

How older adults walk: Daily life walking characteristics in relation to age, sex, and physical function - The HUNT4 Trondheim 70+ Study

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Abstract

Background: Knowledge about how older adults walk is crucial for effective prevention and treatment of various mobility issues, as well as treatment evaluation, but is to date largely limited to lab-based measurements. Although this provides relevant information about what older adults can do under standardized conditions, it does not give insight into how they actually walk in their daily life, a gap that needs to be addressed urgently.

Objective: The objective of the current study is to describe how older adults walk in daily life in relation to age, sex, and level of physical function, using wearable sensor data from a large sample of older adults with a wide range of age and function from the HUNT4 Trondheim 70+ study.

Methods: The current study is based on one-week accelerometer data (Axivity AX3) from 1289 older adults (mean age 77.41 (SD 6.06) years, range 70-105 years; 54.7% women). Physical function was assessed using the Short Physical Performance Battery (SPPB). To investigate the effect of age and SPPB score on gait metrics (daily number of steps, 95th percentile speed, mode speed, 95th percentile cadence, mode cadence, and maximum WB distance) for women and men, univariate gamma regressions with log link were performed on each outcome measure, with age and SPPB score in separate models. Sex differences were investigated through Mann-Whitney U tests.

Results: Older adults showed large variation in how and how much they walked in daily life across age, sex, and physical function, particularly younger participants and those with better physical function. Most gait metrics decreased at an increasing rate with higher age, with men maintaining their levels up to higher ages than women. Poorer physical function led to an exponential or close-to-linear decrease in all gait metrics apart from habitual cadence, which remained stable up to high age. Women had a lower daily number of steps, gait speed, and maximum distance, yet higher cadence, than men (all $P < .001$). On average, 63% of all walking bouts (WBs) lasted <10 seconds, accumulating to a median of 99 minutes (IQR 66-128). For WBs lasting 10-30 seconds, the accumulated time was 105 minutes (IQR 65-154), WBs lasting 30-60 seconds accumulated 31 minutes (IQR 18-47), while WBs lasting >60 seconds accumulated 113 minutes (IQR 37-219).

Conclusions: Daily life walking performance is affected more by functional ability than by age itself, except for the oldest ages, and differs significantly between sexes. Although most walking bouts are very short, total accumulated walking time is longer in bouts shorter than 30 seconds than in longer bouts. Future research can build upon our findings, considering both the impact of short WBs and relevant group and sex differences when implementing daily life mobility assessment in both clinical studies and patient follow-up.

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Original paper

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Conclusions: Daily life walking performance is affected more by functional ability than by age itself, except for the oldest ages, and differs significantly between sexes. Although most walking bouts are very short, total accumulated walking time is longer in bouts shorter than 30 seconds than in longer bouts. Future research can build upon our findings, considering both the impact of short WBs and relevant group and sex differences when implementing daily life mobility assessment in both clinical studies and patient follow-up.

Keywords: gait analysis; walking; daily life; real-world; older adults; HUNT; SPPB; physical function

Introduction

Mobility, the ability to move around physically, is one of the key features of independence for older

adults, contributing to sustained participation and overall quality of life [1,2]. With increased age, the prevalence of mobility problems increases, with almost a third of people over the age of 75 having moderate to severe walking difficulties [3], leading to increased dependency on caregivers and assistive equipment [4]. Therefore, an in-depth understanding of how older adults walk can provide valuable insights into factors supporting mobility and independence in an aging population. Better understanding is pivotal to prevent reduced walking ability, thereby sustaining independence, lowering societal costs and maximizing available resources [5], as well as maintaining their well-being [6].

Most of our current knowledge about how older adults walk stems from laboratory-based gait assessments which have provided us with detailed information about how older adults can perform under controlled, supervised conditions. This has led to gait speed being identified as a predictor of survival [7] and disability among older adults [8]. Older adults with a preferred gait speed below 1 m/s, but otherwise well-functioning, had a higher risk of adverse health-related outcomes compared to those with a faster habitual gait [9]. Furthermore, higher age, female sex, and lower physical function has been shown to be associated with lower gait speed [10,11]. Additionally, older adults who walk at a cadence of at least 100 steps per minute were shown to have a 21% reduced risk of all-cause mortality compared to those with a lower step frequency [12].

However, laboratory-based gait assessment of what older adults can do under standardized conditions are not representative of what they actually do in daily life, and hence represent two different constructs of mobility [13–16]. Laboratory assessments may be biased by factors such as the “white-coat effect” or the “Hawthorn effect” that can cause over- or underperformance, or a general change in behavior due to the awareness of being observed [17]. In addition, lab assessments are limited to snapshots of a person’s gait, and it has been shown that gait speed as measured in-lab differs significantly compared to gait speed in the real world [14,18]. Moreover, real-world cadence has been found to be significantly associated with number of falls per year, which has not been shown for cadence, gait speed, or distance as measured in a laboratory setting [19]. Therefore, assessment outside the lab is needed to gain detailed knowledge of how older adults walk in a setting that reflects the complexity of their daily environments [1]. Such knowledge can give essential complementary insights into critical factors to prevent functional decline and mobility reduction.

The last two decades have seen a rise and rapid improvement in wearable sensor technology that allows for continuous monitoring outside of a lab or clinic. These technological advances can provide researchers with fine-grained real-world data in a wide variety of mobility contexts. One of the first studies to use this technology was conducted by Orendurff and colleagues [20], who described daily life walking patterns of healthy, employed adults. Since then, additional studies have been published that investigated real-world walking using body worn accelerometers [18,21–23]. Although providing the first insights into real-world gait, most of these earlier studies had low sample size [24], did not include the frailest and/or oldest adults [18,21,22], or used algorithms that were not validated specifically for an older population [22,23,25].

Recent developments in algorithms and analysis pipelines specifically developed for older adults and people experiencing mobility problems, along with improved sensor technology, make it possible to account for atypical walking patterns that can occur in these populations. These state-of-the-art algorithms have been shown to reliably estimate various digital mobility outcomes (DMOs) in a real-world environment, both for healthy older adults in general and for patients with mobility problems [26,27]. This paves the way for investigating how older adults walk in daily life in large study samples that include large variations in age and level of function. Therefore, the objective of the current study is to describe how older adults walk in daily life in relation to age, sex, and level of physical function, using wearable sensor data from a large sample of older adults with a wide range

of age and function from the HUNT4 Trondheim 70+ study.

Materials and methods

Study population

A total of 1,745 adults aged 70 years or older participated in HUNT4 Trondheim 70+, a sub-study in the fourth wave of the population-based Trøndelag Health Study (HUNT) in Norway [28]. Data collection took place from October 2018 until June 2019. In order to recruit also the oldest and frailest older adults, those who could not come to the field station were offered a home visit. The majority of participants were assessed at a field station (74%), with the remaining participants assessed at their own home (11%) or in their nursing home (15%). The participants provided written informed consent. In cases where assessors or health care personnel in nursing homes considered a participant unable to consent, written informed consent was provided by the closest proxy. Of the 1,745 participants included in the Trondheim 70+ sub-study, 1363 older adults (aged 70-105) participated in activity monitoring and were included in the analyses. This study was approved by the Regional Committee for Medical and Health Research Ethics (ref. nr. 51105).

Procedures

All participants in HUNT4 Trondheim 70+ underwent a standardized study protocol, including clinical tests, structured interviews, and self-reported questionnaires, previously described in detail [29,30]. Height and body weight were measured as part of the clinical tests, and Body Mass Index (BMI, weight/height²) was calculated retrospectively. Physical function was assessed using the Short Physical Performance Battery (SPPB), consisting of three sub-tests targeting static balance (feet together, semi-tandem and tandem stance), leg strength (5-times sit-to-stand), and gait speed (4-m walk test). Each sub-test was scored with a value between 0-4, adding to a total score of 0-12 points where higher scores indicate better performance [31]. Cognitive function was assessed using the Montreal Cognitive Assessment (MoCA) [32], generating a score of 0-30, where higher scores indicate better cognitive performance.

After the clinical tests, participants were asked to wear two tri-axial accelerometer devices (Axivity AX3, Newcastle, UK) on their thigh (centrally on the thigh, approx. 10 cm above the upper border of the patella) and lower back (on L3, the third lumbar segment) for seven days. Devices were configured using the OmGui software (version 1.0.0.43; Open Movement, Newcastle, UK) and fixated on the skin using adhesive film (Opsite Flexifix; Smith & Nephew, Watford, UK). Acceleration was measured at a frequency of 50 Hz (range ± 8 g bandwidth). After the measurement period, participants either sent the devices back in a pre-paid envelope or delivered them back to the field station in person, where the data was downloaded using the OmGui software.

