WITHDRAWN: A Systemtic Review on Gait Measurement Techniques Using Prisma 2009

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Research Article

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Posted Date: June 22nd, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1761927/v1

Additional Declarations: No competing interests reported.

EDITORIAL NOTE:

The full text of this preprint has been withdrawn by the authors while they make corrections to the work. Therefore, the authors do not wish this work to be cited as a reference. Questions should be directed to the corresponding author.

A SYSTEMTIC REVIEW ON GAIT MEASUREMENT TECHNIQUES USING PRISMA 2009

Abstract

Academics and prosthetics are interested in gait evaluation since it is a highly focused research field. There is a lot of literature in this field because it is a popular diagnostic tool for measuring abnormalities and the beginning of musculoskeletal illnesses. Although there are several gait measurement Techniques (GMT) for motion analysis in the literature, there are only a few studies that indicate the comparative analysis and applicability of different methodologies. The goal of this work is to give a useful recapitulation of various gait assessment methods and to investigate the relative prevalence of various GMT based on several researchers' applications.

The findings of a comprehensive review of gait measurement methods utilising the PRISMA methodology are summarised in this publication. A total of 53 research articles published between 1989 and 2021 were considered for critical review. The categories of gait measurement systems were compared and ranked using the Analytic Hierarchy Process, based on particular criteria (AHP). The review helps to summarise many areas of gait analysis, including task kinds, gait characteristics, and gait measurement techniques. The study compares gait assessment methods using a specially created capacity index and gives appropriate mappings between these aspects. It also includes helpful advice for choosing gait systems depending on the criteria.

Keywords: Gait analysis, Gait measurement, Comparative study, PRISMA methodology, wearable Sensors

1. Introduction

Gait analysis is a biomechanical examination of a person's movement that identifies patterns in walking and other problems. Walking patterns are developed organically and stay consistent over a lengthy period of time. Habits and lifestyle are likely to alter gait patterns, which indicate the body's capacity to move, flex, remain steady, and strong. The gait style is also affected by anatomical and physiological changes caused by age, illnesses, or trauma. In general, human walking entails a series of compensations that might result in efficiency losses. These locations may be efficiently identified via gait analysis. The human gait cycle is split into two phases[1] (stance and swing), each of which is further divided into seven stages (loading response, first contact, mid stance, terminal stance, pre-swing, initial swing, mid-swing, and terminal swing), each of which is represented by seven events. During key events in the gait cycle, the lower extremity muscles are responsible for supplying the combination of torque or forces required to produce lower body motion and change the centre of gravity [2].

1.1 Importance of gait studies

Gait analysis is a multi-part musculoskeletal action that includes bones, muscles, tendons, ligaments, and blood. These aspects work together to make it easier for a person to go from one location to another. During this motion, the human skeleton executes a variety of rotational, translatory, and oscillatory motions. The physiological activity of the aforementioned system in a normal human being is dependent on neuromuscular balance. The smooth walking mechanism is disrupted by ageing, usage, underuse, bad habits, and inherited or unintentional deformities. As a result, the gait functions are harmed. Bergmann et al. [3] analysed everyday activities' gait patterns and provided the hip contact forces and accompanying gait patterns. When walking at roughly 4 km/h, the typical person's hip joint is loaded with 238 percent of his body weight (BW), 251 percent of BW when ascending stairs, and 260 percent of BW when going downwards. When a person is carrying a burden, these combined forces are amplified. Load and exhaustion change usual gait characteristics, as Qu and Yeo [4] discovered. The gait attentional burden is affected by changes in walking pace. [5]. In [6–9], the effects of bearing weight on kinetic and kinematic responses are identified. In terms of the lower extremities, load carrying affects the hip, knee, and ankle joints kinetically, while inappropriate footwear impacts the knee and hip. [10]. Chang et al. investigate the effects of different kinds of walking surfaces on gait characteristics. [11]. Though technology advancements are attempting to automate job processes, many activities still need physical labour, such as manual materials handling (MMH) or manual force exertion using a tool. Manufacturing plants, warehouse facilities, service-providing facilities, building sites, and other workplaces are all affected by the MMH. All of the foregoing tasks include carrying a burden in an uncomfortable position, using non-standard footwear, and walking on uneven ground. As a result, gait analysis is an important technique for predicting and avoiding musculoskeletal problems (MSD). Medical rehabilitation, diagnosis, and biometric identification all benefit from regular evaluations of gait parameters. [12,13].

1.2 A brief of gait analysis methods

Gait analysis is a biomechanical method for assessing human movement that has a long history. Connor and Ross provide a short overview of the evolution of several gait measuring methodologies. [13]. Different gait data gathering technologies aid in the accurate measurement of particular parameters. In industrial settings, the video posture-based occurrence sampling approach was utilised to detect unsafe posture using standard instruments such as the

OVAKO Working posture Analyzing System (OWAS). [14]. For kinematic gait analysis, an automated image processing method was shown to be useful [15]. For motion capture, a variety of accelerometry-based sensors are employed. [16]. Adaptive algorithms [17] has also piqued academics' interest in developing better measuring methodologies. A user-friendly approach of gait analysis is provided by an accelerometer included in mobile phones, such as igait analysis system [18] and sum-vector analysis. [19]. With RGB (Red-Green-Blue) data from the Kinect, computers can automatically extract kinematic elements that characterise human gait. [20]. IMU-based methods have been successfully validated for foot pitch angle estimation 22 and thigh angle estimation [23] against Optical Motion Capture Systems, especially Vicon systems [3, 6, 22–31]. Optical gait measuring devices are the most precise and costly kinematic gait measurement tools. Electromyography (EMG) [3,32–35], force platform [3,6,11,26–28,30–33,36–40], instrumented treadmill [10,24,41], computerised carpet [42,43], capacitive pressure distribution platform [44], and electronic walkway [45] are among the techniques used for force measurement, according to the literature reviewed. Advanced gait analysis techniques are being developed once again, this time employing individual sensors and customised firmware. MagicSox, for example, uses pressure sensors, flex sensors, and a gyroscope implanted in socks to evaluate gait irregularities [46,47]. All of the strategies listed above are useful for a specific application and may be used to conduct a thorough investigation. There are a few studies in the literature that concentrate on employing gait analysis methods in medical rehabilitation [12] and studies that utilise recently developed techniques such inertial sensors and adaptive algorithms [48]. The analysis of the literature demonstrates the potential for comparing different measuring techniques depending on the activities at hand and the gait metrics involved.
As described in Sec. 2, we have enlisted widely used motion analysis methodologies in this document using different search criteria. Using the PRISMA methodology flow chart, the publications that were found were chosen and included in the research. The articles were then divided into categories based on their intended use and measuring methodologies. The articles that were chosen were extensively investigated, with pertinent data retrieved and presented. Measurement system capability scores (MSCSs) in percent were determined using the results of several methodologies. The link between the measuring process and the activity completed has been established, making the task of choosing particular gait measurement techniques for a certain application easier.

The purpose of the investigation described in this article is threefold. For starters, it serves as a valuable summary of the numerous gait measuring methodologies used by different practitioners. Second, it investigates the link between the task at hand, the gait characteristics measured, and the gait analysis methodologies used. Finally, it tries to rate different gait measuring systems based on a set of criteria and gives helpful advice for choosing the right one.

2. Review methodology

The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method 38,49,50 was followed while conducting this study. PRISMA is widely regarded as a suitable method for conducting systematic reviews in any scientific subject. Authors may use the PRISMA technique to improve the reporting of well-organized reviews and meta-analyses. The PRISMA methodology, according to Moher et al., is effective in providing systematic evaluations of varied studies, particularly when reviewing treatments. The PRISMA approach is divided into four stages, as indicated in Fig. 1. The four stages i.e. Identifying records via database searches and other sources, as well as deleting duplicates, Screening titles and abstracts to exclude records that do not meet the study's requirements, Examining journal papers for eligibility and eliminating the number of articles with justifications and the number of papers examined for meta-analysis were included.

