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► **To cite this version:**

Félicia Santos, Adeline Renuy, Anna Ozguler, Céline Ribet, Marcel Goldberg, et al.. Norms for Usual and Fast Walking Speed in Adults 45-69 Years Old From the French General Population: Constances Study. *Journal of the American Medical Directors Association*, 2024, 25 (2), pp.266-274. 10.1016/j.jamda.2023.10.001 . hal-04474792

HAL Id: hal-04474792

<https://hal.science/hal-04474792v1>

Submitted on 4 Jun 2024

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Original Study

Norms for Usual and Fast Walking Speed in Adults 45–69 Years Old From the French General Population: Constances Study



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A B S T R A C T

Keywords:

Walking speed
aging
population
reference values
selection bias

Objectives: Walking speed (WS) represents an objective measure of motor function and health. We aimed to develop usual (UWS) and fast WS (FWS) norms for the general population using a regression-based approach, while considering age, sex, height, and education.

Design: Cross-sectional analysis of a population-based study.

Setting and Participants: French Constances study (45–69 years).

Methods: UWS/FWS were measured over 3 m (dynamic start) using photoelectric cells. We addressed selection effects (related to survey sampling and nonresponse) and missing data using a combination of inverse probability weighting (IPW) and multiple imputation (MI). Norms by sex, age, height, and education (<tertiary/≥tertiary) were estimated using a 3-level linear mixed effects model (random effects on center and year) allowing for nonlinear relations that were adjusted for age, sex, height, education, and significant 2-way interactions.

Results: Analyses are based on 44,772 participants (51.2% women) with a mean age of 56.8 years (SE = 0.2) for women and 57.3 years (SE = 0.2) for men, and a mean height of 161.4 cm (SE = 0.1) for women and 174.2 cm (SE = 0.1) for men after IPW/MI. WS estimates decreased after IPW/MI. The mean UWS was 116.9 cm/s (SE = 0.8) in women and 120.7 cm/s (SE = 0.8) in men, and the mean FWS was 168.7 cm/s (SE = 1.0) in women and 182.8 cm/s (SE = 1.2) in men. In the multiaadjusted model, UWS/FWS decreased with age and increased with height and education. Men had faster FWS than women; they had slightly slower UWS than women in the low-education group, but there were no sex differences in the high-education group.

Conclusions and Implications: We developed UWS/FWS norms by age, sex, height, and education for the French general population (45–69 years) that are available through a web app (<https://cesp-proxy2.vjf.inserm.fr/NORMES-VM-EN/>). These norms can be used to identify in midlife persons with lower motor performances than the general population, given their age, sex, height, and education, who are at higher risk of adverse outcomes.

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Funding: The Constances Cohort Study was supported and funded by the French National Health Insurance Fund [Caisse nationale d'assurance maladie (CNAM)]. The Constances Cohort Study is an Infrastructure nationale en Biologie et Santé and benefits from a grant from the French National Agency for Research (ANR-11-INBS-0002). Constances is also partly funded by Merck Sharp & Dohme (MSD) and L'Oréal. None of these funding sources had any role in the design of the study, collection and analysis of data, or decision to publish. Félicia Santos is the recipient of a doctoral grant from Université Paris-Saclay, France.

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<https://doi.org/10.1016/j.jamda.2023.10.001>

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Walking speed (WS) represents a valid, simple, and objective measure of motor performances and individual health, commonly used in clinical and research settings.¹ Slower WS predicts several outcomes (falls, disability, dementia, mortality) and represents one of the main sarcopenia criteria.

In order to compare an individual's performance to a reference population, norms for that population are needed. WS is influenced by individual characteristics (eg, age, sex, height, and education).^{2–4} Previous studies generally provided age- and sex-specific WS norms,^{5,6} whereas fewer considered height,^{7–11} and none considered

education. Most studies included selected participants or convenience samples,⁵ whereas few were representative of the general population^{9,12,13}; in addition, the influence of the sampling method on the accuracy of norms has never been examined.⁶ Finally, although most studies provided norms for usual WS (UWS), few examined fast WS (FWS).^{2,12,14,15}

Traditionally, norms were obtained by splitting samples into subgroups (eg, by age and sex), and estimating test summary statistics within subgroups.¹⁶ More sophisticated regression-based methods have several advantages over the traditional approach,¹⁶ but few studies used them.^{7,8,17}

We estimated UWS and FWS norms in a large sample of French adults aged 45–69 years from the general population using a regression-based approach, while considering age, sex, height, and education. We developed a web application allowing to compare an individual's WS to these norms (<https://cesp-proxy2.vjf.inserm.fr/NORMES-VM-EN/>).

Methods

Participants

We used baseline data from the French population-based cohort Constances that recruited >220,000 participants (2012–2020). Participants from 26 French regions and 21 Health Screening Centers (HSCs) aged 18–69 years old at baseline were drawn from a database including all members of the Régime Général de la Sécurité Sociale (RGSS) health insurance scheme and smaller health insurance schemes that cover health expenses of salaried workers (professionally active, unemployed, retired) and their unemployed partners (>85% of the French population, >55 million people). Demographic and socioprofessional characteristics of these 26 regions is virtually identical to the overall French population.¹⁸

All procedures contributing to this work comply with ethical standards of relevant national and institutional committees on human experimentation and the Helsinki Declaration of 1975 revised in 2008. All procedures were approved by the Institutional Review Board of the French Institute of Health (INSERM). Constances has been approved by the French Data Protection Authority (Commission Nationale de l'Informatique et des Libertés). Written informed consent was obtained from all participants included in the study before data collection began.

