Title: Age- and Sex-Based Differences in Gait Pattern Characteristics Among Adults Over 50: A Cross-Sectional Study

ABSTRACT

Background/Objective: Walking is essential for maintaining functional independence, and understanding gait changes due to aging is crucial, as chronic conditions often overlap with normal aging. The objective of this study was to describe gait characteristics in adults aged 50 and over, and to identify differences between age groups and between sexes.

Methods: The study included 34 adults aged 50–59, 38 adults aged 60–69, and 28 adults aged 70+. Participants characteristics (age, sex, height, weight, falls in the last six months, and comorbidities) were collected. Participants walked a 30-meter round trip at a self-selected pace. Gait was measured using inertial measurement units (IMUs).

Results: Results showed that stride length, stride velocity, push-off ratio and minimal toe clearance decreased with age ($p<0.03$), that flat-foot ratio increased with age ($p<0.01$), while cadence, walking phases (stance, swing, double support, loading ratio), and maximal heel clearance (maxHC) were similar across age groups ($p>0.05$). Males had a lower cadence, a longer stride and a higher maxHC than females ($p<0.04$). Stride velocity and minimal toe clearance were similar between sexes ($p>0.05$).

Conclusion: This study found that stride length and velocity decrease with age, and notable sex differences exist in stride length and maxHC. These findings underscore the importance of considering both age and sex when assessing walking and functional capacity in older adults.

Significance/implications: Aging impacts gait, and IMUs offer a valuable tool to examine how age and sex affect walking. This is an initial step towards deeper understanding of gait characteristics in older adults.

Keywords: Gait analysis, middle-aged, older adults, aging, Gait Pattern Characteristics, Walking

INTRODUCTION

Walking is one of the most prevalent and preferred forms of physical activity performed by older adults (Dawson et al., 2007; DiPietro, 2001). As a widely practiced low-intensity activity in older adults (Valenti et al., 2016), walking plays a crucial role in maintaining their functional independence (Aboutorabi et al., 2016; Beauchet et al., 2017). However, walking capacity (Pirker & Katzenschlager, 2017; Winter et al., 2010), which refers to an individual's ability to move and perform daily tasks, is generally impacted in older adults due to age-related physiological changes, such as decreased muscle strength (Keller & Engelhardt, 2013). In addition to the aging process, walking capacity can also be impacted in older adults by chronic diseases or musculoskeletal disorders (Prince et al., 2015). Improving physical function (e.g., walking capacity) is therefore commonly identified as a key target in the clinical management of older adults with chronic conditions, such as cardiovascular diseases (Dobkin, 2005; Forman et al., 2017), Parkinson's disease (Ni et al., 2018) and osteoarthritis (Brophy & Fillingham, 2022). Since chronic conditions often overlap with normal aging processes, it is important to thoroughly understand the changes in gait pattern characteristics that are attributable to healthy aging. This understanding makes it possible to distinguish between age-related changes and those induced by chronic conditions, ultimately enabling early detection of potentially harmful gait alterations that require specific attention.

Aging is well known to be associated with several physiological changes, particularly in the sensorimotor system (Aboutorabi et al., 2016; Beauchet et al., 2017; Yoshimura et al., 2020). In terms of gait pattern characteristics, current evidence indicates a decrease in step length and an increase of temporal characteristics, such as step duration, stride duration, stance duration, swing duration and double support duration with increasing age while step width remains stable (Herssens et al., 2018). A previous scoping review reported similar changes, in addition to reporting a reduction in gait symmetry with increasing age (Aboutorabi et al., 2016). Furthermore, other previous studies have shown a decrease in cadence with increasing age (Aboutorabi et al., 2016; Laufer, 2005; Thaler-Kall et al., 2015). Since most chronic diseases and musculoskeletal conditions that affect walking, such as Parkinson's disease and spinal stenosis, are more prevalent in adults over the age of 50 (Jensen et al., 2020; Pringsheim et al., 2014), including middle-aged individuals is important to understand age-related changes in gait (Frimenko et al., 2015). A recent systematic review highlighted the important gap in gait pattern characteristics in middle-aged individuals (Herssens et al., 2018). To date, changes in gait pattern characteristics have primarily been studied by comparing the gait pattern of young adults (18-50 years old) to that of older pain-free adults (over 65 years) or between specified decades (e.g., 60s, 70s and 80s) (Chung et al., 2023; Frimenko et al., 2015; Hollman et al., 2011; Ostrosky et al., 1994). Even if these comparisons provided insights about the differences in gait pattern characteristics observed in different age groups, they do not provide information about the onset of aging effects on gait pattern characteristics in middle-aged individuals (50 to 65 years old). A better understanding of gait pattern characteristics among individuals in this age group could contribute to the development of more impactful strategies to promote healthy aging and maintain walking capacity and autonomy, thereby improving the quality of life of middle-aged individuals as they transition into their later years (Herssens et al., 2018).