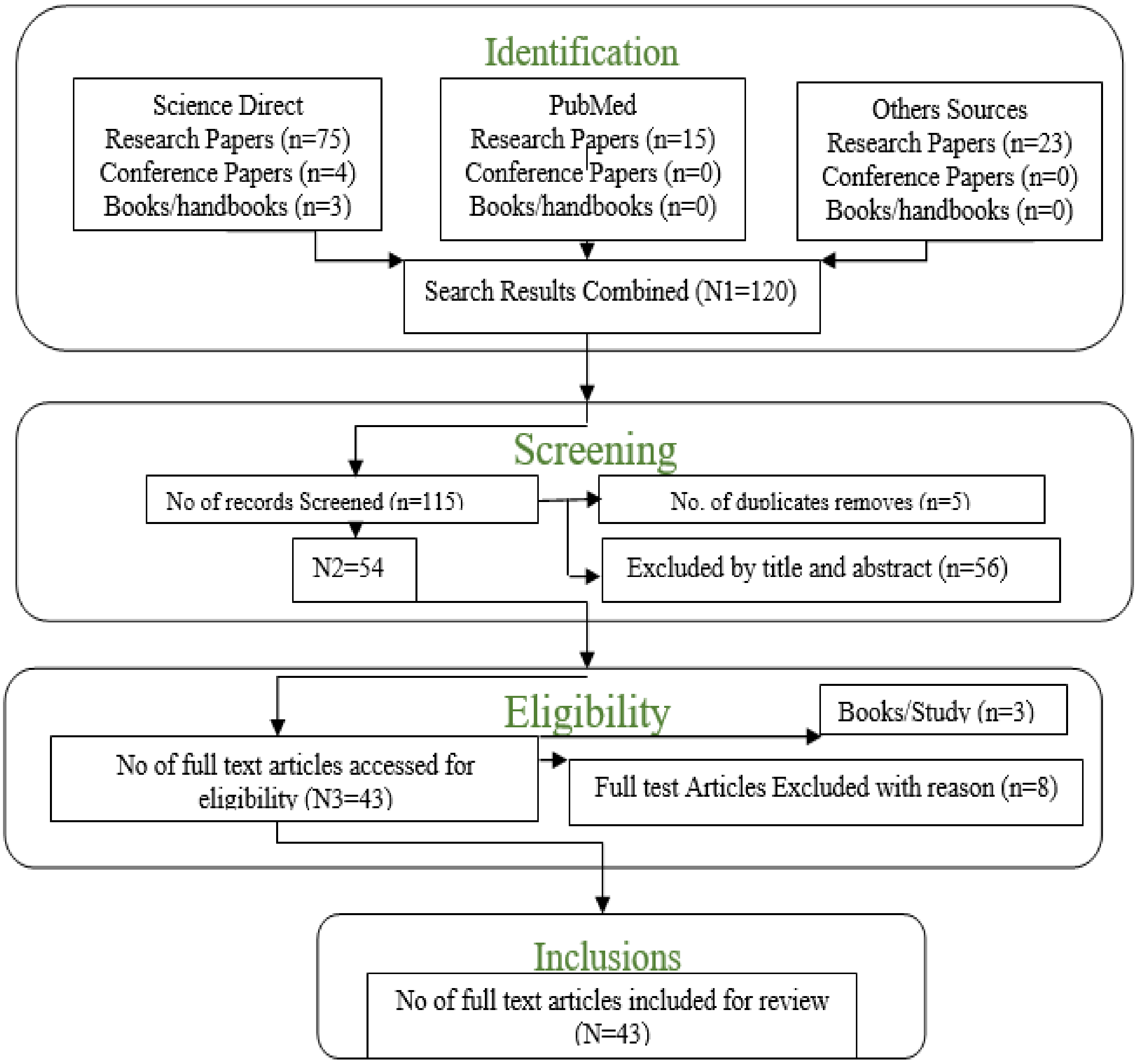

Fig. 1 Application of PRISMA methodology for the present review

Our research found 120 records from a variety of sources, including journal publications from Science Direct, PubMed, and other sites, conference proceedings, and books/handbooks, as shown in Fig 1. A total of 56 entries were eliminated from the investigation due to duplication (n = 5) and non-relevance (as determined by reading abstracts and books) (N2 = 54). For the remaining 54 articles, a full-text examination was conducted, with eight items being eliminated for good cause. As a result, a total of 43 papers were evaluated for evaluation.

2.1 Criteria for including the articles

Inclusion criteria for the research papers included in this review contains research that has been done on gait/motion analysis in a real or laboratory setting, research focuses on several motion analysis methods and their application to a specific area and publications published in prestigious journals including Scopus, SCI, and SCIE. Because of the variety of methodologies and gait analysis applications, research publications with comparable application areas are removed from examination.

2.2 Study search and selection

The current analysis takes into account published studies from 1998 to 2021. During the assessment of the literature, it was discovered that most of the progress in this subject happened after the year 1998. Through various resources such as books, articles, full-text journals, conference proceedings, and databases such as Science Direct, PubMed, and other open access journals, various word combinations were searched to acquire a vast number of things. (gait or motion or human movement) and (analysis or evaluation or assessment) and (methodology or approaches) and (level walking or stair walking or walking on a slope or slippery surface) were used as search phrases (walking with different speed or footwear or method of carrying the load or type of loads). The current research looked at kinematic, kinetic gait characteristics, gait phases, or spatiotemporal aspects in the lower limbs, as well as ground reaction force (GRF) in healthy and impaired patients. The titles and abstracts were screened, and papers that did not meet the inclusion requirements were eliminated. Later, the articles in hand were examined, and ineligible things that did not satisfy the established criteria were eliminated. The review includes all of the remaining papers once they were reviewed.

2.3 Data acquisition

Four of the 43 articles chosen were review pieces. The material in these review papers was helpful in comprehending the current literature's comparative analysis of measuring methodologies. Appendix contains a summary of the information taken from the remaining 39 research publications. The data is organised in a table with the headings: Author (Year), Application area, Method of data collection, Statistical tool used (if any), Sample size considered in the research, Concluding comment and study limitations.
The 39 research publications were scrutinised in order to learn more about the task-specific gait characteristics assessed by the authors, as well as the apparatus they employed. Table 1 summarises the conclusions of the review under the headings such as Author (Year), Task completed, Instrumentation utilised, and Gait parameters taken into account in the study.

Table 1 summarises the conclusions of the review

S. N.	Author (Year)	Task completed	Instrumentation utilised in the study	Gait parameters taken into account
1	Chen and Qu (2018)	30 men participated in this research, which included them ascending a stairs three times, once with no burden, once with a modest load, and three times with a heavy load.	An eight-camera motion capture system (Motion Analysis Eagle System).	Lower limb and trunk kinematics, foot clearance measures, spatial-temporal gait parameters, and postural stability measures.
2	Bidabadi et al. (2017)	One subject had normal foot drop, while the other had foot drop. Both participants were free to walk as fast as they liked on the ground in this trial.	Inertial measurement unit (MPU-9250)	Foot drop, Pitch angle of thigh, shank, and foot.
3	Khandelwal and Wickstrom (2017)	Analysis of a database of 20 people' walking and running gaits in both indoor and outdoor settings has been conducted.	3-axes Shimmer3 accelerometer (8 g), shoes with piezo-electric force-sensitive resistors (FSRs), treadmill.	Gait event detection protocol
4	Qu and Yeo (2011)	A total of 12 young male volunteers participated in this investigation, which included them walking on a treadmill twice, with a backpack weighing 0, 7.5, and 15 kg on each occasion.	Treadmill, eight cameras, MAC-Eagle motion analysis system, retro-reflective markers.	Step length variability, step width variability, hip Range of motion (ROM), knee ROM, Trunk ROM
5	Rosenbaum et al. (2013)	In this experiment, 20 developing youngsters walked barefoot at three different speeds: average, slow, and rapid.	A capacitive pressure distribution platform, infrared light gates.	Contact time, peak pressure, force, and force time interval.
6	Bergman et al.(2009)	Four patients with complete hip implants do nine various tasks, including slow walking, quick walking, ordinary walking, going upstairs and downstairs, standing up, knee bending, standing on 2-1-2 legs, and sitting down.	A Vicon system with six cameras, two force plate, EMG setup	Hip contact forces, joint angles, EMG, GRF
7	Givon et al. (2009)	In this research, 81 MS patients walked barefoot on a 4.6-meter pressure measurement mat six times at a pace of their choosing.	The GAITRite analysis system is a computerized walking mat with sensors arranged in a grid-like pattern.	Gait velocity, cadence, step length, step width, and period of single-limb support, double limb support and swing phase as a percentage of the gait cycle.