Participants were invited using a random sampling scheme with unequal inclusion probabilities, stratified on HSCs, health insurance scheme, age, gender, and socioprofessional categories, in order to overrepresent persons who tend to participate less in surveys. Because of logistical constraints, sampling was performed each year with different probabilities. Sampling rates applied to HSCs each year are calculated in order to obtain a representative sample of the target population (RGSS). Sampling weights were available for years 2013–2017; hence, our analyses are based on participants included over this period. Because participation is likely to be different across strata defined by age, gender, and socioprofessional categories, we adjusted inclusion probabilities according to expected participation rates: for the first round of invitations, we used data from similar surveys to estimate unknown participation probabilities; for subsequent rounds, probabilities were reestimated using data from previous waves. Using this approach, we obtained a sample of participants whose number per strata was proportional to those of the sampling frame, and that has a structure (ie, age, sex, and socioprofessional category) similar to the target population.^{18–20} Participation rate at enrollment was ~7.3%.¹⁸

Participants completed self-administered questionnaires (on lifestyle, health behaviors, medical history, socioprofessional status, and lifetime employment history) and attended HSCs for a medical examination and blood sampling. Participants aged ≥45 years

underwent standardized cognitive and motor tests by trained neuropsychologists.¹⁸

Walking Speed

WS was assessed as part of the standardized cognitive and motor assessments in 17 HSCs using 2 photoelectric cells (PC; Racetime2 kit light radio, MicroGate), placed 3 m apart and connected to a chronometer, at usual (“walk at your habitual pace,” UWS) and fast (“walk as fast as you can without running,” FWS) pace, with a dynamic protocol (1 m of acceleration or deceleration). Time was recorded at the nearest centisecond after 1 trial; we divided 300 cm by time to estimate the WS (cm/s). Participants were invited to attend HSCs with comfortable shoes, and asked to remove them if wearing heels. Walking aids were allowed.

FWS was always faster than UWS. Times <1 second were considered as aberrant (FWS, n = 48; UWS, n = 0) and set to missing.

Covariates

Age, sex, year of invitation, and HSC were available. Height was measured to the nearest centimeter using a gauge.

Education level was self-reported (2011 International Standard Classification of Education, ISCED; [Supplementary Table 1](#)) and dichotomized as low (lower than tertiary: levels 0–4) and high (tertiary or higher: levels 5–8) for several reasons: (1) we aimed to obtain a relatively balanced number of participants within each group so that norms would be estimated with similar precision; (2) this definition allows to categorize persons in a similar way in different countries, as it distinguishes persons who did not engage in academic education from those who did; (3) clinicians may not have the time to carefully collect ISCED education level, while alternatively, it is relatively straightforward to ask a person whether he or she has a tertiary education degree; and (4) differences in WS within the high education group are small, thus suggesting that the relation between WS and education is not linear. We could not examine WS differences within the low-education group because most participants within this group had reached the highest levels (ISCED-3/4).

Additional covariates are described in [Supplementary Table 1](#).

Correction for Survey Sampling, Nonresponse, and Missing Values

We estimated norms for the source population using a combination of inverse probability weighting (IPW) and multiple imputation (MI) to correct for survey sampling, nonresponse, and missing values. To quantify the impact of IPW and MI, we compared WS estimates before and after MI/IPW.

Inverse probability weighting.

We took into account 3 different weights.

- *Sampling weights* (according to the stratified random sampling scheme, 2013–2017).
- Nonresponse is inevitable in surveys that require contacting sampled persons and obtaining their consent to participate; nonresponse results from failure to contact or refusal to volunteer. The 7.3% participation rate is in line with standards for this type of data collection that imposes constraints on participants. Constances participants are in better health compared to the general French population because healthier persons were more likely to participate.²⁰ To correct for selection effects related to nonparticipation, we drew a random control sample of 400,000 invited persons who did not participate, for whom a wide range of characteristics (>100 variables from 4 groups: sociodemographic, health care

consumption, hospitalizations, free health care for chronic conditions) were extracted from the same databases as for participants. The probability of nonresponse was modeled using logistic regression after a backwards selection procedure ($P < .20$) in order to compute *nonresponse weights*.^{18,20–22} Not all participants were linked to SNDS data to compute these probabilities (Supplementary Figure 1); however, the probability of being linked to SNDS data is included as an intermediate step in the computation of nonresponse weights. We previously showed that correction for nonparticipation increases prevalence estimates of several characteristics associated with poorer health status (eg, underweight or obesity, depression, current smoking).²⁰

- WS was not measured in some HSCs during specific periods (out-of-service photoelectric cells, lack of personnel). We modeled the probability of being invited to attend HSCs over these periods using logistic regression as a function of covariates (age, sex, HSC, education, alcohol, hypertension, rheumatologic and orthopedic conditions, falls, handgrip strength, single-leg balance test, marital status), and computed *nonmeasure weights*.

For each participant, we multiplied the 3 weights and obtained a final weight to perform IPW analyses. Extreme weights (>99 percentile) were truncated.

Multiple imputation.

WS was not measured in all participants because of organizational constraints that were mostly independent from the participants (no neuropsychologist or photoelectric cells available at the time of the visit to the study center). We used MI to impute missing WS values using the chained equations method.^{23,24} We included in the imputation model multiple characteristics associated with WS, including auxiliary variables (self-reported mobility, falls), and predictors from the regression model described below (including quadratic terms, interactions, and transformed covariates; Supplementary Table 1).²⁵ We imputed 22 data sets; pooled estimates were obtained using Rubin's rules.