Furthermore, considering age-related changes in gait, it is also essential to consider sex differences. Current evidence indicates that males and females have similar preferred speed when walking, and that there are sex differences in cadence, stride length and gait cycle length (Ko et al., 2011). However, sex differences in more specific gait pattern characteristics such as gait subphases, peak angle velocity and clearance parameters have not been assessed in middle-aged and older adults.

The primary objective of this study was to describe gait characteristics in adults aged 50 and over, and to identify differences between age groups and between sexes. We hypothesized that cadence, stride length, stride velocity (and thus the swing phase) and clearance variables would all decrease with increasing age. We also hypothesized that, compared to females, cadence would be lower and stride length greater in males, while stride velocity, temporal characteristics (stance phase, swing phase and double support) and clearance variables would be similar between male and female individuals aged 50 and over.

METHODS

Study design

This cross-sectional study was conducted at the XXX. Recruitment and data collection took place from September 2020 to April 2023.

Participants

One hundred adults were recruited via social media platforms, including Facebook pages and the university's institutional website. A post hoc power analysis was performed using G*Power to determine the statistical power of the study. With a sample size of 100 participants, an effect size of $\eta^2 = 0.153$ for walking velocity, and an alpha level set at 0.05, the calculated statistical power turned out to be 0.81. Walking velocity was selected to calculate statistical power because of its direct influence on key gait parameters such as the stance phase, swing phase, cadence, and stride length.

To be included, participants had to be at least 50 years old, be able to walk without a walking aid and report no fall in the last six months. Participants with low back pain, lower limb pain (such as symptomatic knee or hip osteoarthritis), symptomatic disc herniation, vascular claudication, uncontrolled diabetes, toe or limb amputation, known lower limb injury, even if non-painful, cardiac conditions that can impede walking capacity (such as heart failure), Parkinson's disease and participants who had undergone a back or lower limb surgery in the last 3 months were excluded from this study. The project received approval from the university Human Research Ethics Board (CER-20-269-07.14) and all experimentations were carried out in accordance with the relevant guidelines and regulations. All participants provided informed written consent prior to their participation in the study.

Data collection

Data collection began with a brief history taking to gather participants' characteristics, such as age, height, weight, sex, number of falls during the previous six months and the presence of comorbidities. Participants were asked to complete the short version of the International Physical Activity Questionnaire (IPAQ) to assess their physical activity level (low, moderate, or high) (Craig et al., 2003). Participants were also asked to self-report their leg dominance, determined by the foot they use to kick a ball.

Participants were then asked to complete a walking task that consisted of walking on a 30-meter round trip at self-selected speed. The 30-meter distance was determined according to the suggestion in the Physilog user manual, and to ensure a sufficient number of steady state gait cycles. The walking task was performed twice, and participants had a two-minute rest period in a sitting position between the trials. During each trial, the biomechanical gait characteristics were measured using the Physilog®6 (Gait Up, Lausanne, Switzerland) wearable inertial measurement units (IMUs) clipped on the top of each participant's shoes with elastic straps (see figure 1). The first trial served as a familiarization exercise for the participants, while only the second trial was analyzed. Both inertial sensors were synchronized and were manually turned on and off before and after each walking trial. Each inertial sensor includes a three-dimensional (3D) accelerometer (± 4g), a 3D gyroscope (± 1000˚/s) with a sampling frequency of up to 512Hz, a magnetic field sensor (± 50mT; 256Hz), and a barometer (0-64 Hz). Inertial sensors have been shown to be reliable and valid tools for walking assessment in healthy adults (Homan et al., 2022;

Moufawad el Achkar et al., 2016). During the walking task, information from both left and right feet were collected, as some variables such as the double-support phase require the registration of both feet.