8	Wu et al. (2000)	At the beginning of this research, we had 10 patients with a unilateral solid ankle arthrodesis and 10 healthy individuals undergo three trials of walking on force plates.	A Hi-Res ExpertVision system, six 240 Hz cameras, reflective markers sampled at 60 Hz. Three Kistler force plates, and an MA-100 EMG system.	The mean and standard deviation of cadence, swing-to-stance ratio, angular motion data of the ankle and foot.
9	Bovi et al. (2011)	Forty healthy volunteers walked in a variety of ways, increasing and decreasing their pace, walking on their toes or heels, and climbing and descending stairs as part of this research.	9-cameras SMART-E motion capture system, 29 retro-reflective markers (12 mm diameter), Two force plates, 8-channel wireless electromyograph, ZeroWire, 10 mm diameter adhesive electrodes.	Gait speed, cadence, step length, stride length, stance time, first double support time, EMG, GRF, joint moments,
10	Keenan et al. (2011)	The 68 young participants in this research were instructed to walk barefoot and in two different kinds of conventional footwear to measure the kinetic and joint moments in the lower extremity.	Asics footwear line, the Brooks footwear line, 16 retro-reflective markers, AMTI instrumented treadmill, ten camera VICON 624 motion analysis system.	GRF, hip flexion & extension, hip adduction, hip internal & external rotation, knee flexion, knee varus, knee internal & external rotation, ankle dorsiflexion, ankle eversion, ankle internal & external rotation.
11	Yang et al. (2012)	A smartphone-based triaxial accelerometer was attached to the backs of 15 healthy individuals and they were instructed to walk 25 metres at a comfortable pace.	Dynaport Minimod, Xsens MT9, and accelerometer embedded in HTC mobile.	Cadence, gait speed, mean step length, acceleration RMS values in vertical, mediolateral and
12	Qu (2013)	We tested 12 young people's ability to walk at a self-selected pace on a treadmill while being subjected to varying physical (backpack weights ranging from zero to eight and a half kilogrammes to twenty kilogrammes) and cognitive demands.	Treadmill, An eight-camera motion capture system (Motion Analysis Eagle System), reflective markers.	Local dynamic stability is calculated using the sternum velocity time series in the anteroposterior (AP), vertical (VT) and mediolateral (ML) directions.
13	Booij et al. (2021)	A total of 25 sick and 22 healthy individuals between the ages of 60 and 10 years old participated in this research.	GRAIL (Gait Real-time Analysis Interactive Lab), InfraRed optical motion capture with wireless, light-reflecting markers (Vicon 2.5), 2 6D force plates.	Sagittal and frontal joint angles, moments and overall powers for hip, knee, ankle.
14	Auvinet et al. (2014)	During this investigation, eleven individuals were able to walk on a treadmill at a moderate pace.	120Hz Vicon system, Kinect, Treadmill, marker set.	Heel-strikes, the distance between legs at an estimated knee height, gait cycle.
15	Gonzalez et al. (2015)	In this research, 14 elementary school students were requested to walk without trolleys and carry 10%, 15%, and 20% of their body weight for the duration of the experiment.	The GaitRite system.	Velocity, cadence, stride length, stance phase, swing phase, single support phase, and double support phase.

16	Nascimbeni et al. (2015)	In this research, 22 young people were given the task of backward counting while walking on a treadmill at self-selected, slow and rapid gait speeds.	A footswitches-based statistical gait analysis system (STEP 32, DEM Italia), treadmill.	Stride time, coefficient of variation of stride time and double support percentage of the stride cycle.
17	Vedder (1998)	Both shifts of the spinning portion of an industrial facility were observed and documented for this research.	Two video-cameras	No specific gait parameters, but various risky postures (combination of GP) in task.
18	Yeasin and Chaudhuri (2000)	Normal and diseased participants were tested and compared in terms of their gait patterns (backward, frontal, and on sidewalks).	Sequential Architecture (standard 266 MHz Pentium PC), standard frame grabber and digitizer with an external video camera (consumer-grade camcorder)	Centre of gravity, change in elbow angle, shoulder angle.
19	Dierick et al. (2004)	Patients and healthy people were both tested on a treadmill that measures the amount of effort exerted while walking.	A commercial treadmill with four 3D strain-gauge force transducers, Six infrared cameras, reflective markers.	Ground reaction force, net ankle joint moments, the body center of mass, kinematics and mechanics.
20	Abtahi et al. (2017)	Twelve healthy volunteers participated in this investigation by walking normally and simulating a foot drop gait.	Arduino 101 board with the Intel Curie processor module, gyroscope and accelerometer integrated into the Intel Curie, pressure sensor on the heel, two flex sensors, smart phone.	Foot's orientation, swing phase as a gait cycle, gait speed, gait cycle period of the foot, flexion of the ankle.
21	Alamoud et al. (2018)	Carrying a weight of 10 and 30 pounds, 30 men were asked to bear the load in four different positions: frontal, lateral and bilateral.	Active camera (Vicon) and 41 markers (passive), 4 m walkway, two force plates, and weights of 10 and 30 lb.	Locomotion Stability, Gait Spatio-Temporal Parameters, and Spinal stresses.
22	Tajima et al.(2018)	Fourteen male subjects took part in this research, walking in two different ways: with a regular stride and at a tempo designed to minimise impact. (Step length, gait speed, etc.) are all factors to be taken into consideration.).	Vicon plug-in gait model (Vicon Motion System), reflective markers and force plates.	Gait speed, maximum vertical ground reaction force, braking accelerating force, loading rate, joint angle, and external joint moments.
23	Walsh et al. (2018)	As part of this research, 14 men ages 65 to 66 were instructed to bear three different kinds of loads for four minutes: no weight, a steady backpack load, and an unstable backpack load.	A 2 cm inter-electrode distance to measure the electromyographic (EMG), Treadmill, eight camera MAC-Eagle motion analysis system retro-reflective markers.	Gait variability, dynamic stability, and muscle activity.
24	Speedtsberg et al. (2018)	Treadmill walking was required for four minutes in this trial, with eight children with sensory integration disorders and ten healthy children	Accelerometer, treadmill.	Upper body accelerations in vertical, mediolateral and anterior-posterior directions.