Data processing

Of the 1363 participants that contributed activity monitoring data, 16 (1.2%) had a data collection registration error, 20 (1.5%) were missing data from the lower back, and 31 (2.3%) had a data processing error. In addition, age and/or SPPB score were missing for seven participants (0.5%). Data from the remaining 1289 participants (94.6%) were included in further analyses. To distinguish between wearing and non-wearing of the sensor, we used an event-based algorithm that detects changes in the temperature signal from the Axivity AX3 device [33]. The number of days with accelerometry data ranged from 1-7, with a median of 6. Data processing was performed using MATLAB R2022a (MathWorks®, USA). The 456 participants not included in the analyses (due to not wearing sensors or the reasons mentioned above) were older (82.2 (SD 8.2) vs 77.4 (SD 6.1)

years), had a lower MoCA score (19.8 (SD 6.9) vs. 23.5 (SD 4.2)), and had a higher proportion of women (66.9% vs. 54.7%) compared to the analyzed sample.

Real-world walking analysis

The data processing pipeline included validated, top-ranked algorithms [26,27] associated with the following processing blocks: foot initial contact (IC) detection, walking bout (WB) detection, cadence estimation, step length, speed, and distance estimation. The *Step IC detection* algorithm used the pre-processed vertical acceleration signal. Pre-processing included detrending, low-pass filtering, numerical integration, and continuous wavelet transformation. The IC events were identified as the positive peaks between zero-crossings [27]. For *walking bout detection*, the norm of the triaxial acceleration signal was first detrended and low-pass filtered (FIR, $f_c=3.2\text{Hz}$), then steps-related peaks in acceleration signal were selected using thresholds for amplitude and peak-to-peak duration [34,35]. A WB was identified as a sequence of two or more consecutive steps, potentially including steps during turning but no breaks to ensure a more accurate estimation of gait metrics (e.g., speed, cadence) and avoid biases in shorter bouts. *WB duration (s)* was defined as the time interval from the first to the last foot IC within the WB. *Cadence (steps/min)* estimation was based on the step IC detection algorithm and was calculated for each detected WB as step frequency during the respective WB [27]. The *Step-length (m)* estimation algorithm was based on the inverted pendulum biomechanical model proposed by Zijlstra et al. [27,36,37], using a correction factor in the model for impaired gait patterns. *Speed (m/s)* was estimated as the product of cadence and step length. For each WB, step length and speed were obtained as averaged values across all steps within the WB. Finally, *WB distance (m)* was estimated as the product of WB duration and WB speed.

Data aggregation and gait outcome metrics

As the parameters characterizing real-world walking were estimated for each detected WB throughout the monitoring period, a data aggregation procedure is required to summarize these WB parameters as gait outcome variables for each participant before subsequent statistical analysis. To this end, for each participant, the walking bouts and the respective parameters were aggregated from: (i) all WBs across valid wear days (daily aggregation); (ii) all WBs across the entire measurement period (weekly aggregation). *Daily number of steps* was obtained by summing the steps within all detected WBs across all valid days, then averaging across all valid days WBs. Valid days were defined as days having at least 18 hours of detected wear time. The weekly aggregation procedure was based on various statistical metrics that describe the distribution of walking parameters across pooled walking bouts. *Within-subject mode* was used to represent habitual walking. *Within-subject 95th percentile* was used to represent walking capacity and is referred to as fast cadence and fast walking speed. Additional gait outcome variables derived for weekly aggregated WBs were: (1) *walking bout duration distribution*: the percentage of WBs in each of four duration categories (≤ 10 seconds, $>10 - 30$ seconds, $>30 - 60$ seconds, >60 seconds); (2) *time in WB duration categories*: the accumulated time in each of the four WB duration categories.

Cohort stratification criteria

Age and SPPB score were categorized into groups for graphical portrayals of group variance. Age (years) was categorized into six groups (70-74.9, 75-79.9, 80-84.9, 85-89.9, 90-94.9, ≥ 95), labeled as 70+, 75+, 80+, 85+, 90+, and 95+, respectively, in tables and figures. SPPB score (0-12 points) was

categorized into three groups (high score: 12-10 points, medium score: 9-7 points, and low score: 6-0 points) [38].

Statistical analysis

Statistical analyses were performed using R version 4.4.3 (R Core Team, 2025) and RStudio version 2024.04.1+748 "Chocolate Cosmos" (RStudio Team, 2024). Participant characteristics were summarized using means and standard deviations for continuous variables, and frequencies and percentages for categorical variables. Dependent variables were graphically and statistically checked for normality, using histograms and Q-Q plots, and the Shapiro-Wilk test and the Skewness and Kurtosis test, respectively. To assess whether participant characteristics and gait metrics differed significantly by sex, we applied the non-parametric Mann-Whitney U test. A Chi-Square Test of Independence was employed to test whether the distribution of SPPB score differed between sexes. To investigate the effect of age and SPPB score on gait metrics (daily number of steps, 95th percentile speed, mode speed, 95th percentile cadence, mode cadence, and maximum WB distance), univariate gamma regressions with log link were performed on each outcome measure, with age and SPPB score in separate models. Gamma family and log link were chosen after inspecting residual distributions and model fit to account for the distribution of the data, and age and SPPB score were treated as continuous variables. The SPPB score was reversed to make the max score of 12 points the reference. To prevent disproportionate influence on the results, single representatives of a specific age (two females aged 97 and 99, and two males aged 93 and 100) were excluded from the gamma regressions. A power law relationship was observed between several of the log gait metrics and age or SPPB score. Therefore, the power providing the best fit was determined using maximum likelihood estimation. When the AIC did not improve, the power was set to one. Regression analyses were performed separately for women and men.

The relationship between each gait metric and age was assessed using gamma regressions assuming

$$\text{gait metric} = \exp(\beta_0 + \beta_1(\text{age} - 70)^{\beta_p})\epsilon$$

with a gamma-distribution with mean 1 and variance ϕ for the error term ϵ .

The relationship between each gait metric and the SPPB score was assessed using gamma regressions assuming

$$\text{gait metric} = \exp(\beta_0 + \beta_1(12 - \text{score})^{\beta_p})\epsilon$$

with a gamma-distribution with mean 1 and variance ϕ for the error term ϵ .

Results

A total of 1289 participants (54.7% women) were included in the analyses. The mean age of the participants was 77.41 (SD 6.06) years, ranging from 70 to 105 years. Significant differences were found between sexes in age, height, weight, BMI, and overall SPPB score (all P 's < .01). Furthermore, the distribution of SPPB categories differed significantly between women and men ($\chi^2=8.34$, $P<.015$), with a higher proportion of men in the highest scoring group. For additional participant characteristics and group frequencies, see Table 1.

Table 1. Participant characteristics and group frequencies, presented as mean (SD) [range], or frequency (percentage). P -values are derived from Mann-Whitney U tests.

	All	Women	Men	P -value
n (%)	1289 (100%)	705 (54.7%)	584 (45.3%)	
Age (years)	77.41 (6.06) [70.1-105.4]	77.96 (6.45)	76.74 (5.49)	<.005

Height (cm)	168.80 (9.26) [141-199]	162.70 (6.36)	176.10 (6.49)	<.001
Weight (kg)	76.20 (14.81) [36.4-195.7]	69.90 (12.72)	83.74 (13.56)	<.001
BMI ^a (kg/m ²)	26.71 (4.43) [13.4-65.4]	26.45 (4.68)	27.02 (4.09)	<.003
MoCA ^b score	23.50 (4.19) [3-30]	23.56 (4.45)	23.43 (3.87)	.099
SPPB ^c score	9.96 (2.94) [0-12]	9.71 (3.09)	10.27 (2.71)	<.001

Group frequencies (%)

SPPB^c

categories:

0-6p	163 (12.7%)	102 (14.5%)	61 (10.6%)
7-9p	203 (15.8%)	121 (17.2%)	82 (14%)
10-12p	923 (71.6%)	482 (68.4%)	441 (75.5%)

Age categories:

70-74.9	588 (45.6%)	310 (44%)	278 (47.6%)
75-79.9	341 (26.4%)	174 (24.7%)	167 (28.6%)
80-84.9	188 (14.6%)	110 (15.6%)	78 (13.4%)
85-89.9	104 (8.1%)	65 (9.2%)	39 (6.7%)
90-94.9	54 (4.2%)	35 (5%)	19 (3.2%)
≥95	14 (1.1%)	11 (1.6%)	3 (0.5%)

^aBMI: Body mass index.

^bMoCA: The Montreal Cognitive Assessment. Generates a score of 0-30, where higher scores indicate better cognitive performance.

^cSPPB: Short Physical Performance Battery. Generates a score of 0-12, where higher scores indicate better physical performance.

