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Research Article

What Cut-Point in Gait Speed Best Discriminates Community-Dwelling Older Adults With Mobility Complaints From Those Without? A Pooled Analysis From the Sarcopenia Definitions and Outcomes Consortium

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Abstract

Background: Cut-points to define slow walking speed have largely been derived from expert opinion.

Methods: Study participants (13 589 men and 5043 women aged ≥65years) had walking speed (m/s) measured over 4–6 m (mean ± *SD*: 1.20 ± 0.27 m/s in men and 0.94 ± 0.24 m/s in women.) Mobility limitation was defined as any self-reported difficulty with walking approximately 1/4 mile (prevalence: 12.6% men, 26.4% women). Sex-stratified classification and regression tree (CART) models with 10-fold cross-validation identified walking speed cut-points that optimally discriminated those who reported mobility limitation from those who did not.

Results: Among 5043 women, CART analysis identified 2 cut-points, classifying 4144 (82.2%) with walking speed ≥0.75 m/s, which we labeled as "fast"; 478 (9.5%) as "intermediate" (walking speed ≥0.62 m/s but <0.75 m/s); and 421 (8.3%) as "slow" (walking speed <0.62 m/s). Among 13 589 men, CART analysis identified 3 cut-points, classifying 10 001 (73.6%) with walking speed ≥1.00 m/s ("very fast"); 2901 (21.3%) as "fast" (walking speed ≥0.74 m/s but <1.00 m/s); 497 (3.7%) as "intermediate" (walking speed ≥0.57 m/s but <0.74 m/s); and 190 (1.4%) as "slow" (walking speed <0.57 m/s). Prevalence of self-reported mobility limitation was lowest in the "fast" or "very fast" (11% for men and 19% for women) and highest in the "slow" (60.5% in men and 71.0% in women). Rounding the 2 slower cut-points to 0.60 m/s and 0.75 m/s reclassified very few participants.

Conclusions: Cut-points in walking speed of approximately 0.60 m/s and 0.75 m/s discriminate those with self-reported mobility limitation from those without.

Keywords: Classification and regression trees, Gait speed, Mobility limitation

Slow usual pace gait speed measured over a short distance is predictive of mortality and disability [1,2]. Several cut-points to define slowness and dichotomize gait speed into "slow" and "not slow" categories have been proposed: 0.6 [3], 0.8 [4,5], and 1.0 m/s [6]. However, these cut-points are largely based on expert opinion or consideration of the prevalence of slowness defined by the various cut-points by age. For example, in Health ABC, a cut-point of 1.0 m/s was selected based on visual inspection of a graph relating walking speed to incident lower extremity limitation in a random subset, and then positive and negative likelihood ratios were compared across a number of cut-points in a separate subset of participants [7]. As noted by Cesari et al., the relation between walking speed and risk of functional imitation (and other conditions in aging) appears to be log linear with no clear inflection point that could be refined by splines or other methods [1,2,7–9]. Few, if any, reports have used data-driven approaches to identify a cut-point in gait speed that classifies people as slow based on self-reported function, particularly in community-dwelling adults. How "slowness" is defined has important implications for incorporating slowness into composite definitions of conditions such as sarcopenia [4–6] and frailty [10] and for predicting the risk of distal outcomes based on slowness.

Therefore, using a subset of cross-sectional data from cohort studies of older adults included in the Sarcopenia Definitions and Outcomes Consortium (SDOC), we used a machine learning technique, classification and regression tree analysis (CART), to identify cut-points in gait speed that best discriminate those who self-report a mobility limitation (at least some difficulty walking a short distance) from those who do not report such limitation. Herein we aimed to use the prevalence of a common patient-reported outcome, mobility limitation, as the "anchor," or the term the CART models aimed to make most different across subsets of participants as identified by the model-derived cut-points. Self-reported outcomes represent a person-centered approach and are in line with efforts by the Patient-Centers Outcomes Research Institute and the National Institute of Health. A patient-reported outcome was selected as our focus because our ultimate goal is to identify cut-points in walking speed that are most important to the day-to-day health of older adults.