		participating.		
25	Caetano et al. (2018)	Using normal and dual activities, 50 healthy older persons were divided into two groups based on their risk of falls: the high-risk group and the low-risk group.	An electronic walkway (GAITRite® mat, v4.0), The projection system, three torches, a control box, a force-sensitive resistor (Sparkfun), wireless transmitter.	Visual contrast sensitivity, lower limb proprioception, postural sway, and hand reaction time.
26	Prakash et al. (2018)	Fifty participants were given the opportunity to go along a corridor, where cameras were set up perpendicular to the path.	Sony digital home camera with 29 frames per second.	Foot length, step size, cadence, stride length, gait cycle time, velocity, swing and stance phase
27	Bidabadi et al. (2018)	A self-selected comfortable pace was allowed to 19 participants in this research.	Inertial measurement unit (MPU-9150), Vicon motion analysis system with 14 semi- infra-red cameras, and retro-reflective markers.	Pitch and roll related to ankle movement, foot drop.
28	Kirkwood et al. (2018)	At a self-selected tempo and in low-heel footwear, 653 women walked six trials on a computerised walkway over the research period.	A 5.74m computerized carpet (GAITRite®, CIR Systems).	Gait velocity, cadence, steptime, step length, the base of support, swing time, stancetime and double support time.
29	Krkeljas and Moss (2018)	During this research, 35 pregnant women walked a 30-meter circular course at different points in their pregnancies.	Fitmate metabolic system, portable K4b2, 8 Oqus 300+ cameras from Qualisys Motion Analysis System, 4 AMTI BP400600 force plates, reflective markers.	Oxygen consumption, Respiratory quotient, restingmetabolic rate, heart rate, walking speed, step length & step width normalized for leg length, double-support time, vertical and mediolateral excursion of the center of gravity.
30	Abhaysinghe et al. (2019)	Twenty-nine healthy volunteers consented to walk for two seconds at a steady pace on a straight route as part of this research.	Inertial measurement unit (MPU-9150), Vicon motion analysis system with 14 semi- infra-red cameras, and retro-reflective markers.	Pitch & roll related to thigh movement
31	Rashid et al. (2020)	At the beginning of this trial, 20 healthy youngsters were instructed to carry either no bag at all or one that contained 10%, 15%, or 20% of their own weight.	Two cameras (Logitech C922x Pro stream, 60 fps at 1080p webcam) mounted to stationary tripods, retro-reflective color tape markers.	Joint ROM during various gait events.
32	Naaim et al. (2019)	After three months and one year, 75 patients who had had knee prosthetic surgery were asked to evaluate their post-surgical gait.	Vicon 12-camera motion analysis system.	Three-dimensional hip and knee angles, Knee crosstalk, the amplitude of knee adduction-abduction.
33	Temporiti et al. (2019)	Walking on a wooden track, 35 patients with one or both total hip arthroplasty and 20 healthy volunteers were tested in this research.	22 spherical retro-reflective markers (diameter 10 mm), optical motion capture system.	Spatial-temporal parameters, GPS and Gait Variable Score of pelvis, hip, knee and ankle.
34	Abbasi et al.	32 children with cerebral palsy and 32 healthy children were instructed	39 retro reflective markers, 8 infra-red	Movement of trunk, pelvis and hip joints in 3

	(2020)	to walk 7 metres at their natural pace for 10 trials in this research.	cameras of Qualisys motion analysis system.	planes during initial contact, pre- swing, peak stance, peak swing phase.
35	Babu et al. (2020)	In this experiment, 18 individuals walked a 5 metre pathway twice, doing three cycles each time.	Tri-axial accelerometers.	Acceleration in x, y and z- directions, the joint angles.
36	Beyrami and Ghadery an (2020)	People suffering from four different conditions were permitted to walk the 77-meter-long boardwalk at their own pace as part of this research.	Force-sensitive resistors	Vertical GRF
37	Strutzen ber ger et al. (2021)	On an instrumented ramp, 14 people walked at an inclination of zero, six, 12 and 18 degrees, mimicking tiny to severe hills.	12 infrared-camera, Vicon motion capture system, two force plates.	Step length, cadence and GRF.
38	Visscher et al. (2021)	In this research, 90 individuals aged 3 to 18 were taught to walk on a 10 m instrumented track at a natural gait pace without footwear or supporting devices.	Optoelectronic motion capture system (12-camera MTX20) 64 Plug-in Gait (PiG) model, force platforms embedded in the walkway.	Gait event detection (Initial contact, toe off), stride length, stride time, stride width, walking speed, single limb support.
39	Park et al. (2019)	During this experiment, a participant was instructed to walk barefoot and at his own pace.	A motion capture system, A Plug-in-Gait marker set, two force plates.	Muscle force, GRF, walking speed.

2.4 Data presentation

The papers in this study were mostly culled from two types of sources: reputable journals and conference proceedings. From 1998 through 2021, the papers were ordered in chronological order; there were a maximum of 12 articles published in 2018. The trend analysis graph in Figure 2 shows the year-by-year publishing of the included research publications.

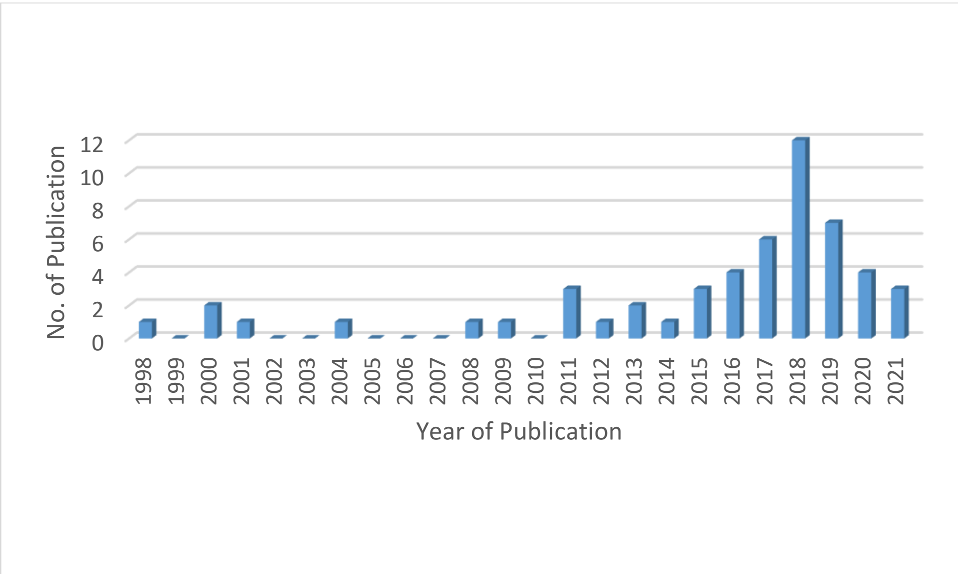

Fig. 2 Literature after 1998

Each item in the collection was assigned a category depending on the kind of application it addressed, such as medical diagnosis or instrumentation or review or rehabilitation or academic research. Instrumentation studies account for 30 percent of all investigations, followed by academic research (see Fig. 3). (28 percent). 25 percent, 11 percent, and 6 percent of all gait studies were connected to rehabilitation or review or medical diagnosis.

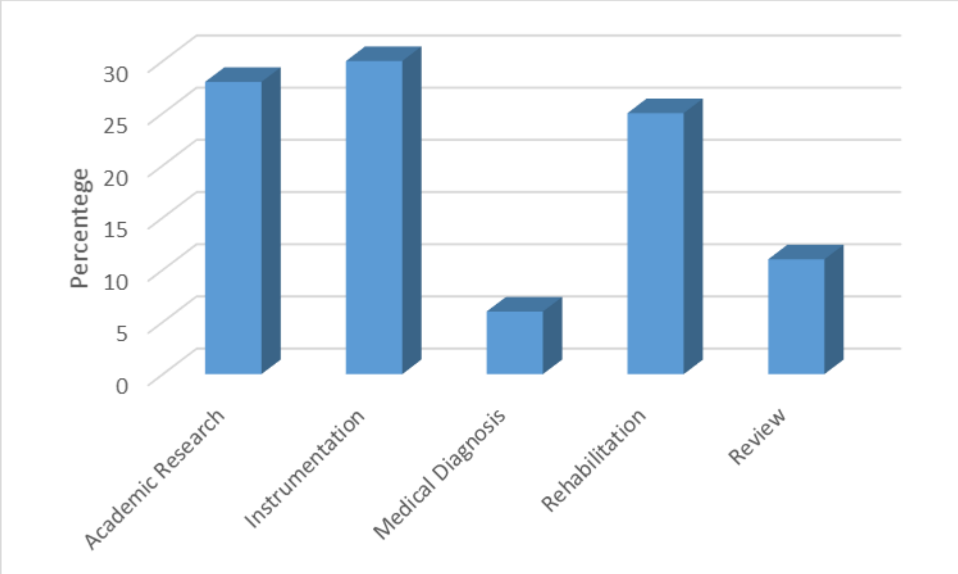

Fig. 3 Application-wise published literature (%)

3. Gait measurement systems

Measuring systems are made up of two components: gait measurement techniques and the necessary hardware. Gait characteristics, accuracy, and the topic being investigated all influence the technique and instruments that are used to collect data. On the other end of the spectrum, there are more advanced techniques such as videography and photography that disclose the gait metrics of interest in more detail. On the other hand, there are ultra-modern optical systems that analyse movies using several cameras and specialised algorithms. With the development of sensor technology, a new kind of gait monitoring system became widely used. Continuous-type gait parameters benefit from the employment of these systems. There is a broad range of gait measuring devices, in terms of technology, accuracy in measurement, setup cost and mobility. As a result, the researchers must decide which kind of gait assessment device is most suited to their study.