Walking bouts

The mean number of daily walking bouts (WB) was 253.46 (SD 123.63), ranging from 2.25 to 865.5 WBs. There was no significant difference between women and men in number of WBs ($P=0.47$). On average, 63% of all WBs across age, sex, and physical function had a duration of 10 seconds or shorter, while only 6% of all WBs were longer than 30 seconds. The median total accumulated time spent walking in WBs <10 seconds was 99 minutes (IQR 66-128), while the median time was 105 minutes (IQR 65-154) for WBs lasting between 10-30 seconds. Furthermore, WBs lasting between 30-60 seconds compiled a median of 31 minutes (IQR 18-47), while the median time in WBs >60 seconds was 113 minutes (IQR 37-219). Only one participant (0.1%) did not have WBs >10s, 35 participants (2.7%) did not have WBs > 30s, while 83 participants (6.4%) did not have WBs >60s. For women, WBs <10 seconds accounted for 66.3% of all WBs, adding up to a median total of 101 minutes (IQR 65-133). In contrast, men had 59.2% WBs <10 seconds with a median total of 96 minutes (IQR 66-125). Bouts lasting between 10-30 seconds accounted for 28% of WBs for women and 33.6% for men, with a median total of 92 (IQR 58-137) and 120 minutes (IQR 78-178), respectively. Furthermore, 2.7% of women's and 4.0% of men's bouts lasted between 30-60 seconds, with a median of 27 minutes (IQR 14-39) for women and 37 (IQR 24-55) for men. Only 2.3% of women's WBs and 2.8% of men's lasted longer than 60 seconds, adding up to a median total of 96 (IQR 29-210) and 134 minutes (IQR 54-227), respectively.

Daily number of steps

The average number of steps per day varied widely, particularly in younger ages and better SPPB scores (see Figure 1). Overall, women took significantly fewer daily steps compared to men

(medians 5704.5 (IQR 3441.6-8264.8) and 6504.5 (IQR 4442.3-8837.0), respectively, $P<.001$), and participants with higher age and lower SPPB scores had fewer daily steps.

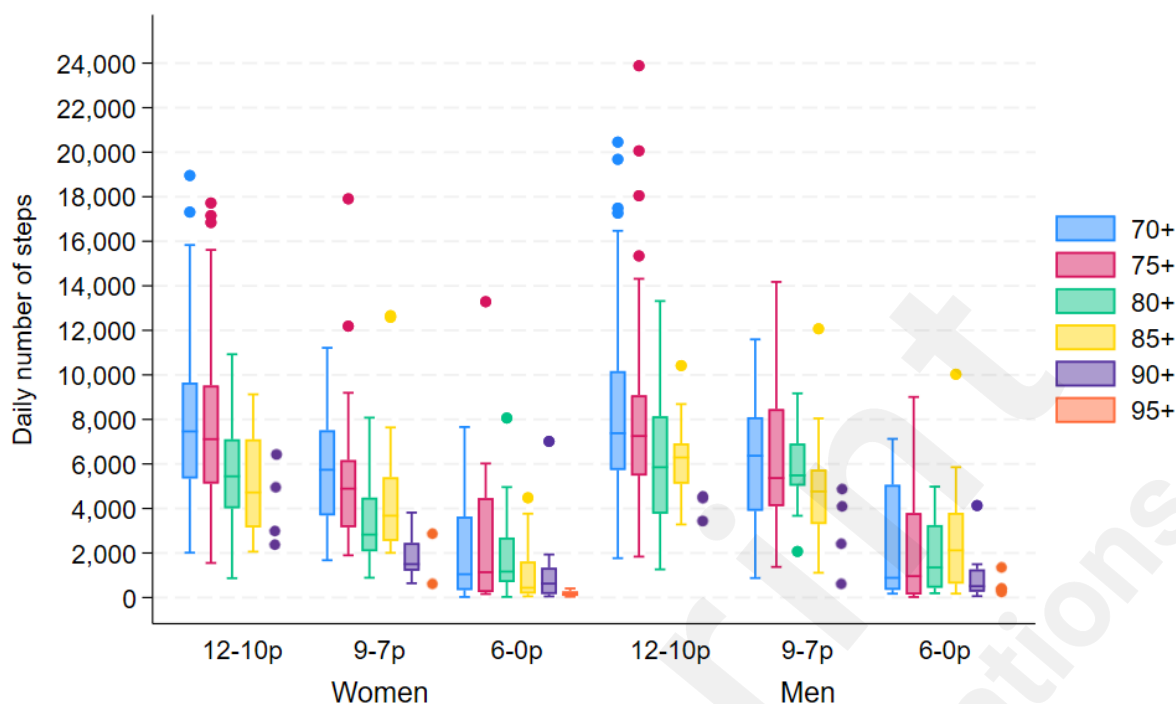


Figure 1. Box plot of daily number of steps, showing the median and interquartile range (whiskers) of daily steps averaged across all days with walking activity, stratified by age group, sex, and SPPB group. For groups with fewer than 5 participants, individual data points are displayed.

Daily number of steps decreased with higher age and lower SPPB scores for both women and men. Results from the gamma regression analyses examining the effect of age on daily number of steps predict that, for women, daily number of steps decreases gradually until approximately 77 years, before decreasing at an accelerating rate with higher age (see Table S1-S4 in the Multimedia Appendix 1 for detailed results from all gamma regressions). In comparison, men are predicted to have a slower decrease in number of steps up to approximately 80 years, after which the rate of decrease becomes more prominent with increasing age, eventually exceeding the rate of decrease for women. The predicted decrease in daily number of steps from 70 to 71 years was 0.06% for women and 0.006% for men, with the rate of decrease accelerating to 5.6% and 3.6% from 80-81 years, and 14.8% and 15.2% from 90-91 years for women and men, respectively.

Likewise, gamma regressions predicted an accelerating rate of decrease in daily number of steps with poorer SPPB scores, although less prominent than for age. Women showed a larger decrease already in the highest range of the SPPB score, while men decreased more slowly in higher scores before exceeding women's rate of decline in the lowest scores. The predicted decrease in daily number of steps from 12 to 11 points on the SPPB score was 5.45% for women and 1.19% for men, with the decrease escalating to 23.4% and 20.9% from 6 to 5 points, and 34.6% and 44.9% from 1 to 0 points, respectively.

Walking speed

Similar to the findings regarding daily steps, there was large variation in both fast and habitual walking speed, particularly in the younger groups and those with better SPPB scores (see Figure 2 for fast speed and Figure 3 for habitual speed). Furthermore, both fast and habitual speed decreased with increasing age and poorer SPPB score, and women generally walked slower compared to men

(for fast speed (m/s), the median (IQR) was 1.08 (0.91-1.24) and 1.19 (1.03-1.35), respectively, $P<.001$; for habitual speed (m/s), the median (IQR) was 0.80 (0.68-1.01) and 0.91 (0.76-1.12), respectively, $P<.001$).

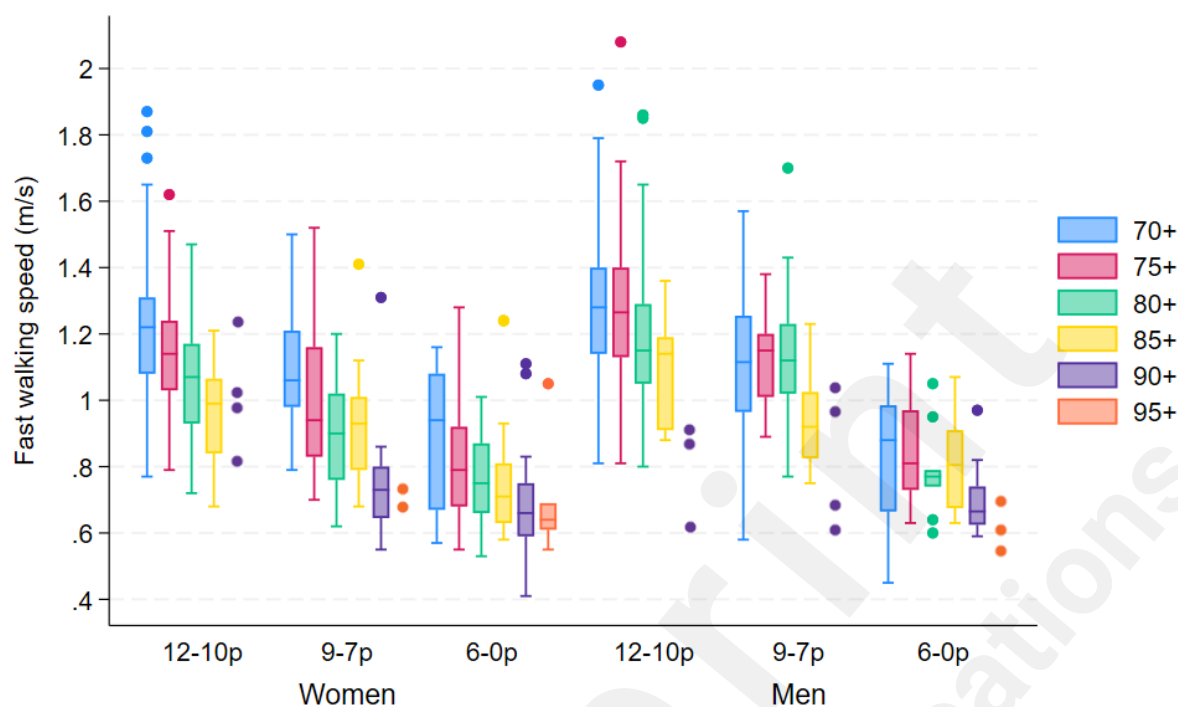


Figure 2. Box plot of fast speed, showing the between-subject median and interquartile range of the within-subject 95th percentile of gait speed (m/s), stratified by age group, sex, and SPPB group. For groups with fewer than 5 participants, individual data points are displayed.