Method

Study Population

We used data from 8 cohort studies that were assembled for the analyses of the SDOC [11–13] (Supplementary Table 1). These studies have been extensively described elsewhere and in the SDOC publications. Analyses were limited to community-dwelling older adults aged 65 years and older with dual-energy x-ray absorptiometry body composition, grip strength, walking speed, and mobility complaints data. Participants were included if they had complete data for self-rated mobility limitation, gait speed, and age and sex. Data from the baseline visit of each study were used, except for Health ABC where the Year 7 (Visit 8) and the Cardiovascular Health Study (CHS) where Year 6 data were used. Health ABC was a high-functioning cohort at baseline. We chose to use follow-up data to enrich our sample with lower-functioning older adults. Thus, for Health ABC, data from Year 7 were used from Health ABC in order to have a broader range of function (as all participants were nondisabled at enrollment). Data from Year 6 were used from CHS because that was the first visit in which gait speed and self-reported function were available.

Walking Speed

Walking speed was assessed at the participant's usual pace over 20 m in Health ABC; over 6 m in MrOS, Mr&MsOS Hong Kong, MrOS Sweden, SOF, CHAMP; and over 4.6 m (15 ft) in CHS. In the Johnston County Osteoarthritis Project, walking speed was assessed over 2.4 m (8 ft). Because walking speed is slower over shorter distances than over longer distances due to the acceleration phase when initiating movement, walking speed on the 8-foot course was harmonized to an equivalent speed that would have been observed over 4–6 m using equations previously published by Guralnik et al. [14].

Mobility Limitation

In Health ABC, MrOS, SOF, CHS, MrOS Sweden, and Mr&MsOS Hong Kong participants self-reported difficulty walking short distances outside, either 2–3 blocks or ½ mile. In the CHAMP, participants were queried "are you able to walk half a mile (approx. 1 km) without any help?" In the Johnston County Osteoarthritis Project, the participants were asked "During the past seven days … have you been able to walk outside on flat ground?" Participants with any difficulty or inability to walk these distances were classified as having a prevalent self-reported mobility limitation.

Statistical Analysis

Means ± *SD* and *N* (%) for selected characteristics are presented; characteristics across walking speed groups were tested by chi-square for categorical variables and analysis of variance for normally distributed continuous variables; and Kruskal–Wallis test for skewed continuous variables. To identify cut-points(s) in walking speed that most strongly discriminated self-reported mobility limitation, we developed CART models using the rpart package in R (version 3.1.2). Cross-validation was used to "prune" less important splits to prevent overfitting and produce a more parsimonious tree. Cross-validation was performed by randomly partitioning the pooled data into 10 equally sized mutually exclusive data sets (ie, each set excluded 10% of the original pooled data). The tree was then applied to 10 subsamples that contained 90% of the data (ie, 10% of the data was left out of each subsample), and the prediction error from each subsample was calculated. The 10 prediction errors (error sum of squares) were used to calculate the empirical standard error of the prediction error. Following published guidelines ([15]), the tree was pruned to the most parsimonious tree that was within 1 *SE* of the tree with the smallest prediction error. For utility in clinical settings, we also aimed to round cut-points to the nearest 0.05 m/s and compare classification against the CART-derived versions. We examined race and ethnicity as a sensitivity analysis in the final CART model. If CART did not select race or ethnicity as a variable of importance, it was subsequently dropped from the final models. We found that adding a variable for being Chinese did not change the nodes identified. We repeated this approach with Black race and found similar results. Race/ethnicity also did not show up in the variable importance list. As such, we did not stratify the results by being a citizen of China, race, or ethnicity.

To quantify the discriminative ability of the identified cut-points, we used logistic regression models to estimate relative odds of mobility limitation based on being classified according to the identified cut-points. No covariates were included in the logistic models as these models were used to quantify the risk represented by the different prevalence values at different walking speeds.