[Insert fig 1. About here]

Figure 1: Walking task and IMUs positioning.

Variables

Independent variables

Participants were first divided into three groups according to age (group 1: 50-59 years, group 2: 60-69 years, group 3: ≥ 70 years). Then, all participants were further divided by sex to address our second objective.

Dependent variables

Data from the synchronized Physilog®6 inertial sensors were analyzed using the Gait Analysis Software (v. 5.2, Gait Up Lausanne, Switzerland). All gait characteristics were divided into four categories: general characteristics (cycle duration, cadence, stride length, stride velocity), spatial characteristics (peak angular velocity between maximal heel clearance and minimal toe clearance, heel-strike pitch angle, lift-off angle), temporal characteristics (including stance phase, which consists of loading phase ratio (heel strike), foot-flat ratio (loading response and midstance), and push-off ratio (terminal stance and pre-swing), swing phase, and double support), and clearance characteristics (maximal heel clearance and minimal toe clearance). All gait characteristics are defined in the Appendix 1. The first and last two gait cycles (initiation and termination) were discarded as recommended in the device user manual and previous studies (Hollman et al., 2011; Jian et al., 1993; Mulas et al., 2021) to ensure that only data associated with the steady state were processed. Values related to turns were also discarded to ensure gait analysis in a straight line. Except for gait characteristics requiring information from both feet, such as cycle duration, cadence and walking phases, only the data recorded on the dominant leg was used.

Statistical analysis

The normality of data distribution was assessed with the Shapiro-Wilk test and by visual inspection of corresponding histograms for each dependent variable. Because some variables did not follow a normal distribution, mixed analyses involving both age and sex, such as mixed analysis of variance (ANOVA), could not be performed, as all assumptions were not met. Therefore, comparative analyses were first conducted based on age groups, followed by distinct analyses based on sex. Depending on the data distribution for each dependent variable, parametric tests or nonparametric tests were conducted. Proportions were reported for dichotomous variables, while means and standard deviations (SD) were reported for continuous variables. Preliminary analyses (t-test or Mann-Whitney test) comparing the dominant and non-dominant legs revealed no significant differences in the key gait parameters ($p > 0.05$). Therefore, only the dominant leg was included in subsequent analyses to reduce redundancy and simplify data interpretation. All statistical analyses were performed using IBM SPSS Statistics version 29 (Armonk, NY: IBM Corp.), and the level of significance was set at a p-value of <0.050.

Comparisons between age groups for male-to-female ratio, physical activity level and comorbidities were conducted using Chi-square analysis. Comparisons between age groups for all participant characteristics and gait pattern characteristics were conducted using one-way ANOVA when variables were normally distributed, or Kruskall-Wallis test when variables were not normally distributed. When necessary, the Bonferroni's post hoc test was performed as the post hoc analysis for pairwise comparisons.

Comparison between males and females for physical activity level was conducted using Chi-square analysis. Comparisons between males and females for all other participants characteristics and gait pattern characteristics were conducted using the t-test for independent groups for normally distributed variables or the Mann-Whitney test for variables that were not normally distributed.

RESULTS

Sociodemographic data

One hundred participants aged 50 or older (64 females, 36 males) were recruited for this study and included in the data analyses. All participant characteristics by age groups are presented in Table 1, and all participant characteristics according to sex are presented in Table 2. According to Chi-square analysis and based on age groups, the male-to-female ratio and the physical activity level were similar between groups (p=[0.175 – 0.192]). Comparisons between age groups showed that participants from each group were also considered similar in terms of height, weight, and BMI (p=[0.512-0.778]). With regard to the presence of comorbidities, Chi-square analysis showed no significant difference between age groups (p=[0.059-0.496]), except for the proportion of participants with high blood pressure, which was higher in group 3 compared to groups 1 and 2 (p=0.022). Comparisons according to sex groups showed that all participant characteristics, except for height and weight (p<0.001), were similar between males and females (p=[0.198 – 0.640]).