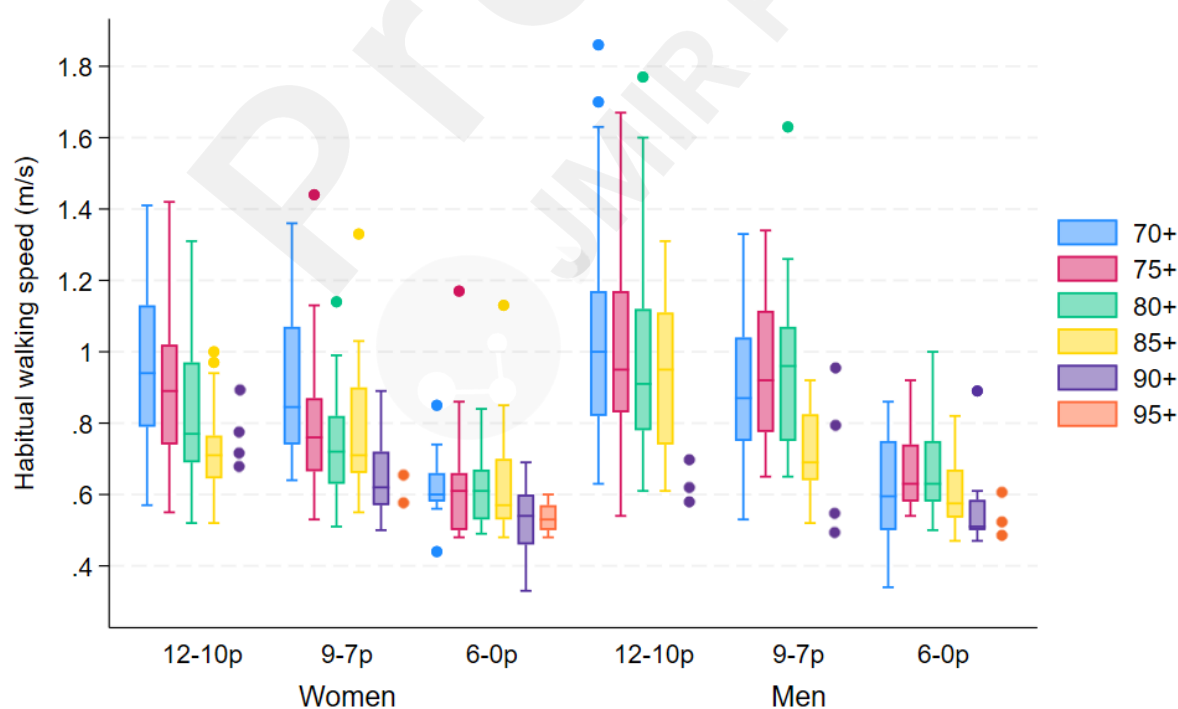


Figure 3. Box plot of habitual walking speed, showing the between-subject median and interquartile range of the within-subject mode of gait speed (m/s), stratified by age group, sex, and SPPB group.

For groups with fewer than 5 participants, individual data points are displayed.

Overall, both fast and habitual walking speeds were predicted to decrease at an accelerating rate with age. However, both fast and habitual speed were predicted to decrease evenly across age for women, but to have a slow initial decline and steeper decline with higher age for men, similar to the predicted decline for daily number of steps with age. In other words, women experience a more prominent decline at an earlier age compared to men, the latter decreasing at a slower rate until approximately 80 years. From 70-71 years, women's fast speed was predicted to decrease by 0.97% and their habitual speed with 1.13%, with the decrease accelerating to 2.16% and 2.20% from 80 to 81 years, and 2.55% and 2.51% from 90 to 91 years for fast and habitual speed, respectively. In contrast, men were predicted to have an initial decrease of only 0.02% for fast speed and 0.01% for habitual speed, accelerating to 1.88% and 1.69% from 80 to 81, and 5.12% and 5.42% from 90 to 91, respectively. With decrease in SPPB score, an exponential decrease was predicted for in both fast and habitual speed for both sexes. In other words, results indicated a rapid initial decrease in gait speed moving from 12 points downwards, with a diminishing rate of decrease moving down the scale. Per 1-point decrement in SPPB score, women's fast speed was predicted to decrease by 5.06% and their habitual speed with 5.15%. For men, the predicted decrease per 1-point decrement was 5.44% for fast speed and 5.29% for habitual speed.

Cadence

Although there was overall large variation in cadence within all age and SPPB groups, both fast and habitual cadence remained stable up to higher ages compared to daily number of steps and speed. Furthermore, women had an overall higher cadence compared to men (fast cadence (steps/min), medians 107.9 (IQR 103.3-112.2) and 103.3 (IQR 99.1-107.6), respectively, $P < .001$; habitual cadence (steps/min), medians 92.1 (IQR 86.8-97) and 86.4 (IQR 82.4-91.1), respectively, $P < .001$) (see Figure 4 for fast cadence and Figure 5 for habitual cadence).

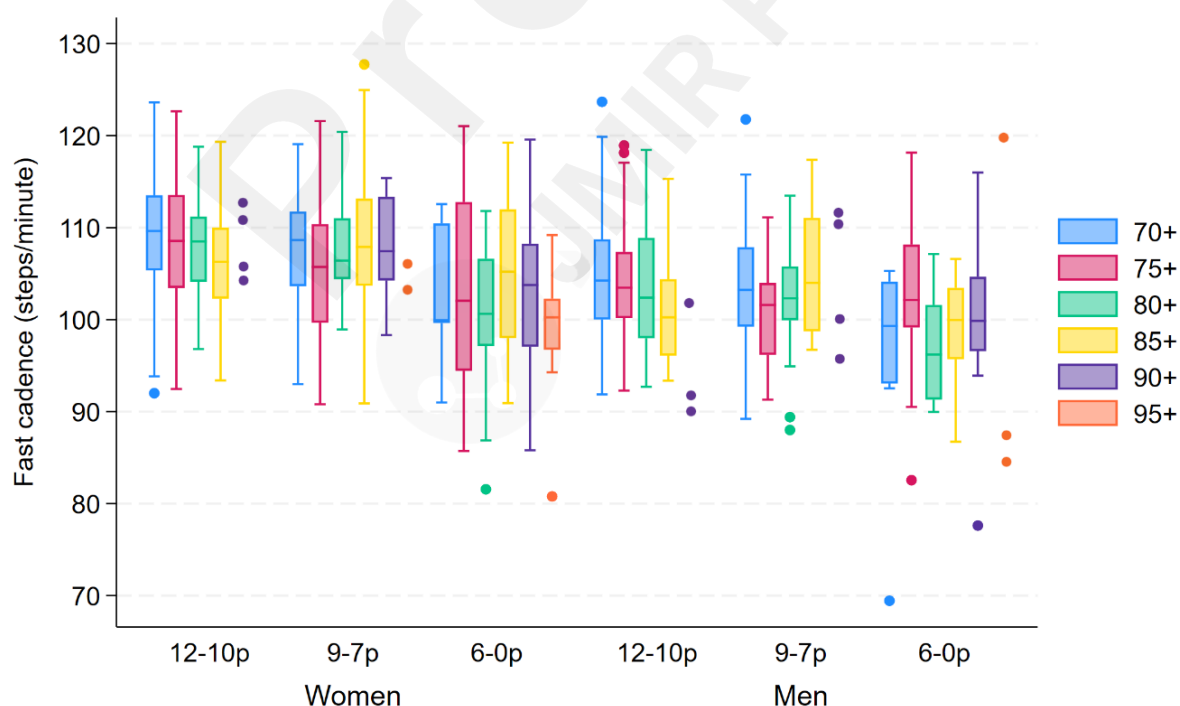


Figure 4. Box plot of fast cadence, showing the between-subject median and interquartile range of the within-subject 95th percentile of cadence (steps/minute), stratified by age group, sex, and SPPB

group. For groups with fewer than 5 participants, individual data points are displayed.