Statistical Analysis

Statistical analyses were performed using SAS 9.4 (SAS Institute) and R (R-Foundation for Statistical Computing). We used the *shiny* R package to visualize norms through an interactive web application.²⁶

We implemented a 2-stage regression-based approach^{16,27}:

- **Model specification:** UWS/FWS were regressed on age, sex, height, and education using a 3-level linear mixed effects model. A few participants passed the WS test barefoot ($n = 523$) or using a cane ($n = 38$; total = 561, Supplementary Table 3); this variable was included in the model (yes/no), but norms were only estimated for the majority participants who took the test with shoes on and without a cane. Random effects included the year of invitation to participate to Constances (weights were estimated each year) and HSCs; participants were nested into HSCs, and HSCs were nested into year. For continuous variables (age, height), we examined departures from linearity by including quadratic terms. We first fitted a full model including all variables, quadratic terms, and 2-way interactions. This model was progressively simplified by excluding nonsignificant terms ($P > .05$).
- **Comparison to norms:** a z score is obtained by dividing the difference between the WS measured in a person (WS_{observed}) and predicted by the regression model ($WS_{\text{predicted}}$) by the SD of the residuals from the regression model ($SD(e)$), $z = (WS_{\text{observed}} - WS_{\text{predicted}}) / SD(e)$, and is compared to the dis-

tribution of standardized residuals (converted into percentiles) from the regression model.^{16,27}

Results

Of 83,883 participants, we excluded those seen in 4 HSCs where WS was never measured ($n = 9256$); differences between these participants and those seen in other centers were generally small (Supplementary Table 2). We excluded participants not linked to SNDS (for whom nonresponse weights cannot be computed; $n = 21,535$), and those seen in HSCs when WS was not measured over specific periods ($n = 8320$), leaving 44,772 participants (Supplementary Figure 1). Education was missing for 1213 (2.7%) participants, FWS for 9867 (22.0%), and UWS for 9779 (21.8%). After adjusting for age, sex, and HSC, those with missing values were younger, more frequently men, and generally in poorer health compared to participants without missing WS; they had lower cognition, mobility, and education (Supplementary Table 3).

After IPW and MI, mean age was 56.8 years for women and 57.3 years for men (Table 1). Mean height was 161.4 cm (174.2 cm) for women (men); 58.9% (62.9%) women (men) had low education. Average WS was faster in men than women; the difference was larger for FWS (men: 182.8 cm/s; women: 168.7 cm/s) than UWS (men: 120.7 cm/s; women: 116.9 cm/s). Participants walked slower and had a poorer health profile after IPW and MI compared to before (Supplementary Table 4).

After IPW and MI, UWS and FWS decreased with increasing age, and increased with increasing height and education (Table 2). Supplementary Table 5 compares our findings to those from 2 nationally representative US samples (static start).^{12,13,28} Our WS estimates were in the same range, although slightly faster.

Regression Models

FWS declined with age with a quadratic relation ($P < .001$), leading to a slightly faster decline at older ages (Table 3, Figure 1A). There were significant Education \times Sex ($P_{\text{Education} \times \text{Sex}} < .001$) and Education \times Age ($P_{\text{Education} \times \text{Age}} = .014$) interactions. Men walked faster than women: at 57 years, the sex difference in FWS in the low- (7.1 cm/s) and high-education group (7.1 + 2.2 cm/s) was equivalent to the effect of +10 years of age. FWS increased with height (Figure 1B) and education ($P < .001$), and the age effect was more pronounced in more-educated participants.

UWS declined with age (Figure 1A), with a linear relation in participants with low education ($P_{\text{Age}}^2 = .744$) and a quadratic relation in more-educated participants ($P_{\text{Education} \times \text{Age}}^2 = .004$); the age effect was more pronounced in more-educated participants ($P_{\text{Education} \times \text{Age}} < .001$). There was a complex relation of sex, height, and education with UWS (Figure 1B). Men tended to walk slightly slower than women in the low-education group ($\beta_{\text{Male}} = -1.4$, $P = .004$), but there was no sex difference in the high-education group ($\beta_{\text{Male}} = -1.4 + 1.5 = 0.1$, $P = .777$) because of a significant Education \times Sex interaction ($P_{\text{Education} \times \text{Sex}} = .039$). UWS increased with height; it increased less in men ($\beta_{\text{Height}} = 4.5 - 0.9 = 3.6$, $P < .001$) and in the high-education group ($\beta_{\text{Height}} = 4.5 - 0.8 = 3.7$, $P < .001$) compared to women or less-educated participants ($\beta_{\text{Height}} = 4.5$, $P < .001$) because of significant Sex \times Height ($P_{\text{Sex} \times \text{Height}} = .011$) and Education \times Height ($P_{\text{Education} \times \text{Height}} = .043$) interactions.

According to standardized regression coefficients, age, sex, and education had larger effects on FWS than UWS (Table 2). The UWS-FWS difference between the low- and high-education groups (in participants of average height) is similar to the effect of +20 years of age (Figure 1A). Persons who passed the test barefoot or with a cane walked slower than the others.