Table 1. Group comparisons of participant characteristics according to age groups

[Insert table 1. about here]

Table 2. Group comparisons of participant characteristics according to sex

[Insert table 2. about here]

Gait pattern characteristics

General gait and spatial characteristics

Comparisons according to age groups

Means and standard deviations for all general and spatial gait characteristics are presented in Table 3. Comparisons between age groups for general gait characteristics showed no significant differences for cycle duration and cadence (*p*=[0.279 – 0.456]). However, significant differences were found between age groups for other general gait characteristics such as stride length and stride velocity (*p*<0.001). Bonferroni post hoc analyses showed that individuals aged ≥ 70 had a significantly shorter stride length and slower stride velocity than those aged 50-59 and 60-69 (*p*<0.002). With regard to spatial characteristics, results showed significant differences between age groups for all of them (*p*<0.001). Bonferroni post hoc analysis revealed that individuals aged ≥ 70 had a slower peak velocity, a lower strike angle and a lower lift-off angle than those aged 50-59 and 60-69 (*p*=[<0.001 – 0.007]).

Comparisons according to sex

Means and standard deviations of all general and spatial gait characteristics are presented in Table 4. When looking at the between-sex comparisons for general gait characteristics, results showed that females had a higher cadence, a shorter stride length as well as a shorter gait cycle duration (*p*=[<0.001 – 0.004]) than males. Results also showed no significant difference between females and males for stride velocity (*p*=0.935). With regard to spatial gait characteristics, results showed that the strike angle was significantly greater in males than in females (*p*=0.016). All other spatial gait characteristics were considered similar between females and males (*p*=[0.071 – 0.456]).

Table 2. Group comparisons for general and spatial gait characteristics according to age groups

[Insert table 2. about here]

Table 3. Group comparisons for general and spatial gait characteristics according to sex

[Insert table 3. about here]

Temporal characteristics

Means and standard deviations of all general and temporal gait characteristics are presented in figure 2.

Comparisons according to age groups

Comparisons between age groups showed no significant difference for the stance phase, loading ratio, swing phase and double support phase (*p*=[0.133-839]), while there were significant differences for the flat-foot ratio and pushing ratio (*p*=[<0.001 – 0.003]). Results from the post hoc analyses showed that the flat-foot ratio was higher and the pushing ratio was lower in individuals aged ≥ 70 than those in the 50-59 and the 60-69 age groups (*p*=[<0.001 – 0.006]).

Comparisons according to sex

Comparisons between sex showed no significant difference between the sexes for the duration of the stance phase, the swing phase and the double support (*p*=[0.295 – 0.372]). When looking at the walking subphases, results showed that the loading ratio was higher in males than in females (*p*=0.008), while the pushing ratio was lower in males than in females (*p*=0.006). There was no significant difference in the flat-foot ratio (*p*=0.209).

[Insert fig 2. about here]

Figure 2. Group comparisons regarding temporal characteristics of gait according to age (A) and sex (B)

◊ = Significant difference between group 1 – group 3 (*ps*=[<0001 - 0.007]), ᵻ = Significant difference between group 2 – group 3 (*ps*=<0.001)

Clearance characteristics

Comparisons according to age groups

The Kruskal-Wallis analysis showed no significant difference between age groups for maximal heel clearance (H(2) = 0.696, *p*=0.706). Means and standard deviations for the three groups were 0.29 ± 0.10m, 0.30 ± 0.09m and 0.31 ± 0.13m respectively. Results showed a significant difference between age groups regarding minimal toe clearance (H(2) = 8.398, p=0.015) and the Bonferroni post hoc analyses revealed that individuals ≥ 70 years lifted their foot higher during the swing phase than individuals from the 50-59 and 60-69 age groups (p=[0.007-0.017]). In fact, minimal toe clearance was 0.027 ± 0.016m and 0.025 ± 0.010m respectively for groups 1 and 2, while it was 0.034 ± 0.014 for group 3.

