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Descriptive analysis of gait using inertial sensors and clinical assessment in elderly people

Análisis descriptivo de la marcha mediante sensores inerciales y evaluación clínica en personas mayores

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Abstract

The aging process leads to a gradual decline in physical and mental abilities and an increased risk of disease. Older adults are particularly susceptible to a decline in their mobility. The aim of this study was to assess the gait of older adults using inertial sensors and clinical evaluation. A descriptive study was conducted using clinical evaluation, which included: lower limb length, scapular asymmetry, pelvic asymmetry, ability to walk on tiptoes, and the presence of a claudicating gait. Inertial sensors were also used to measure walking speed, cadence, and symmetry. The results indicated that walking cadence averaged 100 steps per minute, walking speed averaged 0.74 m/s, and 68 % of the participants exhibited symmetry. Furthermore, the clinical gait analysis revealed that 21 % of participants exhibited a claudicating gait. In addition, scapular asymmetry was observed in 52 % of participants, and pelvic asymmetry in 48 % of participants. Therefore, clinical assessment is still considered an indispensable tool in gait evaluation; however, it is important to corroborate these observations with state-of-the-art equipment that bases its results on precise data, as it uses accelerometers and gyroscopes, which can detect micro-movements that are not visible to the human eye during visual inspection.

Keywords: elderly people, gait, inertial sensors

Resumen

El proceso del envejecimiento lleva a un descenso gradual de las capacidades físicas y mentales, y un mayor riesgo de enfermedad. Las personas mayores son especialmente sensibles a disminuir su capacidad locomotora. El objetivo de la investigación fue evaluar la marcha de las personas mayores mediante sensores inerciales y evaluación clínica. El estudio fue de tipo descriptivo mediante una evaluación clínica que incluyó el análisis de: longitud de miembros inferiores, desnivel escapular, desnivel pélvico, capacidad para realizar marcha en puntas y presencia de marcha claudicante. También se midieron mediante sensores inerciales: velocidad, cadencia y simetría de la marcha. Los resultados señalaron que la marcha y la cadencia tuvieron una media de 100 pasos por minuto; en la velocidad se obtuvo una media de 0.74 m/s; y el 68 % de las personas presentaron simetría. Además, en el análisis clínico de la marcha, se encontró que el 21 % de las personas mostraron marcha claudicante. Aunado a esto, se observó asimetría escapular en el 52 % de las personas y asimetría pélvica en otro 48 %. Por lo tanto, se considera que la evaluación clínica sigue siendo una herramienta indispensable en la evaluación de la marcha, sin embargo, resulta importante corroborar lo observado con equipos de última tecnología que basan sus resultados en datos precisos, ya que utilizan acelerómetros y giroscopios, que permiten detectar micromovimientos que no son observados por ojo humano durante la inspección visual.

Palabras clave: personas mayores, marcha, sensores inerciales

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1. Introduction

People today live longer than before, as life expectancy exceeds 60 years. In this regard, every country in the world is experiencing an increase in both the number and the proportion of older people in the population. By 2030, it is estimated that one in six people will be aged 60 or over. At that point, the population group aged 60 or over will have risen from 1 billion in 2020 to 1.4 billion. Furthermore, by 2050 the world population aged 60 or over will have doubled (2.1 billion). The number of people aged 80 or over is expected to triple between 2020 and 2050, reaching 426 million (World Health Organization [WHO], 2024).

The aging process leads to a gradual decline in physical and mental capacities, and to a greater risk of disease. Older people are particularly vulnerable, since their locomotor capacity decreases. Bipedal locomotion is characteristic of human beings, setting them apart from all other living creatures. Walking on two feet frees our upper limbs and allows us to carry out other activities of daily living and to interact with the environment around us. At age 60, 15% of individuals present gait alterations, rising to 35% at age 70 and to nearly 50% among those over 85 (WHO, 2024).

According to recent data from the National Institute of Statistics and Geography ([INEGI], 2020), there are approximately 8.8 million people with disabilities in Mexico, of whom close to 50% are adults aged 60 or over. The main limitations include motor impairments related to walking, going up or down stairs, and maintaining balance. These difficulties are mainly associated with aging, chronic diseases, and musculoskeletal deterioration. Based on the above, motor disabilities are seen to affect the autonomy, social participation, and quality of life of older people. This increases the demand for health, rehabilitation, and specialized care services in the country.

Gait is the way human beings move from place to place. Just as each animal species has its own particular form of locomotion: birds fly, fish swim, and quadrupeds run, human beings move by walking. This biomechanical process is known as gait. It is complex and cyclical, and it requires the integration of several systems, such as the skeleton, the muscles, and the nervous system.