Results

The overall prevalence of self-reported mobility limitation in men was 12.6%; in women, the prevalence of self-reported mobility limitation was more than twice as high (26.4%). Mean ± *SD* walking speed was 1.17 ± 0.26 m/s in men and 0.94 ± 0.23 m/s in women.

For women, 2 cut-points were identified: the first at 0.75 m/s and a second among those who walked more slowly at 0.62 m/s (Figure 1). We considered 4144 (82.2%) women who walked ≥0.75 m/s as "fast"; 478 women (9.5%) who walked ≥0.62 m/s but <0.75 m/s as "intermediate"; and 421 women (8.3%) who walked <0.62 m/s as "slow." The prevalence of self-reported mobility limitation was
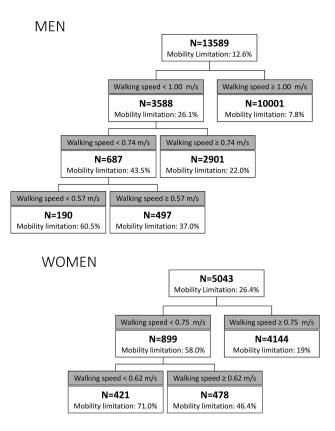

Figure 1. CART results: Classification of men and women by walking speed cut-points that best discriminate the prevalence of self-ported mobility limitation.

higher in women classified as slow compared to classified as fast (71% vs 19%, *p* < .001).

For men, 3 cut-points were identified: the first at 1.0 m/s, the second at 0.74 m/s among those who walked more slowly, and the third at 0.57 m/s (Figure 1). The CART models identified 10 001 men (73.6%) who walked ≥1.00 m/s which we classified as "very fast"; 2901 men (21.3%) who walked ≥0.74 m/s but <1.00 m/s who we classified as "fast"; 497 (3.7%) who walked ≥0.57 m/s but <0.74 m/s who we classified as "intermediate"; and 190 (1.4%) who walked <0.57 m/s who we classified as "slow." As seen with women, the prevalence of self-reported mobility limitation in men was the lowest in those with faster gait speed (7.8% in those considered "very fast") and the highest in those considered "slow" (60.5%). For parsimony across sexes, we evaluated the effect of classifying men into 3 groups by collapsing the "very fast" and "fast" groups. The resulting group ("very fast or fast") had 12 902 men (94.9% of men) with a prevalence of self-reported mobility limitation of 11.0%. Those in the slower walking categories were older, had lower grip strength and appendicular lean mass, and higher body mass index (BMI; although the BMI association only reached statistical significance for women, Table 1). Race and self-reported mobility limitation also varied by walking speed category.

In logistic models, men and women classified as slow were at least 10 times more likely to report a mobility limitation than those who were classified as fast or very fast (Table 2); and those classified as intermediate were at least 3 times more likely to report a mobility limitation than those who were fast or very fast.

Table 1. Characteristics (N (%) or mean ± SD) of Participants by Walking Speed Categories