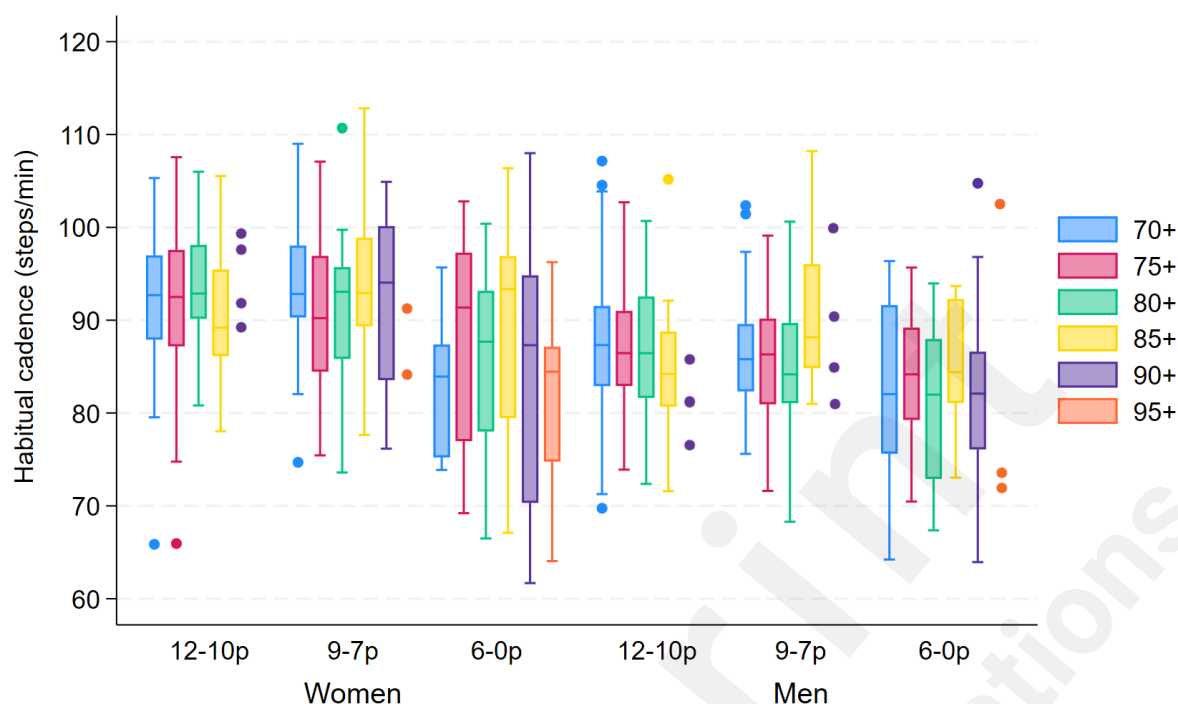


Figure 5. Box plot of habitual cadence, showing the between-subject median and interquartile range of the within-subject mode of cadence (steps/minute), stratified by age group, sex, and SPPB group. For groups with fewer than 5 participants, individual data points are displayed.

With increasing age, fast cadence decreased slowly for both women and men, with a decrease of 0.20% and 0.25% per 1-year increase in age, respectively. Results indicated virtually no decrease in habitual cadence until approximately age 85-90 for both women and men, followed by a steep decline after age 90. From 70 to 71 years, habitual cadence decreased by <0.001% for both women and men, with the rate of decrease accelerating to 0.04% and 0.003% from 80 to 81, and 0.88% and 1.18% from 90 to 91, respectively.

With a decrease in SPPB score, fast cadence decreased exponentially for both women and men, with an overall larger effect for women than men. For every 1-point decrement in the SPPB score, fast cadence was predicted to decrease by 0.69% for women and 0.50% for men. However, habitual cadence was predicted to decrease at an accelerating rate for every decrement in SPPB score for both sexes. In other words, the habitual cadence remained more stable in the higher scores before decreasing at an accelerating rate towards the lowest scores, particularly for men. The decrease in habitual cadence from 12 to 11 points was 0.18% for women and 0.02% for men, with the rate of decrease accelerating to 0.98% and 0.62% from 6 to 5 points, and 1.64% and 1.77%, respectively.

Maximum WB distance

The maximum distance covered in a single WB showed a similar pattern as daily steps and speed, with large variation particularly in the youngest age groups and those with the highest SPPB scores (see Figure 6). Additionally, higher SPPB score and younger age showed an overall longer maximum distance, and women generally covered a shorter maximum distance (m) than men (medians 615.4 (IQR 229.6-1332.6) and 869.8 (IQR 365.6-1724.1), respectively, $P < .001$).

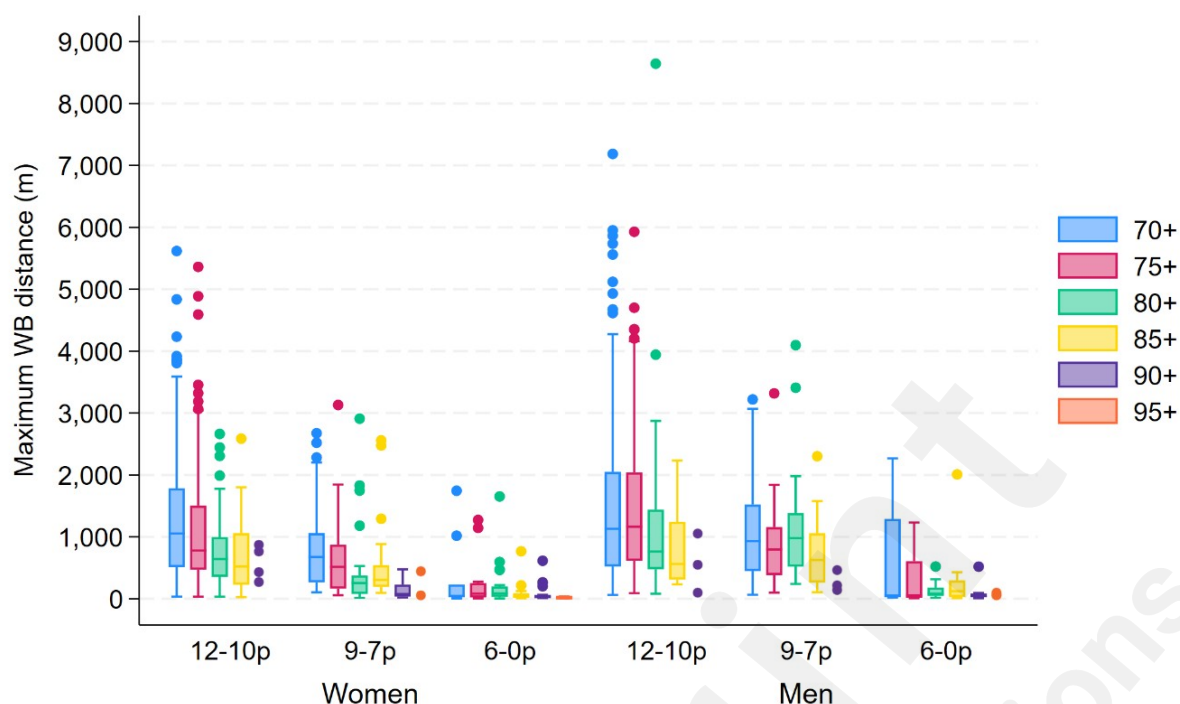


Figure 6. Box plot of maximum walking bout distance, showing the between-subject median and interquartile range of the within-subject maximum WB distance (m), stratified by age groups, sex, and SPPB groups. For groups with fewer than 5 participants, individual data points are displayed.

For maximum WB distance, women initially exhibited an even decrease before stabilizing between a median of 10 and 40 meters after the age of 90. Interestingly, although men's maximum WB distance initially decreased gradually as well, the rate of change subsequently accelerated from around 80 years, ultimately leading to men having a steeper decrease in older ages than women. However, men's maximum WB distance did not get below a median of 40 meters until the age of 93. The predicted decrease in maximum WB distance from 70 to 71 years was 0.28% for women and 0.01% for men, with the decline accelerating to 8.14% and 5.13% from 80 to 81 years, and 16.47% and 20.29% for 90 to 91 years, respectively.

As observed in Figure 6, both women and men had lower maximum WB distances with lower SPPB scores. Women showed a relatively even decrease with lower scores, while men to a larger degree maintained a higher maximum WB distance despite lower SPPB scores, dropping to low WB distances only in the highest age groups. Gamma regression analysis predicted a decrease in maximum WB distance of 11.74% for women and 2.97% for men when the SPPB score decreased from 12 to 11 points, with the rate of decrease accelerating to 28.56% and 26.26% from 6 to 5 points, and 36.11% and 46.16% from 1 to 0 points, respectively.

Discussion

In contrast to the rich literature on lab-based walking assessment, knowledge about daily life walking performance of the older part of the population is scarce. Hence, the main objective of the current study was to describe how older adults walk in daily life in relation to age, sex, and physical function in a large sample covering a wide range in age and physical function. Overall, older adults showed large variation in how and how much they walked in daily life. This variation was found across age, sex, and physical function, and was particularly large among younger participants and those with better physical function. Furthermore, results showed that daily life walking was more strongly related to physical function than to age itself until the oldest ages, and differed significantly between

sexes. Surprisingly, older adults maintained their habitual way of walking up to high ages.

Consistent with earlier research (e.g. Orendurff et al. [20]), we found that the majority of WBs in daily life are very short (less than 10 seconds), and for the older adults in the current study, a meager 6% of WBs lasted more than 30 seconds. Nevertheless, the total walking time in WBs shorter than 30 seconds exceeded that of bouts longer than 30 seconds, indicating that on average, older adults accumulate the majority of their walking time in short bouts.