Based on a survey of 31 research publications, Viteckova et al. 51 have provided numerous measuring methods with their major aspects, as well as their advantages and disadvantages. Measurements utilised to determine gait symmetry were divided into four categories: mechanical, optical, accelerometer-based system, and gyroscope-based system in this research. On the basis of 53 cited studies, we have identified 17 gait measuring methods." More recent developments like SMART-E motion capture system 33 and Automated Image Processing System 15, MagicSox 46, Kinect based approach 20, and iGait system 18 were also included in the research. There are 19 gait measuring systems listed in Table 2, along with the instruments and papers referencing them (coded M01 to M19). Table 2 lists the systems and articles citing them. For example, Wu et al. 32, Dierick et al.41, and Krkeljas and Moss38, among others, use the infrared camera and reflective marker-based system.

Table 2. Gait measurement systems along with instruments used in the literature studied

Code	Measurement system	Instruments used	Article citing system /instrument (Sr No from Table 1)
M01	Vicon-based optical system	Active camera (Vicon) and markers Vicon plug-in gait model, reflective markers	4,9,13,18,25,31,34,35,37,19,26
M02	Motion Analysis Eagle System	An eight-camera motion capture system, reflective markers	7,11,16,20,24,27
M03	Other infra-redcamera	Infra-red cameras, reflective markers	2,5,33,39
M04	Reflective marker-based system SMART-E motion capture system	9 cameras, 8-channel wireless electromyography, Zerowire	8
M05	The GaitRite system	Electronic walkway, computerized carpet	6,14,29,32

M06	Direct measurement of human movement by accelerometry	Accelerometer, 3-axes Shimmer	22,28,42
M07	Inertial measurement unit	MPU-9250, MPU-9150	21,31,34
M08	Video-based occurrence sampling method	Video camera	1
M09	Automated Image Processing System	Sequential architecture (standard 266 MHz Pentium PC), Standard frame grabber and digitizer with an external video camera (consumer-grade camcorder)Two pairs of timing gates Infrared light gates	3, 19, 12
M10	A footswitches-based statistical gait analysis system	STEP 32, DEM Italia	15
M11	Vision-based Identification of Joint Coordinates	Sony digital home camera	30
M12	IGait system	Dynaport Minimod, Xsens MT9, Accelerometer embedded in HTC mobile	10
M13	Kinect based method	Kinect 2 with RGB data and smart-phone	17
M14	MagicSox / smart socks	Arduino 101 board with the Intel Curie processor module, Gyroscope & Accelerometer integrated with the Intel Curie, Pressure Sensor on the heel, 2 Flex Sensors, Smart Phone to collect the data via Bluetooth	23,36
M15	MRI and OpenSim system	Magnetic resonance scanners	18
M16	Foot pressure system	Force sensitive resistor placed under the shoe and connected to wireless transmitter A capacitive pressure distribution platform	22, 29, 12
M17	EMG system	EMG system	2,4,8,27,36
M18	Instrumented treadmill	Instrumented treadmill	5,9,19
M19	Force platform	Force plates	2,4,8,16,18,20,25,26,33,35, 37,39

The gait measuring method described in Table 2 may be divided into the following categories: Optical measuring systems (OPS) are a kind of optical measurement system (M01-M04), Video/image processing system (VBS) based on vision (M08, M09, M11, M13, M15), Sensor-based system (M05, M06, M07, M10, M12, M14, M17) and Force-measuring system (FMS) (M16, M18, M19).Figure 4 shows the proportion of included publications that use a certain measuring method. Vicon based optical system (19%), Motion Analysis Eagle System (8%), infrared camera & reflective marker-based system (8%), SMART E-motion capture system (1%), GaitRite system (5%), inertial measurement unit (4%), and accelerometer-based systems were the most commonly used kinematic gait parameters measuring methods by researchers (4 percent). Researchers typically use force platforms (19%), foot pressure systems (5%), instrumented treadmills (4%), and electromyography (EMG) to measure kinetic gait characteristics (6%).

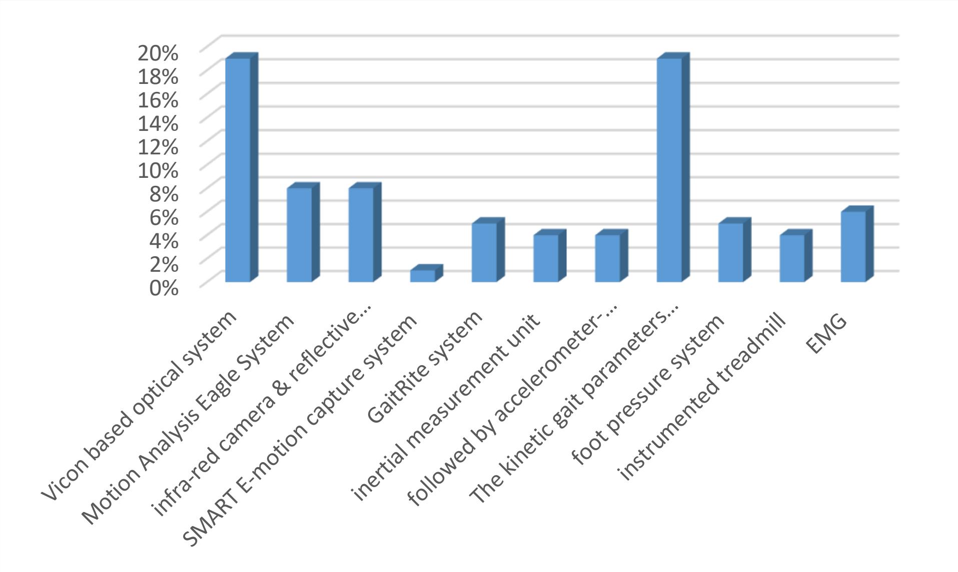

Fig. 4 % of studies using various measurement systems

4. Exploring relationship between tasks, gait parameters, and gait measurement systems

Gait analysis, as the name implies, is concerned with walking, however there are other variants. Walking may be done on flat or slanted terrain. It might happen on a straight or curved course with smooth, rough, or slick surfaces. Gait variation also affects stair navigation, such as step-ascent or step-descent. A healthy adult, an elderly person, a youngster in a specified age range, or a patient suffering from a disease may be the subjects of the gait analysis. Dependent on the intended use, a particular impairment Gait analysis may either be done in a real-world situation or in a controlled laboratory setting, such as a treadmill or force platform. All of these characteristics create task categories that are candidates for gait analysis. We identified 18 categories of tasks from the 39 publications that were referenced, as shown in Table 3.

Table 3. List of tasks identified from the literature.