Table 1
Characteristics of Constances Participants

Characteristics	Overall (N = 44,772)	Women (N = 22,903)	Men (N = 21,869)
Sociodemographic characteristics			
Mean age, y	57.0 (0.2)	56.8 (0.2)	57.3 (0.2)
Low education (ISCED levels 0-4)	60.9	58.9	62.9
Single, separated, divorced, widowed	37.9	40.8	35.1
Physically strenuous work	45.9	38.1	53.8
Anthropometric characteristics, general health			
Mean height (cm)	167.8 (0.1)	161.4 (0.1)	174.2 (0.1)
Mean body mass index	26.3 (0.1)	25.7 (0.1)	26.9 (0.1)
Perceived general health status: bad	17.5	17.0	18.0
Cognitive and motor assessments			
Mean fast WS (cm/s)	175.6 (1.1)	168.7 (1.0)	182.8 (1.2)
Mean usual WS (cm/s)	118.8 (0.8)	116.9 (0.8)	120.7 (0.8)
WS test barefoot or with a cane	1.4	2.6	0.3
Mean handgrip strength (kg)	32.9 (0.3)	24.8 (0.3)	41.0 (0.3)
Single-leg balance test <30 s	15.7	17.2	14.1
Mini-Mental State Examination	27.7 (0.1)	27.7 (0.1)	27.7 (0.1)
Verbal episodic memory (free immediate recall)	31.4 (0.2)	32.9 (0.2)	29.9 (0.2)
Verbal episodic memory (free delayed recall)	12.3 (0.1)	12.9 (0.1)	11.7 (0.1)
Fluency—semantic	22.7 (0.1)	22.8 (0.1)	22.6 (0.1)
Fluency—phonological	14.3 (0.1)	14.9 (0.1)	13.8 (0.1)
Trail Making Test—part A	7.6 (0.0)	7.8 (0.0)	7.5 (0.0)
Trail Making Test—part B	3.8 (0.0)	3.9 (0.0)	3.7 (0.0)
Digit Symbol Substitution Test	63.1 (0.2)	66.4 (0.3)	59.9 (0.3)
Mobility			
Cannot get up from the floor or lie down without difficulty	11.9	13.5	10.2
Cannot walk 1 km without stopping without difficulty	10.7	12.1	9.4
Cannot carry 5 kg over 10 m without difficulty	13.3	19.5	7.2
Fall in the last 12 mo	20.0	24.1	15.9
Health behaviors			
Fruit consumption <1/d	40.5	49.6	31.4
Vegetable consumption <1/d	31.0	41.5	20.4
Alcohol drinking: not recommended	11.8	7.8	15.7
Smoking (current, ex)	57.6	49.4	65.8
Physical activity outside of work: inactive	28.9	26.7	31.1
Cardiovascular risk factors and disease			
Hypercholesterolemia	38.2	36.1	40.3
Diabetes	9.6	6.1	13.2
Hypertension	44.2	35.9	52.5
Cardiovascular event	5.8	2.8	8.9
Other comorbidities			
Mean CES-D	11.8 (0.1)	13.2 (0.1)	10.4 (0.1)
Hearing impairment	5.9	4.3	7.5
Vision impairment	1.0	1.0	1.0
Visual correction	69.0	73.9	64.0
Rheumatologic condition	15.8	18.6	13.0
Orthopedic condition	22.6	17.0	28.2
Kidney disease	4.5	6.7	2.3
Respiratory condition	10.3	10.5	10.1

CES-D, Center for Epidemiologic Studies—Depression Scale.

Continuous variables are described as means and SEs and categorical variables as average frequencies across imputed data sets after inverse probability weighting.

Using Regression-Based Norms

UWS and FWS norms are available through a Rshiny application that allows to compare a person's WS to Constances norms (<https://cesp-proxy2.vjf.inserm.fr/NORMES-VM-EN/>). **Supplementary Table 6** shows norms in a tabular format.

Suppose a 49-year-old woman (height = 168 cm, education = high, comfortable shoes and no cane) took 2.2 seconds to walk 3 m at a fast pace (FWS_{observed} = 136.4 cm). According to the regression model (**Table 3**),

$$\begin{aligned} \widehat{\text{FWS}}_{\text{predicted}} &= 168.1 - 5.7 \times ((49 - 57)/10) - 1.1 \\ &\times ((49 - 57)^2/100) + 5.6 \times ((168 - 168)/10) - 0.4 \\ &\times ((168 - 168)^2/100) + 7.1 \times 0 + 13.1 \times 1 + 2.2 \\ &\times 1 \times 0 - 1.1 \times 1 \times ((49 - 57)/10) - 1.1 \times 1 \\ &\times ((49 - 57)^2/100) = 185.2 \text{ cm/s} \end{aligned}$$

The z score $[(136.4 - 185.2) / 26.7 = -1.8]$ corresponds to the second percentile of the distribution of standardized residuals from the regression model: 2% of women from the general population with the same characteristics walk slower than this woman.

Correction for Survey Sampling, Nonresponse, and Missing Values

Correcting for survey sampling, nonresponse, and missing values yielded slower WS estimates (**Figure 2**). For instance, for a 55-year-old man with low education (height = 174.2 cm), FWS decreased by 4.5 cm/s (from 184.1 cm/s before IPW/MI to 179.6 cm/s after); this difference corresponds to the effect of +7 years of age. IPW had a stronger effect than MI: IPW alone decreased FWS by 3.5 cm/s, whereas MI alone decreased FWS by 1.0 cm/s. IPW/MI had a more pronounced effect for participants with low than high education; in those with low education, it was more pronounced for men than women.