Comparison according to sex

Regarding maximal heel clearance, the means and standard deviations were 0.33 ± 0.11m and 0.28 ± 0.10m for males and females respectively. The Mann-Whitney test showed that males had significantly higher maximal heel clearance (U = 1958.00 p<0.001) than females, while there was no significant difference between sexes for minimal toe clearance (U = 1349.00, p=0.094) (females = 0.026 ± 0.010 m ; males = 0.033 ± 0.018).

DISCUSSION

The objective of the present study was to describe gait characteristics in adults aged 50 and over, and to identify differences between age groups and sexes. As hypothesized, stride length, stride velocity, and minimal toe clearance decreased with age, but cadence, swing phase and maximal heel clearance parameters were similar across all age groups. In terms of sex differences of individuals aged 50 and over, males had a lower cadence and a longer stride than females, while stride velocity, temporal characteristics and minimal toe clearance were similar between sexes, which is consistent with our second hypothesis. However, males had a higher maximal heel clearance than females, contrary to our second hypothesis.

Gait characteristics and age

This study provides, through the use of wearable technology in a free-walking environment, new insights into gait pattern characteristics across different age groups. It highlights that age-related changes in gait pattern characteristics become more important after the age of 70, with significant differences observed with other age groups in spatial, temporal and clearance parameters. However, gait characteristics such as cycle duration, cadence, flat-foot ratio, pushing ratio, and minimal toe clearance remained similar between middle-aged adults (50-59 years) and early older adults (60-69 years).

Our results are consistent with previous findings and confirm that most changes in gait pattern characteristics are observable in advanced age (Beauchet et al., 2017; Hollman et al., 2011). Previous studies on individuals aged over 70 reported that the decrease in skeletal muscle strength occurring with aging (Faulkner et al., 2007; Lang et al., 2010; Winegard et al., 1996) leads to a reduction of stride length and therefore affects gait velocity (Ziegler et al., 2024). At slower gait velocities, the reduction in stride length is a common strategy used to maintain cadence. This strategy, known as cautious gait, is associated with age-related sensory declines (Osoba et al., 2019). A decrease in gait velocity has been previously identified as a risk factor for both falls and frailty (Abellan van Kan et al., 2009). It is therefore important to highlight that, in our study, individuals aged over 70 showed a reduction in both stride length and gait velocity. However, their mean gait velocity remained above the 1.0 m/s threshold for increased risk of falls and frailty (Cesari et al., 2005; Shimada et al., 2015).

In addition to its contribution to reduced stride length and gait velocity, decreases in skeletal muscle strength such as the anterior tibialis also contributes to reduced minimal toe clearance during the swing phase (Perera et al., 2021). This decrease in clearance has been previously reported as an increasing risk factor for falls (Killeen et al., 2017; Perera et al., 2021). In our study, older adults appeared to lift their feet higher than younger adults, which is consistent with previous studies that used short walking distance to assess minimal toe clearance (Khandoker et al., 2008; Watanabe, 2018). This strategy may help prevent tripping and reduce the risk of falls during short, level walking tasks. Over a longer walking distance, muscle fatigue can occur in older adults, which could lead to an involuntary decrease in minimal toe clearance values and an increasing risk of falls (Begg et al., 2007; Hamacher et al., 2014). In fact, a previous study showed that minimal toe clearance decreases as walking duration increases in older adults (Watanabe, 2018). It would be pertinent to evaluate gait pattern characteristics during a longer walking protocol with additional muscle fatigue measures, such as surface electromyography, to confirm this hypothesis regarding minimal toe clearance and muscle fatigue over longer walking distances.

When looking at characteristics such as strike and lift-off angles, a decrease in these angles was observed in individuals aged over 70. Our findings are consistent with previous studies reporting a decrease in plantar flexion during lift-off (Arnold et al., 2014). This suggests that, even if this observation did not take into consideration the complexity of joint movements in the sagittal plane (hip, knee and ankle), it may still be useful for assessing interventions that impact foot pitch (e.g., foot drop). Peak angle velocity, strike angle and lift-off angle obtained from the Physilog IMUs have been validated against a combination of optical motion capture systems and force plates, the current gold standard for biomechanical assessment (Homan et al., 2022). Knowing that these characteristics change with increasing age, their measurement could provide new insights on the identification of gait deviations in clinical settings.