Code	Job done
J01	Walking at self-selected speed on a force measuring system by subjects. [32,4]
J02	Normal and diseased persons' backward, frontal, and sidewalks. [15]
J03	Patients with complete hip implants did nine various activities, including slow walking, quick walking, normal walking, upstairs, downstairs, standing up, knee bend, standing on two legs, and sitting down. Patients with multiple sclerosis (MS) walk barefoot on a pressure measuring pad. [28,39,40,43,44]
J05	Fatiguing exercise with a backpack weight of 0 kg, 7.5 kg, and 15 kg interspersed between treadmill walking and fatiguing exercise. [4]
J06	Healthy individuals walked at their own pace, increased and lowered speed 31, walked on their toes, walked on their heels, and stepped rising and descending. [33]
J07	Using two kinds of conventional footwear and walking barefoot. [24]
J08	Walking on a treadmill at a self-selected pace while carrying varying physical and cognitive burdens 9(backpack load of 0 kg, 8.5 kg, and 20 kg) [52]
J09	Walking on a treadmill [25],/level ground [17–22,26,36]/terrain with varying degrees of slickness Obstacles: [11,57 45]
J10	Schoolchildren bearing 10%, 15%, or 20% of their body weight while walking without trolleys. [8]
J11	Walking at 1.5 m/s on the ground in four different ways: barefoot and unloaded, with footwear and unloaded, barefoot and loaded, and with footwear and loaded. [10]
J12	Ascending and descending a stairwell with no, low, and high load situations. [7]
J13	Holding a load of 10 to 30 pounds in frontal, lateral, bilateral, and posterior positions. [6]
J14	Normal gait and impact-minimizing gait are two different forms of walking. (Step length, gait speed, and so on.) [23,35,37,46]
J15	Older individuals walked for 4 minutes with three different loads: no load, stable backpack load, and unstable backpack load. During different months of pregnancy, pregnant women walked around a 30-meter circular walkway. [38]

J16	Walking along a 30-m oval path during various months of pregnancy by pregnant women. [38]
J17	Small to severe slopes were replicated by walking on an instrumented ramp [42] with inclinations of 0, 6, 12, and 18 degrees. [30]
J18	Walking to see whether cognitive stress has an impact. [5]

Depending on the study's aims, a variety of gait metrics are assessed and examined by practitioners. Kinematic, kinetic, spatio-temporal, and derived parameters are the four types of parameters. Table 4 lists and categorises the gait metrics that were notably submitted to investigation as shown by the evaluation.

Table 4. List of gait parameters with their category

Code	**Gait parameters**	**Category**
GP01	Gait speed (m/s)	Spatio-temporal
GP02	Step length/ stride length (m)	Spatio-temporal
GP03	% Double support (%)	Spatio-temporal
GP04	Step width (m)	Spatio-temporal
GP05	Foot clearance (m)	Spatio-temporal
GP06	Cadence (steps/min)	Spatio-temporal
GP07	Center of gravity (mm)	Spatio-temporal
GP08	Periods of gait phase (s)	Spatio-temporal
GP09	Roll, Pitch, Yaw and various joint angles (Degrees)	Kinematic
GP10	Ground reaction force (N)	Kinetic
GP11	EMG profiles of muscles (mv)	Kinetic
GP12	Hip contact force (N)	Kinetic
GP13	Joint moments (Nm/Kg-m)	Kinetic
GP14	Spinal stresses with respect to load applied (N/Kg)	Kinetic
GP15	Dynamic stability (mm)	Derived parameters
GP16	Coefficient of variation of stride time	Derived parameters
GP17	Step length variability/ step width variability/ Gait variability (%)	Derived parameters
GP18	Gait profile score (%)	Derived parameters
GP19	Postural sway (mm)	Derived parameters
GP20	Lower limb proprioception	Derived parameters

The spatio-temporal parameters are time, space, or time-space parameters. The kinematic parameters deal with movement without taking into account the forces involved. The kinetic parameters take into account the forces and reactions that occur during bodily movement. The derived parameters are a collection of attributes that provide task-specific movement information.

Table 2 lists the gait measuring systems that are appropriate combinations of the technique and apparatus employed. The link between the tasks, gait parameters, and gait measurement systems is explored in this section once the tasks, gait parameters, and gait measurement systems have been identified. These connections are based on how important each of the three criteria is in relation to the others.

Based on the significance of the gait characteristics with the tasks, the 20 gait parameters (GP01 to GP 20) were mapped with the 18 tasks (J01 to J18) under consideration. The resulting relationship is shown in Table 5. It can be seen that step length/ stride length (GP02) is related to the maximum number of jobs, which is 10, in this case. Gait speed (GP01), cadence (GP06) and varied joint angles (GP09) have proven relevance to a large number of activities, i.e., 8 each. The least relevant to the job include foot clearance (GP05), joint moments (GP13), spinal stressors (GP14), coefficient of variation of stride time (GP16), postural sway (GP19), and lower limb proprioception (GP20). In general, the spatio-temporal and kinematic categories of gait characteristics are the most relevant to the tasks, followed by the kinetic category, which is somewhat relevant, and the derived category, which is less relevant.

The researchers discovered that for activities requiring more energy, such as stair navigation (J06 and J12) or weight bearing in various postures (J13), they utilised a greater number of gait factors. In such jobs, gait analysis primarily evaluates spatio-temporal factors. The idea is to employ a small number of gait characteristics for uncomplicated tasks with minimal energy costs. However, in medical applications (e.g., rehabilitation), when precise diagnosis is necessary, this may not be the case.

Table 5. Job d and gait parameter relationship

Job	Gait Parameter																				
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**Total**
J1	0	0	0	1	0	1	0	0	1	1	0	0	0	0	0	0	0	0	0	0	***4***
J2	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	***2***
J3	0	0	0	0	0	0	0	0	1	1	1	0	1	0	0	0	0	0	0	0	***4***
J4	1	1	1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	***6***
J5	0	1	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	***3***
J6	1	1	1	0	0	1	0	0	0	1	1	1	0	0	0	0	0	0	0	0	***7***
J7	0	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	1	0	0	0	***4***
J8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0		0	***2***
J9	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	***5***
J10	1	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	***4***
J11	0	1	1	0	0	0	0	1	1	0	0	1	0	0	0	0	0	0	0	0	***5***
J12	1	1	1	1	1	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	***8***
J13	1	1	1	1	0	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0	***7***
J14	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	***4***
J14	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	1	0	0	0	***3***
J16	1	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	***5***
J17	0	1	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	***3***
J18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	***3***
Tota	***8***	***9***	***6***	***7***	***1***	***8***	***2***	***4***	***8***	***6***	***3***	***4***	***1***	***1***	***4***	***1***	***2***	***1***	***1***	***1***	

Note that 'Y' denotes a connection; for example, gait parameters GP04, GP06, GP09, and GP10 are linked to task T01.

Table 6 shows the results of mapping the 20 gait characteristics with the 19 measurement systems (M01 to M19) based on mutual significance. Table 6 shows that the majority of measurement devices (11 out of 19) are capable of measuring all of the spatio-temporal gait characteristics. In a similar vein, 9 of the 19 measurement methods can capture all of the kinematic gait data. Only eight of the 19 measurement systems can measure derived parameters. All three kinds of gait characteristics, spatio-temporal, kinematic, and derived, may be measured by the first four measurement systems (M01 to M04). There are many measuring devices that can quantify kinetic gait characteristics, ranging from M16 to M19. Only spatio-temporal characteristics could be measured by measurement systems M06, M08, M10, M11, and M12, but only kinematic gait parameters could be measured by measurement systems M07 and M15.

Table 6. shows the link between the gait parameter and the measurement system.