Our results also highlighted interesting differences between men and women. Women had a higher proportion of, and accumulated more time in, bouts shorter than 10 seconds compared to men. In contrast, for all WB duration categories longer than 10 seconds, men's accumulated time exceeded women's. Moreover, we found that women generally had fewer daily steps than men, except in the age range of 70-79 years where women had a slightly higher amount of daily steps. The latter is consistent with previous studies that found higher daily step counts for women compared to men in age groups 45-79 [21] and 60-79 [22]. However, as our study included older adults up to 105 years, we were able to show that from age 80, men take a higher amount of daily steps than women, accumulated particularly in walking bouts over 1 minute. Furthermore, women generally walked at slower gait speeds than men across the entire age range, consistent with previous findings from both in-lab [11,39,40] and daily life measurements [21,22,41]. Relatedly, the maximum distance covered within a WB was also shorter for women than men. This stands in contrast to the findings of Kiselev et al., who reported that women walked significantly longer maximum (coherent) distances compared to men [22]. Discrepancies between these results might partly be due to the younger cohort (60-79 years) in Kiselev et al. compared to the current study, which ranged from 70 to 105. Overall, cadence was higher for women compared to men, as found in previous studies as well [39-41]. The sex difference in cadence is likely related to women on average being shorter than men, leading to shorter step lengths and potentially compensating through increased step frequency to obtain a satisfactory gait speed [39,40].

Daily life walking in relation to age

Having successfully included a large sample with a wide age range allowed us to investigate in detail how daily life walking differs across age. Overall, gait speed decreased with increased age, consistent with previous findings from both lab-based assessments [8,10,11,18,40,42,43] and daily life measurements [18,21]. Interestingly, our results highlight that changes with increased age are rarely linear but accelerate with higher age. With increased age, the daily number of steps, walking speed, and maximum WB distance showed a slow initial decrease at younger ages before decreasing at an accelerating rate, but at different rates for women and men. Compared to men, women showed a more pronounced decrease in daily number of steps, speed, and maximum distance from younger ages. For both sexes, the rate of decline accelerated with increased age, eventually resulting in a higher rate of change for men at the highest ages.

In contrast to our non-linear findings on changes in daily steps, Kiselev et al. found age to predict a steady decrease in daily life steps, gait speed, and maximum coherent distance [22]. However, as they performed a linear regression analysis on younger adults (22-36 years, n=118) and older adults (60-79 years, n=436), their results may represent an overall difference between the younger and older adults, rather than capturing potential non-linear trends in the data or changes occurring after the age of 79.

Consistent with our findings in daily life walking, Ko et al.'s lab-based gait assessment found the decrease in both habitual and fast gait speed to get increasingly pronounced with higher age [42]. Other lab-based studies showed a larger decrease in self-selected walking speed with age for healthy, older men compared to women [11] or a slower decrease in fast speed for men compared to women [43], both consistent with our findings in daily life gait. Although the overall change in gait speed

was larger for men in the current study, the initial decrease was more prominent for women. These sex-specific trends correspond with those found by Obuchi and colleagues regarding daily life walking speed in Japanese adults [41].

Notably, both fast and habitual cadence remained far more stable up to high age in both sexes than the other gait metrics. Fast cadence showed a slightly accelerating decrease with age for women, while men showed a more gradual decrease throughout, but both showing little change overall. Furthermore, both sexes maintained their habitual cadence largely until 85-90 years of age, after which the decrease accelerated drastically. With women's habitual cadence remaining stable until approximately age 90 and habitual speed decreasing in the same period, the maintenance of cadence may at least partially have been achieved through a compensation strategy involving fast stepping to compensate for reduced stride length [39,40].

Daily life walking in relation to physical function

As expected, daily life gait metrics decreased with decreased physical function, consistent with earlier findings in a lab-based study that found lower gait speeds with lower SPPB scores irrespective of age group (70-79 vs. 80+ years) [10]. Whereas increased age in our study largely showed small changes initially that accelerated towards the highest ages especially in men, poorer physical function led to an exponential or close-to-linear decrease in all gait metrics apart from habitual cadence. Overall, a 1-point decrement in SPPB score corresponded to a larger decrease in gait metrics than a 1-year increase in age, suggesting that daily life walking performance is affected more by changes in functional ability than by aging per se. Our findings are consistent with the conclusion of Kiselev et al. [22] that changes in gait cannot be explained adequately by age, sex, height and BMI alone, and provide evidence that physical function may need to be added to the mix. In contrast to our findings, van Gameren et al. [13] found only weak correlations between SPPB scores and walking speed and number of steps when investigating daily life gait quality and quantity in community-dwelling older adults with an increased fall risk. However, they excluded WB shorter than 10 seconds, which represents over 60% of all WBs in our dataset.

Overall, cadence remained rather stable in our study except for the lowest levels of physical function. Men maintained both their fast and habitual cadence levels until an SPPB score of 3 points, after which there was a distinct decrease. Women's habitual cadence remained stable across the highest levels of physical function before decreasing by on average 5 steps/minute for those with an SPPB score of 6 or lower. In contrast, women's fast cadence decreased only about 10 steps/minute in total from 12 points to 3 points, after which it increased again for those with scores lower than 3 points. This may potentially reflect an increase in short, quick steps to maintain balance during gait.

In the current study, physical function was assessed using the SPPB test, which is known for its ceiling effect among the best functioning older adults [44,45]. This likely occurred in our study as well, as the majority of participants (71.6%) were in the highest scoring group, and 42.5% scored the maximum of 12 points. To the extent that changes in daily life gait in those with maximum SPPB score can be relevant, future studies should include tests that can differentiate between the best functioning older adults.

Compared to women, men generally have higher muscle strength and perform better on tests of physical function, also in old age [30,44,45]. When investigating physical performance in relation to age, sex, and educational level, Melsæther et al. [30] found that the SPPB scores of men exceeded those of women, with an accelerating decrease with increasing age for both sexes. Along with the findings of the current study, this indicates that men maintain both their physical function and how they walk in daily life into higher ages than women. Furthermore, these findings further support that how older adults walk is more strongly related to physical function than to chronological age as such.

Methodological considerations

The two greatest strengths of the current study are the sample and the use of validated algorithms to derive gait metrics. Compared to previous study samples, HUNT4 Trondheim 70+ consists of a large number of older adults with a wide range in age and function and an almost even sex distribution. Furthermore, all DMOs investigated in the current study were comprehensively validated and shown to have moderate to good performance indicators (sensitivity, specificity, accuracy, and reliability) in older adults and various patient populations [26,27], as well as in an older and more fragile cohort of hip fracture patients [46]. In general, algorithm performances were better when excluding WBs less than 10 seconds, and in the group with better physical function [27,46]. However, with the majority of WBs lasting less than 10 seconds, we did not exclude them from the analyses as they are a considerable part of how older adults walk. Furthermore, although the validated metrics allowed for short breaks (up to 3 seconds) within a WB, we excluded short breaks to get more accurate and robust estimates of the gait metrics particularly for short bouts and for those with poor physical function. The estimation of speed and cadence in particular become more accurate as preventing underestimation due to the inclusion of non-walking time within WBs. On the other hand, excluding breaks could potentially cause an underestimation of WB duration and WB distance, as they can divide a walking period into multiple WBs. Although daily life walking is likely to be interrupted often due to environmental obstacles, complexity of activities or short breaks, further research should investigate how the frequency and duration of breaks influence estimations of the duration and distance covered in real-world walking.

Conclusion

Based on a large study sample with a wide range of age and functional level, this study provides new insights into how older adults walk in daily life. First of all, there is persistent large variation in how older adults walk both across and within age groups up to the highest ages. Furthermore, although gait metrics generally decrease with increased age and decreased physical function, changes are largely non-linear and show relevant differences between men and women, with men maintaining how they walk in daily life up to a higher age than women, but with accelerated change at the highest ages. Surprisingly, cadence remained remarkably stable compared to other gait characteristics in both men and women throughout most ages and levels of physical function. And although most walking bouts are very short, the total accumulated walking time in bouts shorter than 30 seconds exceeds that in longer walking bouts. Finally, daily life walking performance is affected more by changes in functional ability than by increased age per se. Future research can build upon these findings, implementing daily life mobility assessment in both clinical studies and patient follow-up to monitor changes in gait that may point to underlying changes in health condition and function, while considering the impact of short WBs and relevant group and sex differences in how older adults walk in daily life.

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Conflicts of interest

None declared

Abbreviations

BMI: body mass index.

DMO: digital mobility outcome

HUNT: the Trøndelag Health Study

MoCA: the Montreal Cognitive Assessment.