Table 2
Mean Usual and Fast Walking Speed After Inverse Probability Weighting and Multiple Imputation by Sex, Age, Height, and Education Level

Characteristics	Women		Men		Fast WS (cm/s), Mean (SE)		Usual WS (cm/s), Mean (SE)	
	%	%	Women	Men	Women	Men	Women	Men
Age (5-y Groups)								
45–49	22.2	21.2	176.2 (1.0)	190.5 (1.2)	120.9 (0.8)	124.4 (0.8)		
50–54	20.7	19.5	172.9 (1.0)	186.9 (1.2)	119.0 (0.8)	122.5 (0.8)		
55–59	20.2	19.2	168.4 (1.0)	182.9 (1.3)	116.5 (0.8)	121.0 (0.8)		
60–64	17.9	19.1	165.4 (1.0)	179.0 (1.2)	115.1 (0.8)	119.3 (0.8)		
≥65	19.0	21.0	159.0 (1.1)	174.8 (1.2)	111.9 (0.9)	116.5 (0.8)		
Height (cm)*								
≤P5	5.4	5.3	155.7 (1.3)	171.0 (1.6)	108.5 (1.0)	114.7 (1.1)		
P5–P10	4.7	4.1	160.3 (1.4)	174.0 (1.6)	111.4 (1.1)	116.8 (1.1)		
P10–P25	16	14.3	163.0 (1.1)	176.5 (1.3)	113.7 (0.9)	117.4 (0.9)		
P25–P50	24.1	28.1	167.0 (1.0)	181.9 (1.2)	116.0 (0.8)	119.8 (0.8)		
P50–P75	24.6	22.9	171.7 (1.0)	184.9 (1.2)	118.4 (0.8)	121.9 (0.8)		
P75–P90	14.7	14.7	174.2 (1.1)	187.9 (1.3)	120.4 (0.9)	123.5 (0.8)		
P90–P95	6.1	5.9	175.6 (1.2)	189.4 (1.5)	120.8 (1.0)	124.1 (1.0)		
>P95	4.4	4.8	180.3 (1.3)	194.0 (1.6)	123.8 (1.1)	127.7 (1.0)		
Education†								
Low	58.9	62.9	162.4 (0.9)	176.9 (1.2)	114.2 (0.8)	118.5 (0.8)		
High	41.1	37.1	177.9 (0.9)	193.2 (1.2)	120.7 (0.8)	124.6 (0.8)		

*Cutoffs represent sex-specific percentiles of the distribution of height (women/men): P5: 151/163, P10: 153/165, P25: 157/169, P50: 161/174, P75: 165/178, P90: 169/182, P95: 172/185.

†Education level was self-reported based on the 2011 International Standard Classification of Education (ISCED) and dichotomized as low (0 = nursery; 1 = primary education; 2 = first cycle of secondary education; 3 = second cycle of secondary education; 4 = post-secondary non-tertiary education) and high (5 = short-cycle tertiary education; 6 = bachelor's degrees; 7 = master's degrees; 8 = doctoral degrees) education.

Discussion

We provide age-, sex-, height-, and education-specific UWS and FWS norms for adults 45–69 years old from the French general population. We took into account selection effects related to participation and missing data using IPW or MI.

Our results confirm a well-known trend of decreasing WS with increasing age.^{7,9} The age-related WS decline was present in midlife²⁹ and accelerated in older persons.

After adjusting for height and education, men had faster FWS than women.^{12,30} Alternatively, men had slightly slower UWS than women in the low-education group, with no sex difference in the high-

Table 3
Fixed Effects of the Multilevel Linear Mixed Effects Regression Models Used to Estimate the Norms of Usual and Fast Walking Speed After Inverse Probability Weighting and Multiple Imputation

Variable	Fast WS (cm/s)				Usual WS (cm/s)				Standardized WS*			
	[SD (residual) = 26.7]				[SD (residual) = 19.3]				Fast WS		Usual WS	
	Beta	SE	P	P _{global}	Beta	SE	P	P _{global}	Beta	SE	Beta	SE
Constant	168.1	1.0	<.001		118.1	0.8	<.001		−25.9	3.4	−3.1	4.0
Age												
Age (per 10 y)	−5.7	0.3	<.001		−2.8	0.2	<.001		−19.4	1.1	−13.8	1.0
Age ² (per 100 y)	−1.1	0.5	.045	<.001	−0.1	0.3	.744	<.001	−3.6	1.7	−0.6	1.7
Height												
Height (per 10 cm)	5.6	0.3	<.001		4.5	0.3	<.001		19.2	0.9	22.3	1.7
Height ² (per 100 cm)	−0.4	0.2	.012	<.001	—	—	—		−1.4	0.5	—	—
Sex												
Women	Ref	—	—		Ref	—	—		Ref	—	Ref	—
Men	7.1	0.5	<.001		−1.4	0.5	.004		24.2	1.8	−6.8	2.3
Education												
Low	Ref	—	—		Ref	—	—		Ref	—	Ref	—
High	13.1	0.5	<.001		5.1	0.5	<.001		44.9	1.8	25.6	2.6
WS test barefoot or with a cane												
No	Ref	—	—		Ref	—	—		Ref	—	Ref	—
Yes	−8.7	1.2	<.001		−8.3	0.9	<.001		−29.7	4.1	−41.8	4.4
High education × Male sex	2.2	0.6	<.001		1.5	0.7	.039		7.6	2.1	7.5	3.6
High education × Age												
High education × Age	−1.1	0.5	.023		−0.7	0.3	.028		−3.7	1.6	−3.6	1.6
High education × Age ²	−1.1	0.7	.099	.014	−1.6	0.5	.004	<.001	−3.7	2.2	−8.0	2.7
High education × Height	—	—	—		−0.8	0.4	.043		—	—	−4.0	1.9
Male sex × Height	—	—	—		−0.9	0.4	.011		—	—	−4.7	1.8

WS, walking speed.