		Measurement System																			
		M 01	**M 02**	**M 03**	**M 04**	**M 05**	**M 06**	**M 07**	**M 08**	**M 09**	**M 10**	**M 11**	**M 12**	**M 13**	**M 14**	**M 15**	**M 16**	**M 17**	**M 18**	**M 19**	**Total**
Spatio-temporal	**GP01-08**	Y	Y	Y	Y	Y	Y		Y	Y	Y	Y	Y	Y							12
Kinematic	**GP09**	Y	Y	Y	Y			Y		Y				Y	Y	Y					9
Kinetic	**GP10-14**																Y	Y	Y	Y	4
Derived	**GP15-20**	Y	Y	Y	Y	Y											Y		Y	Y	8
	Total	3	3	3	3	2	1	1	1	2	1	1	1	2	1	1	2	1	2	2	

The findings of the relevance-based mapping for the tasks performed (J01 to J18) and measurement methods employed by the researchers in the reviewed literature (M01 to M19) are provided in Table 7. The table shows that optical systems such as the Vicon system (M01), the motion analysis Eagle system (M02), and the infrared camera-based system (M03) were employed in the most jobs. Furthermore, the force platform system (M19) is employed in the most demanding kinetic measuring jobs. The evolving approaches, such as the IMU system (M07), iGait system (M12), and MagicSox (M13), were only employed in a few jobs. Walking on a treadmill, flat ground, ground with varying degrees of slipperiness, and obstacles tasks (J09) have also been undertaken often and may be quantified using a variety of measuring techniques. Researchers in the reviewed literature considered relatively less common tasks, such as backward, frontal, and sidewalks (J02), treadmill walking under physical and cognitive loads (J08), and stair ascent and descent under varying loads (J12), less frequently, and only a few methods were used for them.

Table 7 shows the link between the measurement system and the job accomplished.

	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	
J	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	***2***
J	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	***2***
J	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	***1***
J	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	***2***
J	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	***2***
J	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	***2***
J	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	***2***
J	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	***3***
J	0	0	0	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	***3***
J	1	0	1	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1		***5***
J	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	***1***
J	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	***3***
J	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	1	***5***
J	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	***2***
J	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	***3***
J	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	1	0	***4***
J	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	***1***
J	1	0	0	0	1	1	1	1	1	0	1	0	1	1	0	0	1	0	1	***13***
	9	***5***	***5***	***3***	***4***	***3***	***1***	***2***	***2***	***2***	***2***	***1***	***1***	***1***	***1***	***2***	***3***	***3***	***8***	

5. Measurement system ability

The relationship between the activities, gait characteristics, and measuring technique outlined in the preceding section is mostly qualitative. Each of the measuring devices can handle a certain set of gait characteristics, as shown in Table 6. A quantitative measure is necessary to determine the capabilities of a certain gait measuring system for a specific application. This section describes the MSCS (Measurement System Capability Score), which is calculated using data from the cited literature.

Three important parameters were established in order to compute the MSCS. One of the most essential considerations is instrument accuracy. An individual's gait changes depending on the walking surface [11], footwear [58], and weight carried [4]. The erroneous measurement of gait characteristics is caused by the incorrect positioning of markers and sensors on the subject's body. The researchers tested the accelerometer-based system 18, the smartphone-based system [46], the inertial sensor-based system [22,23], the video-based occurrence sampling method [59], the Kinect-based method [25], the MRI-based method [26], and the Asics footwear line system 24 against optical systems, particularly the Vicon system. According to the findings, inertial sensors are more precise than accelerometers. In kinematic gait analysis, optical measuring devices are regarded the gold standard. The number of cameras and their resolutions affect the accuracy and readability of visual gait detection algorithms. The measuring system specs were gathered from OEM websites. We awarded an accuracy rating to each measuring system on a scale of 1-5, with 1 being the least accurate and 5 being the most accurate, based on the specification data and validation findings of investigations. Another key issue is the amount of gait parameter categories that the system measures. It has been noticed that the amount of parameters assessed by a technique varies depending on the study's aims. To compute MSCS, we used the categories of gait parameters (as indicated in Table 4) rather than the gait parameters themselves. The amount of publications mentioning certain systems is the third element taken into account when calculating MSCS. It is thought that the greater the number of studies conducted using a given system, the greater the system's capabilities. MSCS is calculated by multiplying three factors: accuracy rating, number of categories of gait characteristics that may be monitored, and number of studies that have used the system. For example, the accuracy rating for M01 is 5, the number of gait parameter categories is 3, and the number of studies employing the system is 15, resulting in MSCS = 225. Table 8 shows the MSCS of each of the 19 measuring methods. It's clear that the Vicon system (M01) has the highest MSCS, at 225. As a result, the M01 system was used as a comparison point for other systems. As a result, the normalised MSCSs were produced, as shown in Table 8. The average MSCS for each of the four categories is also included in the table.

As noted in Section 3, the 19 gait measuring methods are divided into four groups. This categorization aids in the comparison of one measuring system to others in the same category. The Vicon system (M01) with an MSCS of 100 percent is clearly the most competent system within the optical category of measuring systems (M01 to M04), as shown by MSCSs. Motion analysis Eagle system (M02) and infrared camera-based system (M03) are the second and third most competent optical systems, respectively, with MSCS of 32% and 32%. Similarly, the GaitRite system (M05) and EMG system (M17) are the most competent systems in the sensor-based system category, with MSCS of 14.22 percent and 11.11 percent, respectively, followed by accelerometer-based system (M06) and IMU system (M07) with MSCS of 4% each. The most competent system among vision-based video/image processing systems is the image processing system (M09), which has an MSCS of 8%. The force platform (M19) is the most competent system in the force measurement system category, with an MSCS of 53.33 percent.

Table. 8 MSCS and Normalized MSCs

Category	**Measurement system**	**No of studies adopting the method**	**Instrument accuracy rating**	**Categories of GP that can be measured**	**MSCS**	**Normalized MSCS (%)**	**Category Average MSCS (%)**
Optical Systems (OPS)	M01	15	5	3	225	100.00	42.33
	M02	6	4	3	72	32.00	
	M03	6	4	3	72	32.00	
	M04	1	4	3	12	5.33	
Sensor-based systems(SBS)	M05	4	4	2	32	14.22	5.59
	M17	5	5	1	25	11.11	
	M06	3	3	1	9	4.00	
	M07	3	3	1	9	4.00	
	M14	2	3	1	6	2.67	
	M12	1	4	1	4	1.78	
	M10	1	3	1	3	1.33	
Vision- based, video/ image processing systems (VBS)	M09	3	3	2	18	8.00	2.76
	M08	2	2	1	4	1.78	
	M13	1	2	2	4	1.78	
	M15	1	3	1	3	1.33	
	M11	1	2	1	2	0.89	
Force measuring systems (FMS)	M19	15	4	2	120	53.33	24.89
	M16	4	3	2	24	10.67	
	M18	3	4	2	24	10.67	

6. Gait measurement system categories ranked according to criteria

The accuracy of the measurement of concerned gait parameters, the system's portability, the initial cost of set-up, the adaptability of the supplied system to a range of jobs, and the system's aptitude for outdoor applications are all factors that go into choosing a gait system. As a result, we established five criteria: portability, accuracy, cost, suitability outdoor use and feasibility. The term "portability" refers to the system's ability to be transported to any location. The number of tasks for which a particular system is feasible/suitable is used to determine feasibility and appropriateness. The gait measuring system must be utilised outside of the laboratory for various purposes, such as on the ground, in open workplaces, or on terrains. Outdoor usage denotes the system's suitability for such applications. We used the Analytic Hierarchy Process to compare the four categories of gait measurement systems, namely optical system (OPS), sensor-based system (SBS), vision based and video/ image processing system

(VBS), and force measuring system (FMS), against the five criteria and to determine criteria-wise and overall ranking of the systems (AHP).
The Analytic Hierarchy Process 60 is a multi-criteria decision-making process that organises complicated intuitive data into hierarchical structures. The relative relevance (weight) of alternatives is determined via pairwise comparisons based on some aim, criteria, and sub-criteria in this technique. The purpose of this research is to determine the relative weight (ranking) of the four gait measuring system categories using the five criteria.The relative relevance of the five criteria and four options was assessed in the AHP matrixes using Saaty's 1-9 scale, with 1 representing the lowest significance and 9 indicating the most. The pairwise comparisons were done using the programme Super Decisions (https://www.superdecisions.com/), which is detailed further down.
The pairwise comparison is based on Saaty's 1-9 scale, as indicated before. Cost, for instance, is seven times more significant than portability. Portability, on the other hand, will be 1/7 (i.e. 0.143) times more essential than cost. It should be emphasised that the comparison's quantitative values are based on our perspective, which is determined from pertinent information gathered from the cited literature. In the comparison matrix, all diagonal entries are represented as 1. The geometric mean is calculated using the pairwise comparison matrix. After that, the geometric means are normalised to get Factor Weights (FWs). It can be seen that accuracy has the greatest FW (0.504), while outdoor use has the lowest (i.e., 0.047).