Among the characteristics of gait, a series of rhythmic and repetitive movements can be distinguished which, for the sake of clarity, may be divided into two phases: namely, the stance phase, in which the foot is in contact with the ground. It begins with heel strike, continues with support of the whole foot, and ends with support on the toes alone, the latter known as toe-off, since this is when the body propels itself forward. The second phase of gait is called swing, in which the foot has no contact with the ground; it begins when the tip of the foot leaves the ground, the entire lower limb swings through a force of acceleration, and it ends with heel strike on the ground, decelerating the force of the impulse (Jankovic et al., 2022).

For gait to be performed efficiently, almost all the joints of the musculoskeletal system must be integrated, as well as the musculature that mobilizes them, that is, the spine and the shoulder and elbow joint complexes in

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the upper limb. In the lower limb, the hip, knee, ankle, and foot joints are involved, together with the musculature responsible for the mobility of those same joints.

Biomechanically, gait may vary depending on different factors, such as age, weight, or height. Gait can be altered by pathological conditions, musculoskeletal injuries, or neurological disorders. These alterations manifest as gait disorders known as limping. Most patients with limping present evidence of a disorder of the locomotor system, for example, hip or knee osteoarthritis or foot or ankle pathologies (Atkinson et al., 2025).

Gait assessment is a fundamental part of the orthopedic physical examination. Assessing it can provide information on lower limb length discrepancy and on pelvic or shoulder girdle imbalance due to tilting, which can also provide information on spinal pathologies. Gait disorder is therefore one of the most important geriatric syndromes, since aging produces physiological changes that affect the speed, stability, and efficiency of gait. These include loss of muscle mass, decreased strength, visual and vestibular alterations, reduced postural reflexes, and cognitive decline. Likewise, conditions that are frequent among older people, such as osteoarthritis, Parkinson's disease, peripheral neuropathies, or strokes, can significantly modify the gait pattern. These alterations lead to limping, insecurity when walking, and an increased risk of falls.

The study of gait, as part of the neurological clinical examination, is a fundamental element of pathophysiological and functional diagnosis aimed at preventing falls in older people. Several pathologies may first present with a gait alteration, and this is the most striking clinical finding raising suspicion of disease. The origin of gait disorder is usually multicausal: neurological alterations, musculoskeletal alterations, body biomechanics, and anthropometric factors (Kirkwood et al., 2006).

Another tool used is the gait speed test, considered a functional vital sign in geriatrics; thus, a decrease in walking speed is associated with frailty, hospitalization, and mortality. Because of the multifactorial complexity of gait, various researchers have developed functional tests designed to assess locomotor performance in older people. These tools make it possible to identify functional alterations at an early stage, establish preventive strategies, and guide rehabilitation programs.

Among the most widely used tests is the Timed Up and Go (TUG), which assesses dynamic balance and functional mobility through the time a person takes to rise from a chair, walk three meters, turn, and sit down again. This test has shown high sensitivity for predicting the risk of falls and functional decline (Barry et al., 2014). Likewise, gait speed and the six-minute walk test allow frailty and physical endurance to be assessed.

1.1. Spatiotemporal gait parameters

Human gait is a complex motor process that requires the coordinated integration of the central nervous system, the musculoskeletal system, and the sensory mechanisms. During gait, rhythmic and alternating

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movements of the lower limbs occur that allow the body to move efficiently. To assess this process adequately, various spatiotemporal parameters are used that make it possible to quantify the quality and efficiency of the gait pattern.

1.1.1. Symmetry

Symmetry represents the overall harmony of gait, as well as the individual's ability to accelerate the center of gravity in a similar manner during the right and left gait cycles. This parameter reflects the degree of harmony and functional balance during locomotion. Values close to 100% indicate a symmetrical and efficient gait pattern, whereas lower values suggest functional alterations that may be associated with musculoskeletal injuries, neurological pathologies, or compensatory processes. Values below 90% of the normative threshold suggest that the differences between the right and left limbs should be carefully assessed.

Assessing symmetry is especially important in patients with a history of orthopedic surgery, sports injuries, strokes, or degenerative disorders. A significant decrease in this index may indicate unilateral overload, muscle deficit, or alterations in motor control. For this reason, the analysis of symmetry is a useful tool for assessing the patient's functional progress during rehabilitation.