Regression coefficients (beta) and SEs were estimated using a 3-level linear mixed effects model with random effects on the Health Screening Center (HSC) nested in the year of invitation to participate in Constances. Age and height are centered at their mean (age, 57 years; height, 168 cm).

*Walking speed standardized on its mean and SD × 100.

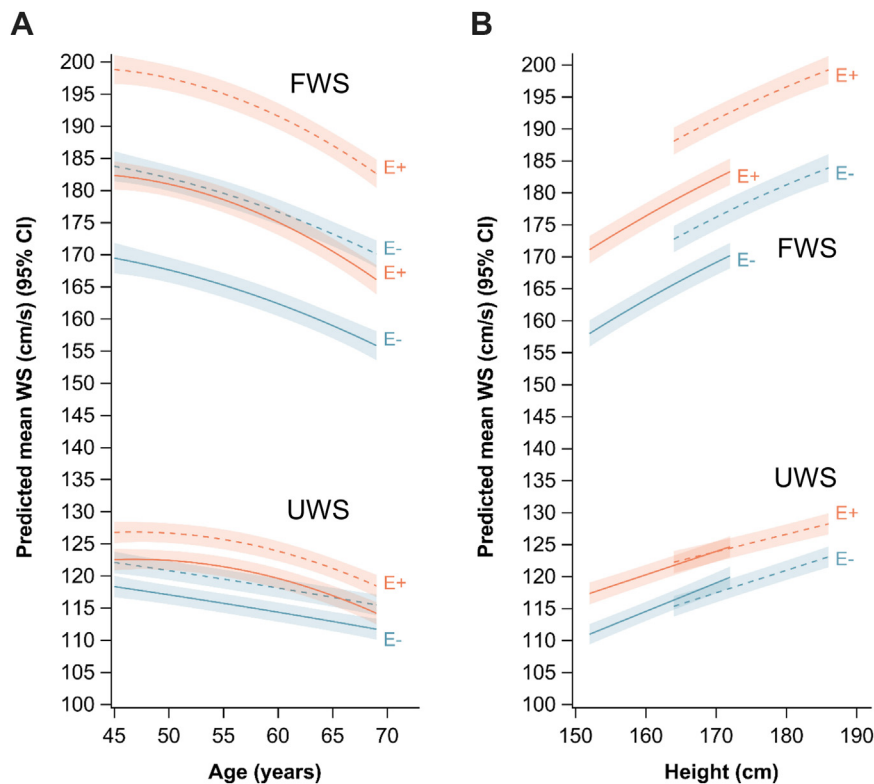


Fig. 1. Relation of usual and fast walking speed with age (A) and height (B), according to the multilevel linear mixed effects regression model after inverse probability weighting and multiple imputation. E+, high education; E-, low education. Solid line: women; dashed line: men. Shaded areas represent 95% CIs. The corresponding regression coefficients are displayed in Table 3. (A) The figure shows the relation between age and the predicted mean UWS and FWS in participants who passed the test with shoes on and without a cane, at the average height of women (161.4 cm) and men (174.2 cm). (B) The figure shows the relation between height and the predicted mean UWS and FWS in participants who passed the test with shoes on and without a cane, at an average age of 57.1 years. Curves are shown for heights comprised between the 5th and 95th sex-specific percentiles of height (men, 164–186 cm; women, 152–172 cm). For UWS, the graph shows the interaction of height with sex (the height-related increase in WS was less pronounced in men than women) and with education (the height-related increase in WS was less pronounced in participants with a higher education than in those with a lower education). For FWS, there were no interactions of sex or education with height.

education group. The sex-UWS relation was inconsistent in previous studies; some studies reported no sex difference,^{7,11,31} whereas others showed that men walk faster than women,³² or the opposite.⁹ Possible explanations for inconsistent relations include whether analyses were height-adjusted or differences in the interpretation of UWS instructions that may depend on sex, height, or education; this may explain why a greater number of interactions were identified for UWS compared to FWS. FWS provides information about an individual's functional reserve capacity, is a more challenging test than UWS, and helps unravel differences not identified by UWS. UWS is a more subjective test than FWS, with lower test-retest reproducibility.⁴

WS increased with height, likely explained by differences in stride length.^{4,7,9,10,33} The association between height and UWS (but not FWS) was modified by sex and education; again, differences in the interpretation of UWS instructions may play a role. Previous studies suggested that the height effect is lost in very old persons^{4,7}; we observed no Age \times Height interaction, likely because of participants being <70 years old. Taking height into account facilitates comparisons between studies, but few studies considered height to establish WS norms.^{7,9–11}

Higher education is associated with better cognitive performances, and norms of cognitive tests generally take education into account. Higher education is also associated with faster WS.^{3,34,35} No previous study determined WS norms by education level. We showed large and clinically relevant WS differences by education; the effect of education on FWS or UWS is similar to the WS difference between the extreme age groups (45–50 and ≥ 65 years). Hence,

norms by education are a more accurate way of determining the functional status of a person and allow to reduce misclassification. It has been argued that education is more difficult to standardize than other characteristics⁷; we used the ISCED classification to facilitate cross-country comparisons and used a simple dichotomization (<tertiary and \geq tertiary) that can be easily implemented in different settings. Education had a stronger association with UWS and FWS in men than women, possibly reflecting sex differences in education length and quality. In addition, the age effect was more pronounced in more-educated participants, suggesting that the advantage conferred by education decreases as persons grow older and comorbidities develop; alternatively, it could reflect differences in education length and quality across birth cohorts.