SPPB: Short Physical Performance Battery

WB: walking bout

References

1. Viceconti M, Tome M, Dartee W, Knezevic I, Hernandez Penna S, Mazzà C, Caulfield B, Garcia-Aymerich J, Becker C, Maetzler W, Troosters T, Sharrack B, Davico G, Corriol-Rohou S, Rochester L, the Mobilise-D Consortium. On the use of wearable sensors as mobility biomarkers in the marketing authorization of new drugs: A regulatory perspective. *Front Med Frontiers*; 2022 Sep 21;9. doi: 10.3389/fmed.2022.996903. PMID: 36213641
2. Delgado-Ortiz L, Polhemus A, Keogh A, Sutton N, Remmele W, Hansen C, Kluge F, Sharrack B, Becker C, Troosters T, Maetzler W, Rochester L, Frei A, Puhan MA, Garcia-Aymerich J. Listening to the patients' voice: a conceptual framework of the walking experience. *Age and Ageing* 2023 Jan 1;52(1):afac233. doi: 10.1093/ageing/afac233. PMID: 36729471
3. Ageing Europe - statistics on health and disability. Available from: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Ageing_Europe_-_statistics_on_health_and_disability [accessed Nov 22, 2024]
4. Vall-Garcia E, Delgado-Ortiz L, Alcock L, Coll-Planas L, García-Navarro JA, Iwarsson S, Jansà JM, Jansen C-P, Koch S, Schwartz S, Rantakokko M, Sarukhan A, van Staaldin W, Rochester L, Garcia-Aymerich J. Aging towards walkable futures: insights from a multidisciplinary workshop held in Barcelona, Spain. *BMC Public Health* 2025 Jan 17;25(1):195. doi: 10.1186/s12889-024-21223-z. PMID: 39825288
5. Wohlrab M, Klenk J, Delgado-Ortiz L, Chambers M, Rochester L, Zuchowski M, Schwab M, Becker C, Jaeger SU. The value of walking: a systematic review on mobility and healthcare costs. *European Review of Aging and Physical Activity* 2022 Dec 29;19(1):31. doi: 10.1186/s11556-022-00310-3. PMID: 36581809
6. Ungvari Z, Fazekas-Pongor V, Csiszar A, Kunutsor SK. The multifaceted benefits of walking for healthy aging: from Blue Zones to molecular mechanisms. *GeroScience* 2023 Dec 1;45(6):3211–3239. doi: 10.1007/s11357-023-00873-8. PMID: 37495893
7. Studenski S, Perera S, Patel K, Rosano C, Faulkner K, Inzitari M, Brach J, Chandler J, Cawthon P, Connor EB, Nevitt M, Visser M, Kritchevsky S, Badinelli S, Harris T, Newman AB, Cauley J, Ferrucci L, Guralnik J. Gait Speed and Survival in Older Adults. *JAMA* 2011 Jan 5;305(1):50–58.

doi: 10.1001/jama.2010.1923. PMID: 21205966

8. Artaud F, Singh-Manoux A, Dugravot A, Tzourio C, Elbaz A. Decline in Fast Gait Speed as a Predictor of Disability in Older Adults. *Journal of the American Geriatrics Society* 2015;63(6):1129–1136. doi: 10.1111/jgs.13442. PMID: 26096387
9. Cesari M, Kritchevsky SB, Penninx BWHJ, Nicklas BJ, Simonsick EM, Newman AB, Tylavsky FA, Brach JS, Satterfield S, Bauer DC, Visser M, Rubin SM, Harris TB, Pahor M. Prognostic Value of Usual Gait Speed in Well-Functioning Older People—Results from the Health, Aging and Body Composition Study. *Journal of the American Geriatrics Society* 2005;53(10):1675–1680. doi: 10.1111/j.1532-5415.2005.53501.x. PMID: 16181165
10. Dapp U, Vinyard D, Golgert S, Krumpoch S, Freiburger E. Reference values of gait characteristics in community-dwelling older persons with different physical functional levels. *BMC Geriatrics* 2022 Aug 29;22(1):713. doi: 10.1186/s12877-022-03373-0. PMID: 36038832
11. Elshehabi M, Del Din S, Hobert MA, Warmerdam E, Sünkel U, Schmitz-Hübsch T, Behncke LM, Heinzel S, Brockmann K, Metzger FG, Schlenstedt C, Rochester L, Hansen C, Berg D, Maetzler W. Walking parameters of older adults from a lower back inertial measurement unit, a 6-year longitudinal observational study. *Frontiers in Aging Neuroscience* 2022;14. PMID: 36172482
12. Brown JC, Harhay MO, Harhay MN. Walking cadence and mortality among community-dwelling older adults. *J Gen Intern Med* 2014 Sep;29(9):1263–1269. PMID:24934147
13. van Gameren M, Voorn PB, Bossen D, Hoozemans MJM, Bruijn SM, Bosmans JE, Visser B, Pijnappels M. The Short Physical Performance Battery does not correlate with daily life gait quality and quantity in community-dwelling older adults with an increased fall risk. *Gait & Posture* 2024 Oct 1;114:78–83. doi: 10.1016/j.gaitpost.2024.09.005. PMID: 39276702
14. Van Ancum JM, van Schooten KS, Jonkman NH, Huijben B, van Lummel RC, Meskers CGM, Maier AB, Pijnappels M. Gait speed assessed by a 4-m walk test is not representative of daily-life gait speed in community-dwelling adults. *Maturitas* 2019 Mar;121:28–34. PMID:30704562
15. Reijnierse EM, Geelen SJG, van der Schaaf M, Visser B, Wüst RCI, Pijnappels M, Meskers CGM. Towards a core-set of mobility measures in ageing research: The need to define mobility and its constructs. *BMC Geriatrics* 2023 Apr 6;23(1):220. doi: 10.1186/s12877-023-03859-5. PMID: 37024827
16. Urbanek JK, Zipunnikov V, Harris T, Crainiceanu C, Harezlak J, Glynn NW. Validation of Gait Characteristics Extracted From Raw Accelerometry During Walking Against Measures of Physical Function, Mobility, Fatigability, and Fitness. *The Journals of Gerontology: Series A* 2018 Apr 17;73(5):676–681. doi: 10.1093/gerona/glx174. PMID: 28958000
17. Warmerdam E, Hausdorff JM, Atrsaai A, Zhou Y, Mirelman A, Aminian K, Espay AJ, Hansen C, Evers LJW, Keller A, Lamothe C, Pilotto A, Rochester L, Schmidt G, Bloem BR, Maetzler W. Long-term unsupervised mobility assessment in movement disorders. *The Lancet Neurology* 2020 May 1;19(5):462–470. doi: 10.1016/S1474-4422(19)30397-7. PMID: 32059811
18. Takayanagi N, Sudo M, Yamashiro Y, Lee S, Kobayashi Y, Niki Y, Shimada H. Relationship

- between Daily and In-laboratory Gait Speed among Healthy Community-dwelling Older Adults. Sci Rep Nature Publishing Group; 2019 Mar 5;9(1):3496. doi: 10.1038/s41598-019-39695-0. PMID: 30837520
19. Urbanek JK, Roth DL, Karas M, Wanigatunga AA, Mitchell CM, Juraschek SP, Cai Y, Appel LJ, Schrack JA. Free-Living Gait Cadence Measured by Wearable Accelerometer: A Promising Alternative to Traditional Measures of Mobility for Assessing Fall Risk. *J Gerontol A Biol Sci Med Sci* 2022 Jan 13;78(5):802–810. PMID:35029661
 20. Orendurff M, Schoen J, Bernatz G, Segal A, Klute G. How humans walk: Bout duration, steps per bout, and rest duration. *Journal of rehabilitation research and development* 2008 Feb 1;45:1077–89. doi: 10.1682/JRRD.2007.11.0197. PMID: 19165696
 21. Chan LLY, Lord SR, Brodie MA. Daily-Life Walking Speed, Quality and Quantity Derived from a Wrist Motion Sensor: Large-Scale Normative Data for Middle-Aged and Older Adults. *Sensors Multidisciplinary Digital Publishing Institute*; 2024 Jan;24(16):5159. doi: 10.3390/s24165159. PMID: 39204870
 22. Kiselev J, Nuritdinow T, Spira D, Buchmann N, Steinhagen-Thiessen E, Lederer C, Daumer M, Demuth I. Long-term gait measurements in daily life: Results from the Berlin Aging Study II (BASE-II). Tan MP, editor. *PLoS ONE* 2019 Dec 11;14(12):e0225026. doi: 10.1371/journal.pone.0225026. PMID: 31825966
 23. Yin S, Du L, He Q, Pan Y, Li T, Ren X, Chen S, Zhang X. Walking more, not faster, is associated with bone health in China of community-dwelling older women:A cross-sectional study. *Prev Med* 2023 Oct;175:107722. PMID:37783314
 24. Ando S, Higuchi Y, Kitagawa T, Murakami T, Todo E, Ueda T. Instrumental activities of daily living and number of daily steps in frail older females. *J Phys Ther Sci* 2019;31(10):780–784. doi: 10.1589/jpts.31.780. PMID: 31645806
 25. Weiss A, Brozgol M, Dorfman M, Herman T, Shema S, Giladi N, Hausdorff JM. Does the Evaluation of Gait Quality During Daily Life Provide Insight Into Fall Risk? A Novel Approach Using 3-Day Accelerometer Recordings. *Neurorehabil Neural Repair SAGE Publications Inc STM*; 2013 Oct 1;27(8):742–752. doi: 10.1177/1545968313491004. PMID: 23774124
 26. Kirk C, Küderle A, Micó-Amigo ME, Bonci T, Paraschiv-Ionescu A, Ullrich M, Soltani A, Gazit E, Salis F, Alcock L, Aminian K, Becker C, Bertuletti S, Brown P, Buckley E, Cantu A, Carsin A-E, Caruso M, Caulfield B, Cereatti A, Chiari L, D'Ascanio I, Garcia-Aymerich J, Hansen C, Hausdorff JM, Hiden H, Hume E, Keogh A, Kluge F, Koch S, Maetzler W, Megaritis D, Mueller A, Niessen M, Palmerini L, Schwickert L, Scott K, Sharrack B, Sillén H, Singleton D, Vereijken B, Vogiatzis I, Yarnall AJ, Rochester L, Mazzà C, Eskofier BM, Del Din S. Mobilise-D insights to estimate real-world walking speed in multiple conditions with a wearable device. *Sci Rep* 2024 Jan 19;14:1754. PMID:38243008
 27. Micó-Amigo ME, Bonci T, Paraschiv-Ionescu A, Ullrich M, Kirk C, Soltani A, Küderle A, Gazit E, Salis F, Alcock L, Aminian K, Becker C, Bertuletti S, Brown P, Buckley E, Cantu A, Carsin A-E, Caruso M, Caulfield B, Cereatti A, Chiari L, D'Ascanio I, Eskofier B, Fernstad S, Froehlich M,