1.1.2. Gait speed

Gait speed corresponds to the distance covered in a given time and is generally expressed in meters per second (m/s). This parameter is considered one of the most relevant functional indicators of overall health status, since it involves multiple physiological components such as muscle strength, motor coordination, balance, cardiovascular endurance, and cognitive function. Various studies have shown that a decrease in gait speed is associated with a greater risk of falls, loss of functional independence, and deterioration in quality of life, particularly in older adults.

Under normal conditions, average gait speed ranges from around 1.2 to 1.4 m/s, although it may vary depending on the individual's age, sex, and physical condition (Boudreau et al., 2002). It is also a useful parameter for assessing the effectiveness of rehabilitation programs. Progressive improvements in this indicator are usually associated with functional recovery and favorable biomechanical adaptation.

1.1.3. Cadence

Cadence is defined as the number of steps a person takes in one minute. In healthy individuals, normal values are usually between 90 and 120 steps per minute. This parameter is closely related to gait speed, since changes in step frequency can alter the rhythm and efficiency of locomotion. A decrease in cadence may be observed in patients with musculoskeletal pain, muscle weakness, or neurological disorders. Conversely, an

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excessive increase in cadence could represent compensatory mechanisms related to instability or functional limitation.

1.1.4. Step length and step time

Other important parameters include step length and stance time. Step length corresponds to the distance between the initial contact of one foot and the initial contact of the contralateral foot. Alterations in this parameter may indicate joint limitations, muscle weakness, or neurological disorders.

Stance time, on the other hand, represents the period during which the foot remains in contact with the ground. An increase in stance time on one limb may suggest pain, insecurity, or balance alterations. These parameters make it possible to understand the biomechanical adaptations developed by the patient during gait.

1.2. Inertial sensors

In contemporary clinical practice, observational gait assessment continues to be widely used. However, it has limitations related to examiner subjectivity and the difficulty of quantifying specific movement parameters. For this reason, over recent decades there has been an increase in the use of instrumented technologies capable of providing objective, reproducible, and quantifiable measurements. Prominent among these technologies are inertial sensors, portable devices that allow body movements during gait to be analyzed precisely.

Inertial sensors measure variations in the linear and angular movement of an object with respect to inertial space (Guler et al., 2023). This refers to a point at which an object free of external forces remains at rest or moves in a straight line at constant speed. Inertial sensors are portable devices that use accelerometers, gyroscopes, and sometimes magnetometers to measure human body movement and analyze biomechanical parameters. These devices translate inertial forces into electrical signals in order to measure specific forces (accelerations) and velocities. This information is sent via Bluetooth to the computer for analysis.

Inertial sensors that detect linear acceleration are called accelerometers, whereas angular movement is detected by sensors known as gyroscopes. A single accelerometer or gyroscope is able to measure the associated quantity along one axis. Therefore, a set of three inertial sensors along orthogonal directions is required to measure the entire quantity in three dimensions; this is commonly defined as an Inertial Reference Unit (Tamura, 2014).

Inertial sensors have become highly relevant tools in the clinical setting because they provide objective, quantifiable information on the patient's functional performance. In addition, they allow assessments to be carried out outside the traditional biomechanics laboratory, which favors their implementation in clinics, hospitals, rehabilitation centers, and even in the patient's home.

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1.3. Clinical applications of inertial sensors

The incorporation of inertial sensors into clinical practice has broadened diagnostic and therapeutic possibilities in various areas of health care. One of their most important applications is gait analysis, where they are used to assess biomechanical alterations, monitor rehabilitation processes, and measure functional outcomes. In neurological physiotherapy, inertial sensors facilitate movement analysis in patients with Parkinson's disease, stroke, multiple sclerosis, and cerebral palsy. These devices make it possible to identify abnormal movement patterns and to quantify functional changes following therapeutic interventions.

In orthopedics and sports medicine, inertial sensors are used to assess joint range of motion, postural stability, motor control, and muscle performance. They also analyze sports technique and detect risk factors associated with injury. Within the field of geriatric rehabilitation, inertial sensors represent a useful tool for identifying balance alterations and the risk of falls. Objective analysis of gait and functional mobility makes it possible to design personalized intervention programs aimed at improving the functional independence of older adults.

1.4. Advantages of inertial sensors

Inertial sensors offer several advantages, but five stand out for their usefulness (Table 1).