The consistency of the pairwise comparison must be evaluated. Weighted Sum vector, Eigen vector, Consistency Index (CI), and Consistency Ratio are used to accomplish this (CR). When the comparison matrix is multiplied by the FW vector, the result is the Weighted Sum vector. To produce Eigen vector, each element of the Weighted Sum vector is split by the corresponding members of the FW vector. The mean eigenvalue is the sum of all the elements in the Eigen vector.The greatest GW (0.289) is found in OPS, which is followed by FMS (0.258). The GW of SBS is 0.253, whereas the GW of VBS is 0.200. As a result, OPS, FMS, SBS, and VBS are ranked first, second, third, and fourth, respectively. OPS is the #1 option among researchers when all five factors are considered, namely portability, cost, accuracy, feasibility & suitability, and outdoor use. Vicon system (M01), Motion Analysis Eagle System (M02), infrared camera & reflective marker-based system (M03), and SMART-E motion capture system are among the four gait measuring systems included in the OPS category (M04). Special cameras and markers are used in these systems. These devices are more expensive and less portable, but they are quite accurate. Furthermore, these systems are adaptable to a wide range of applications, making them flexible. However, these systems are inconvenient to use outside. FMS, which comprises force platforms, instrumented treadmills, and EMG systems, is comparable to OPS in terms of cost and application variety. FMS (particularly force platforms) has been used by researchers for a range of applications, similar to OPS. FMS has a somewhat poorer accuracy than OPS, although this is offset by its greater mobility. Furthermore, as compared to OPS, these systems are more suitable for outdoor application.

SBS is ranked third overall, but these systems are the greatest alternatives if mobility and outdoor usage are the most important factors. These systems use a variety of sensors on the subject's body, which renders them sensitive to inaccuracy. For many applications, keeping the sensors at a specific spot on the human body during the gait cycles being recorded is challenging, and accuracy suffers as a result. These systems have a modest level of appropriateness and are, on average, less expensive than OPS and FMS.VBS is the most affordable of the three, with a decent level of mobility and fitness for outdoor usage. For obvious reasons, VBS loses precision when using rudimentary procedures. In such circumstances, human judgement is used to estimate the relevant gait metrics. It goes without saying that image processing software can help with accuracy. Because the researchers have a restricted number of options, these systems only find a few applications. Table. 9. summarises the four gait measuring methods' criteria-by-criteria and overall rankings.

Table No. 9 Gait measuring methods are ranked by criteria and overall.

Rank	PORTABILITY	COST	ACCURACY	FEASIBILITY & SUITABILITY	OUTDOOR USE	OVER ALL
1	SBS	VBS	OPS	OPS/ FMS	SBS	OPS
2	VBS	SBS	FMS	SBS	VBS	FMS
3	FMS	OPS/ FMS	SBS	VBS	FMS	SBS
4	OPS	-	VBS	-	OPS	VBS

7. Discussion

Various gait measuring techniques, common tasks evaluated by the researchers, and gait metrics considered were identified and mapped with each other in the previous sections. MSCS, a quantitative index, was also suggested to evaluate the gait measuring system's capabilities. AHP was also used to rank the four measuring system categories based on five criteria. The capability scores correspond to the category rankings. The category average MSCS for OPS, which ranks first in the AHP exercise, is the greatest (42.33 percent). Similarly, the average MSCSs for FMS, SBS, and VBS, in order of their rankings, are 24.89 percent, 5.59 percent, and 2.76 percent, respectively. Based on the application and characteristics involved, the mapping, capability scores, and ratings provide insight on the viability of different systems. We created a self-explanatory decision flow chart, as shown in Fig. 1, to assist researchers in making accurate selections. [11]. It should be noted that each gait measuring system type has advantages and disadvantages. The systems that are more accurate are frequently more expensive, while the ones that are more portable are often less accurate. Even if a very precise and expensive system is selected, it may be unsuitable for outdoor usage because to its lack of mobility. The researchers must strike the right balance between the numerous criteria. As a result, there is potential for establishing a gait analysis approach that is economical, accurate, portable, and adaptable.

The video-based posture assessment techniques give basic indications on the degrees of risk associated with various working postures [14.] These methods do not take into account the precise stresses that are involved in posture, nor do they give quantitative data on risk levels. These approaches are excellent for low-cost preliminary analysis. However, algorithm-based strategies for measuring gait characteristics (particularly kinematic) such as digital image processing provide excellent results but fail in long-term obstructive situations or when sampling frequency varies significantly [59]. Although the research in this review show that accelerometer-based devices are acceptable for collecting subjects' movements, they have multiple wires going across the joints and body, making long-term monitoring impractical. IMUs are portable and less costly, according to the research, hence they are a feasible approach when compared to other gait analysis methods [21]. The accuracy of such approaches, on the other hand, should be verified against the method with the greatest MSCS, namely optical systems. The result of an IMU-based approach is a roll, pitch, and yaw, which should be precisely calibrated to joint angles. The Kinect-based technique may extract kinematic gait data, but its use is limited by variables such as the size of the room, camera specs, and available algorithm [20]. A pressure sensor, a gyroscope 46, and other emerging approaches are used.

To extract gait parameters that are more or less relevant depending on their accuracies, accelerometers [16–18, 46, 53], computerised carpet [43], electronic pathways [45], and capacitive sensors [44] are used. Validation of these approaches against optical systems is suggested.Optical systems are the most accurate but also the most costly technologies, according to the literature reviewed, and might be utilised as a validation source. For measuring GRF, the force plate is the most suitable approach. The superior force-measuring treadmill and electronic pathways need to be confirmed against force plates before they can be used to measure GRF. The literature review found that the most widely accepted approaches, such as optical systems and force measuring devices, had difficulty assessing gait aspects involving soft tissues.

8. Conclusion

This article's comprehensive evaluation of gait measuring systems emphasises many elements of gait measurements, including the range of activities, gait metrics, apparatus, and measurement procedures. The included research papers were selected using the PRISMA approach and extensively reviewed to extract all kinds of helpful information in order to arrive at the structured comparison. By evaluating the research's aims, it incorporates the links between the activities under investigation, the gait parameters selected for the study, and the suitable gait measurement technologies used. The mapping not only shows the reciprocal significance of these three factors, but it also aids in identifying the researchers' emphasis regions. Walking (in the real world or on a treadmill) and stairs navigations, both with and without load, are often subjected to gait analysis, which examines spatiotemporal gait metrics. Optical systems are often used by researchers for this aim. In the present research, we devised an index, MSCS, to give a quantitative foundation for comparison in addition to qualitative evaluation of different gait systems. It aids in the differentiation of various approaches depending on their suitability for diverse applications. Following AHP methodology, the four gait system categories of OPS, SBS, VBS, and FMS were graded based on the five criteria of accuracy, portability, cost, feasibility and suitability, and outdoor use. These four categories' total rankings are found to be consistent with their capability ratings. The criterion-specific ratings were also helpful in determining which gait systems to utilise for each of the criteria. Finally, a decision flow chart is presented to assist practitioners in choosing the appropriate gait system for the application. Because no one gait system meets all of the requirements, there is room to design a fresh approach that is more inexpensive, accurate, adaptable, portable, and suitable for outdoor usage.

9. References

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