- Garcia-Aymerich J, Hansen C, Hausdorff JM, Hiden H, Hume E, Keogh A, Kluge F, Koch S, Maetzler W, Megaritis D, Mueller A, Niessen M, Palmerini L, Schwickert L, Scott K, Sharrack B, Sillén H, Singleton D, Vereijken B, Vogiatzis I, Yarnall AJ, Rochester L, Mazzà C, Del Din S, for the Mobilise-D consortium. Assessing real-world gait with digital technology? Validation, insights and recommendations from the Mobilise-D consortium. *Journal of NeuroEngineering and Rehabilitation* 2023 Jun 14;20(1):78. doi: 10.1186/s12984-023-01198-5. PMID: 37316858
28. Åsvold BO, Langhammer A, Rehn TA, Kjellvik G, Grøntvedt TV, Sørgerd EP, Fenstad JS, Heggland J, Holmen O, Stuifbergen MC, Vikjord SAA, Brumpton BM, Skjellegrind HK, Thingstad P, Sund ER, Selbæk G, Mork PJ, Rangul V, Hveem K, Næss M, Krokstad S. Cohort Profile Update: The HUNT Study, Norway. *International Journal of Epidemiology* 2023 Feb 1;52(1):e80–e91. doi: 10.1093/ije/dyac095. PMID: 35578897
29. Gjøra L, Strand BH, Bergh S, Borza T, Brækhus A, Engedal K, Johannessen A, Kvello-Alme M, Krokstad S, Livingston G, Matthews FE, Myrstad C, Skjellegrind H, Thingstad P, Aakhus E, Aam S, Selbæk G. Current and Future Prevalence Estimates of Mild Cognitive Impairment, Dementia, and Its Subtypes in a Population-Based Sample of People 70 Years and Older in Norway: The HUNT Study. *Journal of Alzheimer's Disease* 2021 Feb 2;79(3):1213. PMID:33427745
30. Melsæter KN, Tangen GG, Skjellegrind HK, Vereijken B, Strand BH, Thingstad P. Physical performance in older age by sex and educational level: the HUNT Study. *BMC Geriatr* 2022 Oct 26;22(1):821. doi: 10.1186/s12877-022-03528-z. PMID: 36289472
31. Guralnik JM, Simonsick EM, Ferrucci L, Glynn RJ, Berkman LF, Blazer DG, Scherr PA, Wallace RB. A Short Physical Performance Battery Assessing Lower Extremity Function: Association With Self-Reported Disability and Prediction of Mortality and Nursing Home Admission. *Journal of Gerontology* 1994 Mar 1;49(2):M85–M94. doi: 10.1093/geronj/49.2.M85. PMID: 8126356
32. Nasreddine ZS, Phillips NA, Bédirian V, Charbonneau S, Whitehead V, Collin I, Cummings JL, Chertkow H. The Montreal Cognitive Assessment, MoCA: A Brief Screening Tool For Mild Cognitive Impairment. *Journal of the American Geriatrics Society* 2005;53(4):695–699. doi: 10.1111/j.1532-5415.2005.53221.x. PMID: 15817019
33. Pagnamenta S, Grønvik KB, Aminian K, Vereijken B, Paraschiv-Ionescu A. Putting Temperature into the Equation: Development and Validation of Algorithms to Distinguish Non-Wearing from Inactivity and Sleep in Wearable Sensors. *Sensors Multidisciplinary Digital Publishing Institute*; 2022 Jan;22(3):1117. doi: 10.3390/s22031117. PMID: 35161862
34. Paraschiv-Ionescu A, Newman CJ, Carcreff L, Gerber CN, Armand S, Aminian K. Locomotion and cadence detection using a single trunk-fixed accelerometer: validity for children with cerebral palsy in daily life-like conditions. *Journal of NeuroEngineering and Rehabilitation* 2019 Feb 4;16(1):24. doi: 10.1186/s12984-019-0494-z. PMID: 30717753
35. Paraschiv-Ionescu A, Soltani A, Aminian K. Real-world speed estimation using single trunk IMU: methodological challenges for impaired gait patterns. 2020 42nd Annual International Conference of the IEEE Engineering in Medicine & Biology Society (EMBC) 2020. p. 4596–4599. doi: 10.1109/EMBC44109.2020.9176281

36. Soltani A, Aminian K, Mazza C, Cereatti A, Palmerini L, Bonci T, Paraschiv-Ionescu A. Algorithms for Walking Speed Estimation Using a Lower-Back-Worn Inertial Sensor: A Cross-Validation on Speed Ranges. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 2021;29:1955–1964. doi: 10.1109/TNSRE.2021.3111681. PMID: 34506286
37. Zijlstra W, Hof AL. Assessment of spatio-temporal gait parameters from trunk accelerations during human walking. *Gait & Posture* 2003 Oct 1;18(2):1–10. doi: 10.1016/S0966-6362(02)00190-X. PMID: 14654202
38. Guralnik JM, Ferrucci L, Pieper CF, Leveille SG, Markides KS, Ostir GV, Studenski S, Berkman LF, Wallace RB. Lower Extremity Function and Subsequent Disability: Consistency Across Studies, Predictive Models, and Value of Gait Speed Alone Compared With the Short Physical Performance Battery. *The Journals of Gerontology: Series A* 2000 Apr 1;55(4):M221–M231. doi: 10.1093/gerona/55.4.M221. PMID: 10811152
39. Mobbs L, Fernando V, Fonseka RD, Natarajan P, Maharaj M, Mobbs RJ. Normative Database of Spatiotemporal Gait Metrics Across Age Groups: An Observational Case-Control Study. *Sensors (Basel)* 2025 Jan 20;25(2):581. PMID:39860951
40. Auvinet B, Berrut G, Touzard C, Moutel L, Collet N, Chaleil D, Barrey E. Reference data for normal subjects obtained with an accelerometric device. *Gait & Posture* 2002 Oct;16(2):124–134. doi: 10.1016/S0966-6362(01)00203-X. PMID: 12297254
41. Obuchi SP, Kawai H, Murakawa K. Reference value on daily living walking parameters among Japanese adults. *Geriatrics & Gerontology International* 2020;20(7):664–669. doi: 10.1111/ggi.13931. PMID: 32378318
42. Ko S, Stenholm S, Metter EJ, Ferrucci L. Age-associated gait patterns and the role of lower extremity strength – Results from the Baltimore Longitudinal Study of Aging. *Archives of Gerontology and Geriatrics* 2012 Sep 1;55(2):474–479. doi: 10.1016/j.archger.2012.04.004. PMID: 22564361
43. Abdul Jabbar K, Seah W-T, Lau LK, Pang BW-J, Ng DH-M, Tan QL-L, Chen KK, Mallya Ullal J, Ng T-P, Wee S-L. Fast gait spatiotemporal parameters in adults and association with muscle strength – The Yishun study. *Gait & Posture* 2021 Mar 1;85:217–223. doi: 10.1016/j.gaitpost.2021.01.001. PMID: 33610825
44. Bergland A, Strand BH. Norwegian reference values for the Short Physical Performance Battery (SPPB): the Tromsø Study. *BMC Geriatr* 2019 Aug 8;19(1):216. PMID:31395008
45. Tangen GG, Robinson HS. Measuring physical performance in highly active older adults: associations with age and gender? *Aging Clin Exp Res* 2020 Feb;32(2):229–237. PMID:30977080
46. Berge MA, Paraschiv-Ionescu A, Kirk C, Küderle A, Micó-Amigo E, Becker C, Cereatti A, Del Din S, Engdal M, Garcia-Aymerich J, Grønvik KB, Hansen C, Hausdorff JM, Helbostad JL, Jansen C-P, Johnsen LG, Koch S, Maetzler W, Megaritis D, Müller A, Rochester L, Schwickert L, Taraldsen K, Vereijken B. Walking Towards Recovery: Accuracy and Reliability of Real-World Digital Mobility Outcomes in Older Adults After Hip Fracture (Preprint). 2024. doi: 10.2196/preprints.67792



Supplementary Files

Multimedia Appendixes

Results from gamma regressions with log link for each gait metric with age or SPPB score.

URL: <http://asset.jmir.pub/assets/944840649feaf843cd3b55ec99da8563.docx>