With regard to walking phases, our study suggests that individuals aged over 70 have an increased flat-foot ratio duration and a reduced pushing ratio during the stance phase. This finding aligns with current knowledge, as older adults are known to walk with a smaller propulsive activation of the ankle plantar flexor muscles (Browne & Franz, 2018). Since these subphases are directly related to the stance phase, it would be interesting to assess them during walking protocols at varying velocities to determine how these subphases can be affected by changes in speed. Given the applied research orientation of our study, we focused on raw gait parameters. However, future research could benefit from exploring the normalization of gait cycle phases relative to individual walking speed, as this approach may enhance our understanding of gait dynamics using relative values.

Overall, our results showed that adults of middle-aged (50-59 years) had similar gait pattern characteristics to adults aged between 60 and 69 years, with most changes occurring after 70. Our findings also highlight the importance of monitoring gait characteristics at different stages of aging, as they provide critical insights into how aging affects mobility and can inform targeted conservative interventions, such as exercises, to maintain functional independence and reduce the risk of falls in older adults.

Gait characteristics and sex

The results of the present study indicate some differences between males and females in general, spatial, temporal, and clearance gait pattern characteristics. Our findings show that both males and females walk at the same preferred speed and that females have higher cadence, shorter stride length and shorter gait cycle, which is consistent with previous studies that took place with both young and older adults (Bruening et al., 2015; Ko et al., 2011). When looking at clearance characteristics of gait, our results show that males walk with a longer stride length, while maintaining minimal toe clearance, while both males and females show similar minimal toe clearance values. Given that our results are consistent with those reported in laboratory settings (Espinoza-Araneda et al., 2022), wearable technologies such as IMUs appear to show potential for assessing gait pattern characteristics, although further validation against gold standard technologies is needed. The use of wearable technology in clinical settings may assist clinicians in monitoring changes in minimal toe clearance, potentially contributing to fall prevention strategies. However, further research is needed to better understand how sex and age jointly influence gait parameters relevant to fall risk. Additionally, our study provides further data on walking subphases such as loading ratio, flat-foot ratio, and pushing ratio, as well as characteristics on peak angle velocity, strike angle, and lift-off angle in both older males and females, measured with IMUs. Overall, our results highlight significant sex-based differences in gait characteristics. They also highlight the clinical relevance of using wearable IMUs to capture detailed gait patterns and understand sex-specific gait deviation. However, studies that assess these sex-based gait deviations across various age groups are essential to a comprehensive understanding of the changes in gait parameters that may occur in each sex as they age.

Strengths and limitations

To our knowledge, this study is the first to assess all gait pattern characteristics using IMUs in middle-aged adults. First, the inclusion of a middle-aged adults' group is important to help characterize changes in gait pattern characteristics that occur with increasing age. Individuals in this age group often experience significant changes, such as retirement, declining health, and changes in their social circles (Infurna et al., 2020). These factors may contribute to noticeable alterations in gait patterns over time. In this context, IMUs offer an effective solution for assessing these gait changes across diverse environments, including confined spaces.

This study, however, is not without limitations. Age groups were initially defined according to decades. However, it was difficult to recruit individuals aged over 75 without comorbidities that can negatively affect the gait pattern. Consequently, the oldest decades were merged to form the group of adults over 70 years of age. Further studies should consider including individuals from all age groups (20 to 80 years) to better understand the aging effects on gait pattern characteristics across adult life. In addition, although comorbidities were reported, we did not collect information on medications taken by participants, which can potentially affect walking parameters. An additional potential limitation of this study is the sex distribution, as the sample may be skewed towards one sex, even though the differences were not statistically significant. This could impact the generalizability of the results. Another limitation of this study was the walking distance used to assess gait pattern characteristics. The use of a 30-meter round trip on a flat floor may make it difficult to generalize the results to everyday free walking. In addition, the use of a