Characteristic	Men				Women			
	Fast or Very Fast (≥0.74 m/s)	Intermediate (<0.74 to ≥0.57 m/s)	Slow (<0.57 m/s)	p	Fast (≥0.75 m/s)	Intermediate (<0.75 to ≥0.62 m/s)	Slow (<0.62 m/s)	p
N (%)	12 902 (94.9)	497 (3.7)	190 (1.4)		4144 (82.2)	478 (9.5)	421 (8.3)	
Age (years)	74.4 ± 5.3	78.3 ± 6.0	80.0 ± 5.7	<.001	74.9 ± 5.5	77.4 ± 5.4	78.7 ± 5.6	<.001
BMI (kg/m²)	26.6 ± 3.9	26.8 ± 4.6	27.1 ± 4.4	.080	25.9 ± 4.8	27.6 ± 6.0	28.0 ± 6.3	<.001
Maximum grip strength (kg)	40.1 ± 8.6	32.0 ± 8.0	31.1 ± 8.6	<.001	22.6 ± 5.3	20.5 ± 5.4	20.0 ± 5.6	<.001
Grip strength/BMI	1.53 ± 0.35	1.21 ± 0.32	1.17 ± 0.32	<.001	0.89 ± 0.24	0.76 ± 0.22	0.74 ± 0.25	<.001
Appendicular lean mass (ALM), kg	23.3 ± 3.7	21.0 ± 3.6	20.9 ± 3.9	<.001	15.3 ± 3.0	15.8 ± 3.7	16.1 ± 3.8	<.001
ALM/ht², kg/m²	7.8 ± 1.0	7.5 ± 1.0	7.4 ± 1.1	<.001	6.3 ± 1	6.6 ± 1.2	6.7 ± 1.3	<.001
Race				<.001				<.001
White	10 151 (78.7)	348 (70.0)	140 (73.7)		1594 (38.5)	156 (32.6)	140 (33.3)	
Black	510 (4.0)	36 (7.2)	24 (12.6)		827 (20.0)	163 (34.1)	158 (37.5)	
Asian	2050 (15.9)	110 (22.1)	25 (13.2)		1721 (41.5)	159 (33.3)	122 (29.0)	
Other	191 (1.5)	3 (0.6)	1 (0.5)		2 (0)	0 (0)	1 (0.2)	
Walking speed (m/s)	1.20 ± 0.24	0.67 ± 0.04	0.49 ± 0.09	<.001	1.02 ± 0.18	0.68 ± 0.03	0.49 ± 0.10	N/A*
Self-reported mobility limitation	1414 (11)	184 (37)	115 (60.5)	<.001	808 (19.5)	222 (46.4)	299 (71)	<.001

Note: BMI = body mass index.

*p values are not appropriate for this row, as the walking speed values are known to be different by definition.

The prevalence of self-reported mobility limitation was somewhat higher among women than men classified as "slow" or when classified as "intermediate." Among men and women classified as slow, 71.0% of women and 60.5% of men reported a mobility limitation, while among those classified as intermediate, 46.4% of women and 37.0% of men reported a mobility limitation. Among those classified as "fast" or "very fast," more women (19.5%) than men (11.0%) reported a mobility limitation.

If the cut-points to define 3 groups in both men and women are rounded to 0.75 and 0.60 m/s, some participants would be differentially classified. For women, no change would be made to the "fast" group, and 36 would be classified as "intermediate" rather than "slow" with the rounded numbers for the cut-points. For men, 69 would be classified as "intermediate" rather than "fast or very fast"; 40 would be classified as "slow" rather than "intermediate" with the rounded numbers for the cut-points. If 2 groups were defined based on a cut-point of 0.8 m/s as suggested by others (13,16), rather than 0.75 m/s as identified herein to define "fast" and "slow," a number of men and women would be differentially classified. For men, 12 833 (94.4%) walk faster than 0.75 m/s while 12 427 (91.5%) walk faster than 0.80 m/s. For women, 4144 (82.2%) walk faster than 0.75 m/s while 3758 (74.5%) walk faster than 0.80 m/s.

Discussion

Our data-driven approach found that 2 cut-points of approximately 0.60 and 0.75 m/s stratify men and women into groups with vastly different prevalence of self-reported mobility limitation. An additional cut-point of 1.0 m/s was found for men, but not for women. Although the precise cut-point for the lower value of walking speed was slightly different for men and women (0.62 and 0.57, respectively), the rounded cut-points of 0.6 and 0.75 m/s reclassified relatively few participants (about 0.01% of the population or less). The cut-point of 0.75 is fairly different from 0.8 m/s as previously proposed by other groups (4,5). The difference of 0.05 m/s represents a difference of 0.19 *SD* in men and 0.22 *SD* in women. Using 0.8 instead of 0.75 would reclassify a fair number of individuals (>5%), especially women.