Table 1
Advantages of inertial sensors

Advantage	Description
Portability	One of the main advantages of inertial sensors is their portability. These devices are compact, lightweight, and easy to transport, which facilitates their use in different clinical settings without the need for complex infrastructure.
Objective assessment	Inertial sensors make it possible to obtain quantifiable and reproducible data on human movement. This reduces the subjectivity inherent in observational assessment and improves diagnostic accuracy.
Non-invasive	The devices do not significantly interfere with the patient's natural movement, allowing functional assessments to be carried out under conditions close to everyday activities.
Therapeutic follow-up	Thanks to their ability to store and compare measurements taken at different times, these systems facilitate the monitoring of the patient's clinical progress and the effectiveness of the treatments implemented.
Biofeedback	Some systems include visual and auditory feedback tools that allow the patient to correct their movements in real time. This promotes motor learning and accelerates functional recovery processes.

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1.5. Usefulness in research

The reproducibility of the measurements makes inertial sensors useful instruments for developing research related to biomechanics, physiotherapy, and human movement sciences. However, despite their many benefits, inertial sensors also have drawbacks and limitations.

- Interference: These devices may detect abrupt movements during the test and report erroneous data.
- Internet connection: This type of connection is required for better performance.
- Equipment cost: These devices can be expensive and require maintenance and support.
- Clinical correlation: A gait expert is required to verify that the patient's gait is their habitual one.

1.6. Inertial sensor model

Baiobit is a system that allows rapid, objective assessment of gait, balance, and joint mobility. The system consists of the G-SENSOR 2 inertial sensor, the Baiobit software, and a set of protocols for the analysis of specific movements. Via a Bluetooth connection, the sensor acquires and transmits data to the personal computer (PC) for processing and the automatic generation of reports. The reports provide important information on the spatiotemporal parameters of gait, pelvic kinematics, range of motion (ROM) of the trunk, cervical spine, and shoulder, balance, and vertical jump.

2. RESEARCH METHOD

2.1. Study design

A descriptive, observational, cross-sectional study was conducted, aimed at the clinical and functional analysis of gait in older adults. Through clinical assessment, various characteristics related to the gait pattern were observed, including lower limb length, the presence of scapular and pelvic asymmetry, the ability to walk on tiptoes, and the presence of a limping gait. In addition, spatiotemporal gait parameters were analyzed using inertial sensors, specifically speed, cadence, and symmetry during locomotion.

2.2. Participants

The sample consisted of 61 older adults attending a day center located in the city of Querétaro, Mexico, aged between 60 and 79 years. Participants were selected through non-probability convenience sampling, following an open call issued at the institution. The inclusion criteria were: being an active member of the center, taking part in physical activity workshops, being aged 60 or over, and being able to walk with or without walking aids. Eight participants were excluded for not completing the established assessments.

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2.3. Procedure

For data collection, participants were scheduled to attend at previously established times and were asked to wear comfortable clothing and to bring the signed informed consent form, which had been provided in advance. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki, guaranteeing the confidentiality of the information, respect for autonomy, and protection of the participants' physical integrity. The assessment procedure was also explained and any questions were answered before the measurements began.

The assessment began with the participant in the supine position in order to measure the true length of the lower limbs, taking the distance between the anterior superior iliac spine and the medial malleolus. Subsequently, an observational clinical assessment of gait was carried out, asking the participant to walk six meters there and back without footwear, in order to identify scapular or pelvic asymmetry and the presence of a limping gait. Finally, the Baiobit inertial sensor was placed at the level of the first sacral vertebra to record the spatiotemporal gait variables over an eight-meter course. The assessments were carried out by a trained physiotherapist and a trained orthopedic physician.

2.4. Statistical analysis

The database was processed in Jamovi software version 2.2, which was used to perform the descriptive statistical analysis of the spatiotemporal gait variables. Descriptive measures were calculated for the quantitative variables, whereas frequencies and percentages were obtained for the qualitative variables, such as sex, limping gait, and scapular and pelvic asymmetry.

3. Results

A sample of 61 older adults with a mean age of 69 years (SD=5.73) was assessed, of whom 57 (93%) were women and four (7%) were men. Regarding the assessment with inertial sensors, the results indicate the following: cadence had a mean of 100 steps per minute, while gait speed had a mean of 0.74 m/s. With respect to asymmetry, the results showed that 68% of the older adults presented values above 90%, indicating symmetry (Table 2).