30-meter walking test may not fully capture individual variability in gait pattern characteristics, as some individuals may adjust their gait over short distances. Further studies using a longer walking distance on different floor types are needed to better capture gait pattern characteristics or gait pattern changes during daily living activities of older individuals. These further studies are also needed to validate and expand the findings of the present study. The fact that IMUs do not provide a complete biomechanical analysis of the entire lower limb could also be considered as a limitation in the present study. However, few parameters obtained with IMUs, such as peak angular velocity, can provide information on deviations related to the lower-limb kinematics. This information remains interesting from a clinical point of view. Another limitation is the presence of non-normally distributed data. The non-normal distribution of some variables suggests that a larger sample size is needed to validate the use of IMU data as normative and ensure its generalizability to a broader population. In addition, due to non-normally distributed data, it was not possible to analyze both age and sex simultaneously. While age's impact on sex-related gait differences is acknowledged, the lack of interaction analyses remains a limitation to the present study. Finally, we did not standardized participants' footwear; they were asked to wear comfortable shoes without high heels.

Clinical implications

Understanding age- and sex-related differences is valuable in clinical settings, as it helps improve the understanding of age-related changes in gait, enabling the identification of deviations in adults aged 50 and over, particularly those with chronic conditions. In addition, the use of IMUs could offer clinicians new tools to capture gait patterns characteristics more efficiently in individuals, at a lower cost and in smaller environment, compared to actual gold standard tools used in laboratory facilities (e.g., 3D motion capture systems).

CONCLUSION

This study identified differences in gait characteristics between age groups and sexes in adults aged 50 and over. The results showed the importance of considering both age and sex when evaluating gait patterns. Understanding influence of normal aging and sex will help clinicians to identified gait pattern changes that are linked to chronic conditions.

DECLARATION

Competing interests: The authors declare that they have no competing interests.

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Ethics approval and consent to participate: The project received approval from the university Human Research Ethics Board (CER-20-269-07.14) and all experimentations were performed in accordance with the relevant guidelines and regulations. All participants provided informed written consent prior to their participation in the study.

Consent for publication: Not applicable

Availability of data and materials: The datasets used and/or analyzed during the current study are available from the corresponding author on a reasonable request.

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Table 1. Group comparisons of participant characteristics according to age groups

	50-59 yo (n=34) Mean ± SD	**60-69 yo (n=38) Mean ± SD**	**≥ 70 yo (n=28) Mean ± SD**	***ANOVA or Kruskal-Wallis***	***Chi-square***	***p-value***
Participant characteristics						
M : F	8 : 26	16 : 22	12 : 16	-	4.81	0.175
Age (years)	55.38 ± 2.66	63.55 ± 2.85	74.50 ± 3.62	H(2) = 87.757	-	**< 0.001***
Height (m)	1.7 ± 0.1	1.7 ± 0.1	1.7 ± 0.1	H(2) = 0.502	-	0.778
Weight (kg)	72.8 ± 15.3	71.9 ± 14.1	68.8 ± 13.0	F(2) = 0.674	-	0.512
BMI (kg/m^2)	26.2 ± 4.8	26.2 ± 4.2	25.6 ± 5.2	H(2) = 0.648	-	0.723
Physical activity level (IPAQ) *(low : moderate : high)*	4 : 12 : 18	2 : 22 : 14	5 : 10 : 13	-	0.192	-
Presence of comorbidities						
High blood pressure (n, %)	6 (17.65)	6 (15.79)	12 (42.86)	-	7.615	**0.022**
Dyslipidemia (n, %)	3 (8.82)	4 (10.53)	8 (28.57)	-	5.659	0.059
Controlled diabetes (n, %)	1 (2.94)	0 (0.00)	3 (10.71)	-	4.970	0.083
Hypothyroidism (n, %)	2 (5.88)	1 (2.63)	3 (10.71)	-	1.869	0.393
Others (n, %)	4 (11.76)	3 (7.89)	5 (17.86)	-	3.380	0.496

M = Males, F = Females, BMI = Body Mass Index, yo = years old, ANOVA = Analysis of variance, SD = Standard Deviation, IPAQ = International Physical Activity Questionnaire

* Significant difference between group 1 – group 2, group 1 – group 3 and group 2 – group 3 (*ps*>0.001)