The utility of walk speed cut-points is multifold. First, it is a standardized and objective measure that is free of environmental and psychosocial factors known to influence self-reported function. Second, evidence-based cut-points help practitioners by categorizing individuals into risk groups for further evaluation and/or to target interventions. CART identified a different number of cut-points in men (3 cut-points) and women (2 cut-points). Highlighting features of the CART method may clarify the reason for this apparent sex discordant finding. CART is not based on a prespecified number of cut-points, and its objective is to optimize discrimination (not to identify a given number of cut-points). We intentionally set these analyses up as a classification problem whereby the algorithm minimizes node "impurity" (ie, makes the nodes as homogenous as possible with regard to the prevalence of the outcome, mobility limitation). The best solution for this problem in men was to identify 3 cut-points but for women, it was to identify 2 cut-points. In other words, for men, the algorithm found that it could improve its objective function (reduce node "impurity") beyond noise (the cross-validation) by creating another node, but another node was not helpful in this regard for women.

Across men and women, 2 similar cut-points were found (0.6 and 0.75 m/s). The utility of each cut-point depends on its intended use. The cut-point of 0.6 m/s is emerging as one that distinguishes

Table 2. Likelihood (odds ratio, 95% CI) of Mobility Limitation by Category of Walking Speed in Men and Women

Group	Women		Men	
	With derived cut-points*	With rounded cut-points*	With derived cut-points*	With rounded cut-points*
Fast or very fast	1.0 (referent)	1.0 (referent)	1.0 (referent)	1.0 (referent)
Intermediate	3.6 (2.9, 4.4)	3.9 (3.2, 4.7)	4.8 (3.9, 5.8)	4.4 (3.7, 5.3)
Slow	10.1 (8.1, 12.7)	9.8 (7.8, 12.4)	12.5 (9.3, 16.8)	11.2 (8.6, 14.7)

*Derived cut-points are 0.57 and 0.74 m/s in men and 0.62 and 0.75 m/s in women; rounded cut-points are 0.6 and 0.75 m/s in men and women, respectively.

those with poor function. It is rare for community-dwelling older adults to be below this cut-point, as only 1.3% of men and only 8.3% of women were below this level and classified as slow by our analysis. Thus, in situations where the aim is to maximize the sensitivity of walking speed to identify those with poor function then the lower cut-point is likely most appropriate. On the other hand, previously suggested cut-points of 0.8 or 1.0 m/s[3] result in a very high prevalence of slowness, particularly in the oldest old. For example, data from the National Health and Nutrition Examination Survey suggest that slowness defined by gait speed <1.0 m/s would be nearly universal in the oldest old, with a prevalence in the United States of 88% in men and 94% in women aged 85 and older ([3]). This high prevalence suggests that these higher cut-points for slowness would have little impact on risk stratification for adverse events in the oldest old (as everyone would be classified as "high risk"). On the other hand, if the intended use of the cut-point is to discriminate those with excellent function from those with good to poor function, then the higher cut-point of 0.75 m/s (or 1.0 m/s for men) may be useful. In this case, the goal would be to maximize the sensitivity of walking speed to identify those without any functional limitations. We note that the CART model found cut-points that are somewhat arbitrary in that they relate only to the features included in the model—walking speed and mobility limitation—and do not necessarily represent an underlying biological relationship, especially considering the clear log-linear relationship between walking speed and risk of limitation and disability. Thus, while categorization of walking speed will be useful in many situations, investigators should also consider the analysis of walking speed as a continuous variable especially when aiming to elucidate biological or other factors associated with walking speed.

The medical community often categorizes patients into risk groups despite a linear association between a health predictor and outcome. As an example, the association between systolic blood pressure and risk of stroke is extremely linear—yet, the treatment recommendations are based on cut-points. A similar phenomenon exists for glucose, low-density lipoprotein cholesterol, BMI, and bone density on their respective adverse health outcomes. Interestingly, cut-points for these commonly used measures are often not based on an empirical approach as we have performed. Instead, because of their linear associations with health outcomes, such cut-points are generated from consensus agreement among experts in the field. In clinical situations, the utility of these cut-points is not entirely clear, in part because there are no clear treatment pathways for those who walk slowly. However, patients with walking speeds below a lower cut-point of 0.6 m/s might be considered for treatment that carries higher costs and/or side effects (eg, for a yet-to-be-approved pharmacological treatment), whereas patients above the higher cut-point of 0.75 m/s may not have to be counseled about activities to improve

fitness. Future work should further establish the clinical utility of these cut-points.