Higher body mass index (BMI) is associated with slower WS.³⁶ We voluntarily chose not to create BMI-specific norms. Unlike the other covariates we considered, weight is modifiable, and weight loss in obese persons increases WS.³⁷ Had we accounted for BMI, WS in obese participants would be considered closer to normal than they actually are.⁷

Small differences between participants with and without missing data, even if significant given the large sample size, explain why MI had a small impact. IPW had a stronger impact, reflecting selection effects related to participation into the study. IPW had a stronger impact for participants with low education, consistent with their lower participation.^{20,21} These findings illustrate the importance of taking into account selection effects and missing values to establish norms.

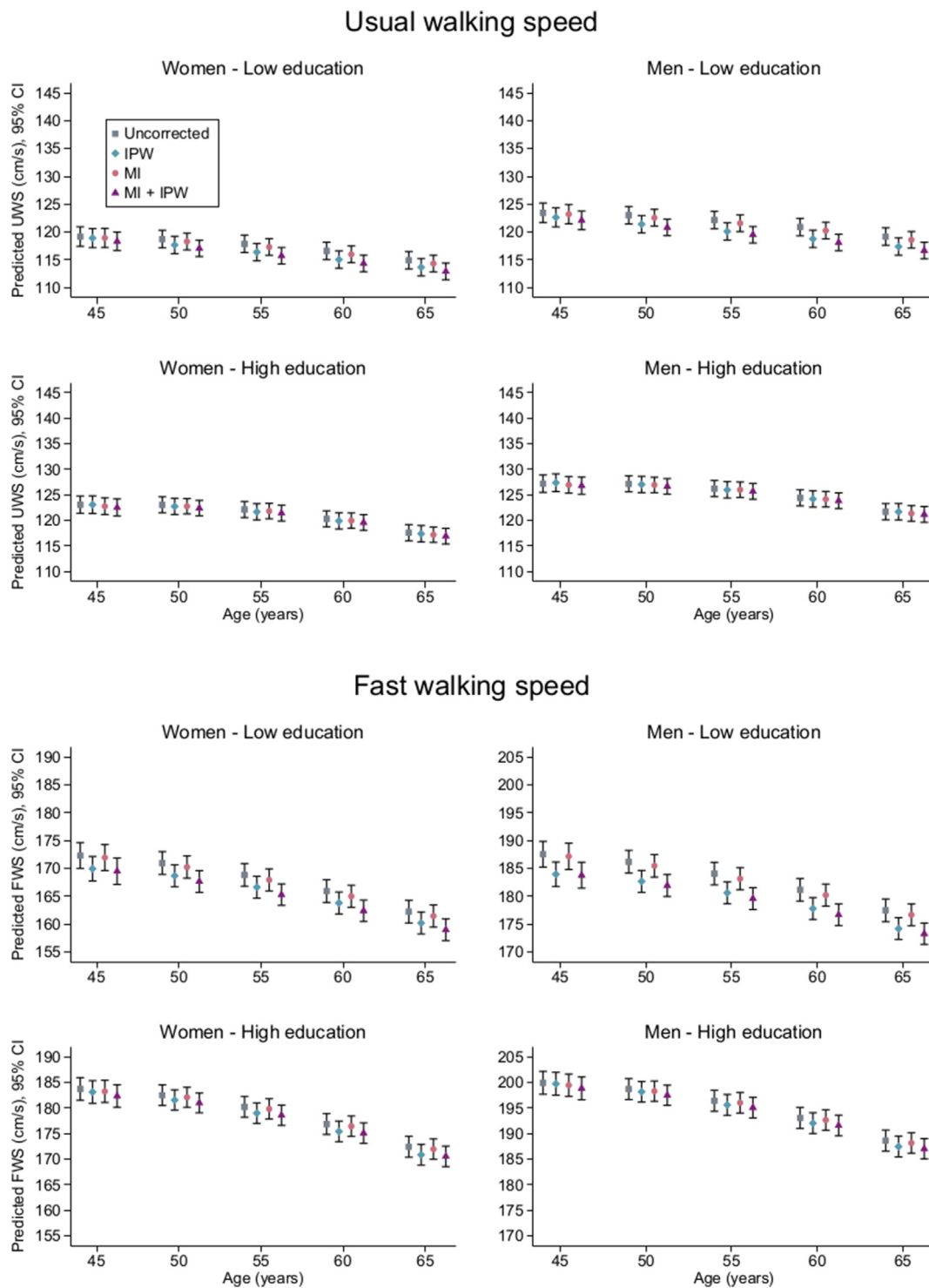


Fig. 2. Mean usual and fast walking speed predicted by the multilevel linear mixed effects regression models before and after inverse probability weighting and multiple imputation. The figures show the predicted mean UWS and FWS (95% CI) in participants who passed the test with shoes on and without a cane, at the average height of women (161.4 cm) and men (174.2 cm). Y axes have different ranges to facilitate the visualization, but the difference between the minimum and maximum WS values is always of 35 cm/s.