Table 2. Group comparisons of participant characteristics according to sex

	Males (n=36) Mean ± SD	**Females (n=64) Mean ± SD**	***Chi-square p-value***	***T-test p-value***
Participant characteristics				
Age (years)	65.17 ± 8.24	63.09 ± 8.00	-	0.221
Height (m)	1.74 ± 0.72	1.61 ± 0.08	**-**	**<0.001***
Weight (kg)	78.01 ± 10.82	67.60 ± 14.56	**-**	**<0.001***
BMI (kg/m^2)	25.71 ± 3.47	26.14 ± 5.21	-	0.617
Physical activity level (IPAQ) (low : moderate : high)	2 : 14 : 20	9 : 30 : 25	0.198	-
Presence of comorbidities				
High blood pressure (n, %)	10 (27.78)	14 (21.88)	-	0.507
Dyslipidemia (n, %)	7 (19.44)	8 (12.5)	-	0.351
Controlled diabetes (n, %)	1 (2.78)	3 (4.69)	-	0.640
Hypothyroidism (n, %)	1 (2.78)	5 (7.81)	-	0.309
Others (n, %)	3 (8.33)	9 (14.06)	-	0.603

BMI = Body Mass Index, yo = years old, ANOVA = Analysis of variance, SD = Standard Deviation, IPAQ = International Physical Activity Questionnaire

* Significant difference between males and females (p<0.001)

Table 3. Group comparisons for general and spatial gait characteristics according to age groups

General and spatial characteristics	**50-59 yo (n=34) Mean ± SD**	**60-69 yo (n=38) Mean ± SD**	**≥ 70 yo (n=28) Mean ± SD**	**ANOVA**	**Kruskal-Wallis**	***p-value***
Cycle duration (sec)	1.06 ± 0.24	1.03 ± 0.10	1.05 ± 0.10	-	H(2) = 1.570	0.456
Cadence (steps/min)	118.92 ± 10.87	118.94 ± 8.99	115.49 ± 8.75	F(2) = 1.294	-	0.279
Stride length (m)	1.41 ± 0.11	1.42 ± 0.14	1.30 ± 0.13	F(2) = 8.395	-	**< 0.001◊ ǂ**
Stride velocity (m/s)	1.41 ± 0.16	1.41 ± 0.18	1.26 ± 0.15	F(2) = 8.775	-	**< 0.001◊ǂ**
Peak angular velocity (°/sec)	432.93 ± 53.42	431.00 ± 34.58	394.16 ± 86.80	-	H(2) = 24.183	**< 0.001◊ ǂ**
Strike angle (°)	27.57 ± 5.19	27.93 ± 3.18	23.50 ± 5.43	-	H(2) = 14.961	**< 0.001◊ ǂ**
Lift-off angle (°)	-73.55 ± 7.59	-74.94 ± 4.88	-68.75 ± 5.17	F(2) = 9.030	-	**< 0.001◊ ǂ**

yo = years old, SD = Standard Deviation, ANOVA = Analysis of variance

◊ = Significant difference between group 1 – group 3 (*ps*=[<0001 - 0.007]), ǂ = Significant difference between group 2 – group 3 (*ps*=<0.001)

Table 4. Group comparisons for general and spatial gait characteristics according to sex

General and spatial characteristics	**Female (n=64) Mean ± SD**	**Male (n=36) Mean ± SD**	**T-test**	**Mann-Whitney**	***p-value***
Cycle duration (sec)	1.03 ± 0.19	1.07 ± 0.09	-	U = 1610.00	**0.001***
Cadence (steps/min)	120.63 ± 8.71	113.23 ± 9.49	t(98) = 3.953	-	**< 0.001***
Stride length (m)	1.35 ± 0.12	1.43 ± 0.15	t(98) = -2.960	-	**0.004***
Stride velocity (m/s)	1.37 ± 0.15	1.37 ± 0.22	t(98) = 0.082	-	0.935
Peak angular velocity (°/sec)	423.68 ± 41.75	417.19 ± 86.17	-	U = 901.00	0.071
Strike angle (°)	25.86 ± 4.02	27.83 ± 6.15	-	U = 1488.00	**0.016***
Lift-off angle (°)	-73.10 ± 6.49	-72.09 ± 6.50	t(98) = -0.748	-	0.456

SD = Standard Deviation

* Significant difference between males and females (p<0.001)