially significant outcome markers such as the medial-lateral center of mass swing. Due to the enormous number of variables produced by the Kinect for this type of regression research, further Kinect-based measures were not examined. The Kinect's accuracy and precision were yet another drawbacks. Another drawback is the clinically determined regression model's combination of the manually measured time and step count. Multiple gait cycles cannot be investigated from a single test due to the limited field of vision of the Kinect.
Poncumhak et al. [64]	The study investigated the Ten Meter Walk Test's potential for assessing ambulatory spinal cord injury individuals' capacity for independent walking. The findings revealed that the time necessary to complete the test could be utilized as a quantitative goal criterion for functional progress for patients with spinal cord injury to walk without a walking aid both during in-patient rehabilitation and after discharge.	The capacity of the patients as well as the accessibility of the place and necessary tools, must be taken into account while applying the test.
Saensook et al. [65]	The Ten Meter Walk Test measures the walking speed that the result connects with motor function, walking endurance, and overall gait quality. Moreover, the conclusion concerning clinically meaningful changes might be problematic when periods between visits are considerable or with changes in the assessors. A quantitative standard measure is easier to be standardized and gives objective data that permits efficient data comparison among testers and test intervals. The results of this study further demonstrate the clinical usefulness of the Ten Meter Walk Test for diagnosing and tracking functional changes in spinal cord injury patients.	The results might not show disordered systems. The subjects were divided into groups based on their chosen ambulatory assistive equipment rather than their best ability, which might impact the results. Moreover, the eligible participants needed the capability to continuously walk independently for at least 50 m to increase the number of subjects. Since many individuals were removed, only patients with strong walking abilities may benefit from the findings. It is difficult to tell whether the results reflect the limitations brought on by the spinal cord injury or the challenges associated with using an ambulatory assistive device. There were no records of spinal cord injury patients using these tools who employed various ambulatory assistive devices. As a result, the number of participants in each group was chosen based on the percentage reported in the earlier reports. The results of these tests indicated a test with acceptable high power (60–95%). The utility of these instruments to track skill levels in various areas is supported by the stark discrepancies across the groups. The usefulness of these tools will be improved by additional research that correctly mitigates the impact of these factors and provides a cutoff score for the capacity for independent ambulation without an ambulatory assistive device.
Scrivener et al. [66]	The research had an excellent follow-up rate for survived patients and a sizeable sample size. Regardless of handicap or other characteristics, all successive stroke survivors admitted to the stroke unit were included. These stroke survivors were also monitored from the beginning of inpatient therapy to the acute stage after their stroke. As a result, there was no chance of selection bias when the authors observed a representative sample of stroke survivors during their hospital stay.	The measurements that were looked at were not all there for measuring different components of motor function.
Schuck et al. [67]	Patients can practice walking more dynamically, varied, and naturally.	The small sample size in this pilot study precludes drawing any reliable conclusions about the impact of patient-cooperative robot-assisted gait training on walking ability. In addition, improvements may not occur if existing compensatory techniques are already so firmly ingrained that an extra behavioral intervention would be required in addition to the motor training, as it very likely occurred in two of the patients in the pilot research.

5. Conclusions

This article has thoroughly examined the usage of wearable and mobile devices with various sensors for automated measurement of the Ten Meter Walk Test. There were 35 papers deemed pertinent for the inclusion criteria, indicating interest in this area as a study topic. Accordingly, mobile software and hardware support the performance evaluation of the Ten Meter Walk Test. Dedicated mobile applications may allow users to evaluate their walking performance and share that information with their doctors.

Overall, some gaps are identified in development, such as creating publicly available sensor-based systems that can promote the patient's autonomy and whose monitoring findings and results are available to the caregiver, physician, or itself (named patient empowerment). Furthermore, neither solution uses AI methods to support the results from the Ten Meter Walk Test measurement. However, it may empower the quality of results, making them more exact and reliable, allowing the early detection of different diseases. Another point of view arises from the individual data privacy regulations, which are never mentioned in the analyzed studies.

As limitations of our study, it can be mentioned that although the vast number of platforms researched to obtain the literature, additional indexing platforms can be used. From another point of view, most of the retrieved studies included and analyzed several physical functional tests (Six Minute Walk Test, Timed Up and Go test, etc.), whose features can be mixed with the ones specific to the Ten Meter Walk Test. Therefore, additional exploration of this subject may be required. Regarding policy implications, it would take additional research and derive this study's goal in a different direction.

This study highlighted the most popular devices, the methodologies, and extracted data that produce the most cutting-edge predictive and analytical performance, as well as the current research trends in continuous application measurements of the Ten Meter Walk Test. Systems for automatically measuring the outcomes of the Ten Meter Walk Test can be developed using the information provided in this review. Additionally, it would be essential for physicians to use telemedicine software to monitor various patients remotely and provide individuals with a tool to manage their health and underlying medical disorders better. Finally, this review has shown that wearable technology is becoming more widespread for assessing the Ten Meter Walk Test. Still, more research is needed to determine a standardized approach and the validity or reliability of instruments.

Author contributions

Cristiana Lopes Gabriel, and Ivan Miguel Pires: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Paulo Jorge Coelho, Petre Lameski, Hiren Mewada, and Filipe Madeira: Analyzed and interpreted the data; Wrote the paper.

Eftim Zdravevski: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools, or data; Wrote the paper.

Nuno M. Garcia, and Carlos Carreto: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.

Data availability statement

No data was used for the research described in the article.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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