The CART models did not perfectly group individuals into high- versus low-functioning groups—while the prevalence of mobility limitation was much higher in the "slow" group than the "fast" or "very fast" groups, it was not negligible in the "fast"/"very fast" groups: about 11% in men and 19% in women. The reason for the apparent discrepancy for those who walk fast but still report limitation is not entirely clear, but this could be due to pain, endurance, or other factors that affect function over longer distances (~1/4 mile distance for self-reported limitation) versus <20 m distance (for objectively measured walking speed).

These data also reinforce differences between men and women in terms of walking speed and are consistent with previous results from normative databases that consistently demonstrate that women walk more slowly than men ([17],[18]). Also consistent with our results, women are more likely to report mobility limitation than men ([19–28]), despite having better self-rated health and less multimorbidity than men ([28]). These differences are unlikely to be due to reporting differences as studies have found that men and women generally report disability accurately ([19],[22],[29],[30]). Future studies should aim to elucidate the reasons for this consistent sex difference. Categorization of men and women as "slow," "intermediate," and "fast or very fast" classifies more women than men as slow; at every level of walking speed, more women than men report mobility limitation. We believe that this approach is correct, as it correctly reflects the additional burden of limitation that women carry when compared with men. However, an alternative approach could have been used to identify different cut-points in walking speed by sex: For example, we could have used other regression techniques to determine the level of walking speed at which the prevalence of mobility limitation reached some prespecified threshold (eg, 10%) for each sex. However, such an approach would have fixed the prevalence of mobility limitation across sexes as equal: If women have more limitations, then cut-points that identify more women as having such limitations will reflect the underlying burden of disease across the whole population.

While these analyses included a very large number of participants, limitations should be noted. Other reports have noted differences in walking speed or mobility complaints by race and ethnicity ([9],[31–33]). Some race and ethnic groups are underrepresented, precluding our ability to perform analysis stratified by these factors. In addition, while some non-US cohorts were included in these analyses, too few international cohorts were available to stratify analyses by geographical location, so we are unable to determine whether race, geography, or local customs influence the associations reported here, and this should be a topic for future analyses. The data were harmonized, but some differences in the wording of the questions about mobility limitation may have influenced reporting of this condition differentially across studies. This study is cross-sectional and longitudinal models

(for predicting incident mobility limitation) may define other cut-points. In addition, we used descriptive terms of "very fast," "fast," "intermediate," and "slow" to describe the groups of participants. We note that these terms are relative to one another in the context of older adults participating in our studies. Further gradations in walking speed may exist in extremes of the population, such as master's athletes who may be a faster group than the "very fast" or disabled but ambulatory individuals living in care facilities who may be much slower than the "slow." Indeed, a recent analysis suggested that cut-points of 0.35 m/s may optionally differentiate in-hospital walking independence among surgical patients ([8]). However, other terms, such as "normal," did not seem appropriate as our population was ambulatory, community-dwelling older adults who were not necessarily representative of underlying populations. Finally, CART is a useful tool to identify cut-points; however, CART only picks one optimum model comprising a cut-point or set of cut-points; other models that were not identified (that could have included more cut-points or cut-points at different levels) may have performed nearly as well as those reported in this article.

In conclusion, in both men and women, the data-driven models identified cut-points in walking speed of approximately 0.60 and 0.75 m/s that best discriminated individuals based on prevalent mobility limitation. These cut-points should be considered when categorized values of walking speed are required, for example, in research for determining eligibility for clinical trials and in clinical settings for determining those in need of follow-up or treatment.

Supplementary Material

Supplementary data are available at *The Journals of Gerontology, Series A: Biological Sciences and Medical Sciences* online.

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Conflict of Interest

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