Table 2
Spatiotemporal gait variables

Variable	Mean	Standard deviation (SD)	Mode	Range	Other relevant results
Cadence (steps/min)	100	20.1	110	57 – 155	—
Speed (m/s)	0.74	0.17	0.66	0.28 – 1.22	—

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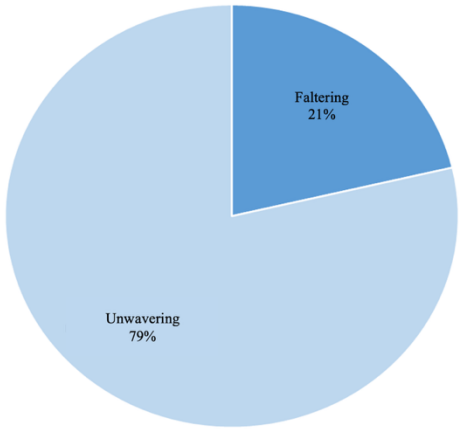
Asymmetry (%)	88.3	15.2	—	—	32% < 90% (asymmetry)/68% ≥ 90% (symmetry)

In the clinical gait analysis, carried out through observation, 13 participants (21%) were found to present a limping gait. In addition, scapular asymmetry was observed in 32 participants (52%) and pelvic asymmetry in 29 participants (48%). Furthermore, the true length of the lower limbs was measured, obtaining a mean of 82.7 (6.10) centimeters for the right limb and 82.6 (6.11) centimeters for the left lower limb, with a mean difference between the right and left limbs of 0.54 cm (SD=0.48) (Figure 1).

Figure 1
Gait type according to clinical assessment



4. Discussion

The present study recorded a mean gait speed of 0.74 m/s. These values are slightly below those reported by Virto et al. (2024) (0.92-1.07 m/s), which places both populations at an adequate gait speed, even though sensors were not used to assess it in the latter. However, this difference could also be caused by the lack of precision when gait is assessed through observational tests.

Gait speed is considered one of the most important indicators of the health status of older people, since it tends to decline progressively with aging (Binotto et al., 2018). In a study conducted in 94 older people with a mean age of 70.72 years who had visual impairments, the mean gait speed was found to be 91.07 cm/s, while mean cadence was 103.44 steps per minute (Duran-Badilllo et al., 2019). As regards cadence, a relationship was observed between the percentage of participants with a limping gait and the percentage with asymmetry recorded

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by inertial sensors, namely 21% and 32% respectively. This indicates how the use of sensors allows greater precision in detecting asymmetries.

In the present study, 52% of participants presented scapular asymmetry and 48% pelvic asymmetry. This reflects consistency in the compensations that their musculoskeletal system makes in order to achieve postural balance between the shoulder and pelvic girdles. In this regard, Villarruel et al. (2020) found a high prevalence of scapular asymmetry; although their study focused on young populations, it is striking that 70% of their sample presented it.

With regard to lower limb length, a mean difference between the right and left limbs of 0.54 cm was observed, which is consistent with the results of Aitken (2021), who observed a difference of 0.4 cm between limbs, despite having conducted the study in a population of varied ages (15-83 years). The above is considered to fall within well-tolerated parameters, that is, less than one centimeter (Fassier, 2024).

5. Conclusions

Based on the results, consistency was observed between the clinical assessment and the assessment with inertial sensors. Likewise, greater sensitivity for detecting asymmetry during gait was identified with the inertial sensors, since clinical assessment detected asymmetry, identified as a limping gait, in only 21% of participants. With the inertial sensor, however, asymmetry was detected in 32% of participants, giving a discrepancy of 12% between the two sets of data.

With regard to the findings obtained with the inertial sensors, most participants achieved cadence values within normal ranges, which translates into a fluid gait. As for speed, most of the population obtained values below what was expected, which means that despite having a fluid gait they did not cover the expected distance, since the reference value considered normal for this age group is 1 m/s.

In conclusion, gait assessment is an essential tool in comprehensive geriatric assessment because of its close relationship with the functionality and quality of life of older people. Aging produces physiological and biomechanical changes that increase locomotor vulnerability and the risk of falls. For this reason, the use of validated functional tests makes it possible to detect mobility alterations at an early stage, guide treatment, and prevent complications associated with functional decline. Systematic gait assessment should be considered a priority in the care of the older adult population, since it favors the preservation of independence and contributes to healthy aging.

In addition to the above, it is important to corroborate observational findings with state-of-the-art equipment that bases its results on precise data, since such equipment uses inertial sensors, which have revolutionized the biomechanical study of human movement thanks to their ease of use, portability, and capacity to record data in real time. These devices integrate accelerometers, gyroscopes, and, in some cases, magnetometers, which make

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it possible to obtain information on linear accelerations, angular velocities, and spatial orientation, detecting micro-movements that are not visible to the human eye during visual inspection. Their application in physiotherapy, rehabilitation, sports medicine, and orthopedics has made it possible to optimize functional assessment and therapeutic follow-up processes.

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