Available WS norms vary across studies because of differences in inclusion criteria, participants’ characteristics, sample size, covariates, and WS protocols.^{5–12,14,17,33} Normative data are defined as a collection of test scores in a sample that is representative of the general population; large sample sizes are needed to obtain stable estimates.³⁸ Several previous studies included a small number of participants from convenience samples or excluded participants with

comorbidities, leading to selected and nonrepresentative samples; hence, it was expected that we obtained slower WS estimates than these studies, as we aimed to provide norms for the general population.^{5,6} Our estimates are similar to those obtained in 2 nationally representative US samples, although they were slightly faster, likely because of the dynamic start compared to the static start in US studies.^{12,13,28} Our estimates for UWS are slower compared to those

from the Rotterdam cohort study (automated 5.8 m UWS measure).⁷ For instance, in men 60 years old of average height (176 cm), median UWS was 127 cm/s in the Rotterdam study and 121 cm/s in our study; the 6 cm/s difference is similar to the effect of high education on UWS in our study (6.6 cm/s in men). In the Rotterdam study, 9692 (65%) of the initial 14,926 participants were alive at the time of the gait assessment at the study center. Of these, 4433 (46%) participants did not visit the study center; they were older and more often women than those who attended, and likely to be in poorer health (healthy volunteer effect).³⁹ Of 5259 persons who attended the center, 601 gait measures were missing or invalid. In total, a valid gait measure was obtained for 31% (n = 4656) of the initial sample. The sample of participants used to determine gait norms was therefore selected by survival and visit to the center. Selection into the cohort and missing data were not taken into account to correct the norms, which likely contributed to overestimate UWS; this may also explain why UWS did not decrease between 50 and 65 years, contrary to our study and the most recent meta-analysis.²⁹

Our study has several strengths. We estimated UWS and FWS norms based on the largest number of participants to date, allowing us to examine nonlinear relations and interactions. We provide norms for middle-aged adults; there is increasing evidence that ageing phenotypes, including cognitive or motor decline and disability, develop over many years and are already apparent in middle age.^{40,41} We measured short-distance WS using an automated method that is more reliable than manual measures.⁴² We used IPW and MI to correct for selection effects and missing values. The regression-based approach has several advantages over traditional methods: continuous variables do not need to be categorized, norms are more precise and smoothed, and interactions can be tested without making a priori assumptions.¹⁶

Our study has limitations. First, MI assumes that missing data are missing at random given covariates included in the imputation model; we imputed WS based on a wide range of variables associated with WS. Second, although we made efforts to take into account selection effects (nonparticipation, missing values), we may have incompletely corrected for these issues. In particular, we excluded HSCs where WS was never measured and were not able to correct for this cause of missing values as all participants from these HSCs were excluded; however, this is unlikely to have a major impact on our findings because there were no large differences with other HSCs. Third, norms were established for the Constances target population in France; however, norms by age, sex, height, and education facilitate comparisons with other countries. In addition, a systematic review showed no large differences in WS across continents.²⁹ Fourth, we dichotomized education level and there may be residual differences within each education group. The choice of the cutoff was partly guided by the data, but also by our desire to enable clinicians in different countries to use the norms easily. Fifth, after taking into account sampling weights and correcting for nonparticipation and missing values, Constances participants were slightly more educated compared to the general French population, but differences were small; for instance, in the 45 to 54-year-old age group, 48% (41%) of women (men) had a tertiary education degree in Constances, compared with 45% (39%) in the general French population according to the Organization for Economic Cooperation and Development (2019).⁴³

Conclusions and Implications

Fixed WS cutoffs have been often used to define slow WS and to predict the risk of adverse outcomes.⁴⁴ These cutoffs are useful to identify persons at highest risk, but are insufficient for general population members, in particular those aged <70 years old, because few will perform worse than these cutoffs. Our norms can be used to identify in midlife persons with lower motor performances than the general population who are at higher risk of adverse outcomes later in

life, including falls, disability, sarcopenia, dementia, or death.^{44–48} Ageing outcomes develop over many years with significant heterogeneity across individuals, and many risk factors have their roots in midlife.^{41,49} Middle-aged adults have a higher capacity for recovery,⁴⁰ and it is increasingly recognized that middle age may be an ideal period to intervene to prevent or delay functional impairment.⁵⁰ Early identification in midlife of persons at risk of functional impairment can encourage examinations to identify reasons for their lower performances in order to implement preventative measures and interventions to improve their performances. This strategy is implemented in programs such as ICOPE (Integrated Care for Older People), developed by the World health organization for persons aged ≥60 years,⁵¹ or SUCCEED (SUCcessful agEing outpatiEnts Department) for persons ≥50 years in France.^{52,53}

Disclosure

The authors declare no conflicts of interest.

Acknowledgments

The authors thank the team of the “Population-based Cohorts Unit” (Cohortes en population) that designed and manages the Constances Cohort Study. They also thank the French National Health Insurance Fund (Caisse nationale d’assurance maladie, CNAM) and its Health Screening Centres (Centres d’examen de santé), which are collecting a large part of the data, as well as the French National Old-Age Insurance Fund (Caisse nationale d’assurance vieillesse, Cnav) for its contribution to the constitution of the cohort, and ClinSearch, Asqualab and Eurocell, which are conducting the data quality control.

Supplementary Data

Supplementary data related to this article can be found online at <https://doi.org/10.1016/j.jamda.2023.10.001>.

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