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Comparison of measurement protocols to estimate preferred walking speed between sites

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ABSTRACT

Background: Walking speed influences a variety of typical outcome measures in gait analysis. Many researchers use a participant's preferred walking speed (PWS) during gait analysis with a goal of trying to capture how a participant would typically walk. However, the best practices for estimating PWS and the impact of laboratory size and walk distance are still unclear.
Research question: Is measured PWS consistent across different distances and between two laboratory sites?
Methods: Participants walked overground at a "comfortable speed" for six different conditions with either dynamic (4, 6, 10, and 400 m) or static (4 and 10 m) starts and stops at two different data collection sites. Repeated measures ANOVA with Bonferroni corrections were used to test for differences between conditions and sites.
Results: Participants walked significantly faster in the 4, 6, and 10 m dynamic conditions than in the 400 m condition. On average, participants walked slower in the static trials than the dynamic trials of the same distance. There was a significant interaction of lab and condition and so results were examined within each lab. Across both labs, we found that the 4 and 10 m dynamic conditions were not different than the 6 m dynamic condition at both sites, while other tests did not provide consistent results at both sites.
Significance: We recommend researchers use a 6 m distance with acceleration and deceleration zones to reliably test for PWS across different laboratories. Given some of the differences found between conditions that varied by site, we also emphasize the need to report the test environment and methods used to estimate PWS in all future studies so that the methods can be replicated between studies.

1. Introduction

Preferred or self-selected walking speed (PWS) is often evaluated prior to a gait analysis so that participants' typical movement patterns may be captured [1,2]. Because common spatiotemporal, kinematic, and kinetic variables change with walking speed [3–5], similar populations could appear different between studies if within-participant PWS is sensitive to different gait analysis settings. Therefore, estimating PWS in a manner that is consistent regardless of setting is important when comparing between groups, or when replicating studies in the literature.

There is a wide range of reported PWSs, even for healthy, control participants, and a variety of tests used to measure PWS [6–8]. While some variation in PWS across studies could be attributed to different subject populations [9], previous research has also suggested that PWS can depend on testing differences including participant awareness [10,11], discrete versus continuous trials [10,12] inclusion of acceleration and deceleration zones [13,14], and verbal cues [15]. Due to a lack of standardized methodology, we need standardized tests that provide consistent within-subject PWS, to ensure that preferred speed gait analyses are not dependent upon a lab's environment or protocol, but represent actual population differences.

Therefore, the purpose of this study was to determine: 1) how measured PWS depends on protocol by varying the distance participants walk and their awareness of being assessed, and 2) how different laboratory environments affect consistency of PWS measurement. We

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then sought to establish a recommendation for the measurement of overground PWS.

2. Methods

This study was performed with different participants at two research sites: the University of Massachusetts Amherst (UMass; 14 M/10 F; 20 ± 2 years; 1.70 ± 0.08 m; 69.1 ± 12.6 kg) and the University of Michigan (UMich; 9 M/21 F; 25 ± 6 years; 1.71 ± 0.10 m; 74.7 ± 19.5 kg). The protocol was approved by the Institutional Review Boards of both institutions. The protocol was the same but the investigators differed between locations. UMass participants were tested along a 25 m walkway inside a biomechanics laboratory and UMich participants were tested in a 25 m hallway.

At the beginning of each session, sex, age, height, and weight were recorded and participants were fit with a sham device placed on a belt around the hips. Participants were informed that the study purpose was to validate a new accelerometer to blind them to the purpose of the experiment (to measure PWS).

Each subject was instructed to "walk at a comfortable speed" for each of the following conditions (Fig. 1): 4, 6, 10, and 400 m distances with additional 3 m zones for acceleration and deceleration (dynamic), and 4 and 10 m distances without acceleration or deceleration zones (static) [14]. Condition order was randomized, and three trials of each condition were performed, except for the 400 m condition (1 trial). The time that it took for the subject to walk the set distance was timed with a hand stopwatch (shown to give consistent results compared to optokinetic timers [13]), and recorded to the nearest tenth of a second. Additionally, walking speed was recorded covertly [10,11] three times over a 10 m distance: once before the conditions began, once following the 400 m trial, and once at the end of the session. In these covert conditions, speeds were secretly timed as participants walked to a new position of the lab/hallway to prepare for the next condition. Following the completion of the protocol, participants were informed of the true purpose of the study and asked if they would like to withdraw their data (no participant chose to withdraw).

Measured walking speed was compared between PWS conditions and between laboratory sites using a two (site) by six (condition) repeated measures factorial ANOVA [SPSS Statistics v24, IBM, Armonk, NY]. Bonferroni corrections were performed to account for multiple comparisons across repeated conditions. Because different individuals were tested at each laboratory, we examined condition × lab interactions to determine if there was an effect of testing site on consistency in walking speed across conditions. Where significant interactions were found ($\alpha = 0.05$), post-hoc RMANOVAs were used to compare across PWS conditions for each lab.

3. Results

There were statistically significant differences between labs ($p = 0.018$), across conditions ($p < 0.001$), and there was a lab by condition interaction ($p < 0.001$). The average walking speed across all conditions was 1.41 ± 0.14 m/s at UMich and 1.31 ± 0.14 m/s at UMass. For the dynamic conditions, participants walked slower for 400 m than for 4, 6, and 10 m (Fig. 2). On average, participants walked slower during static than dynamic conditions, although there were between lab differences for the static trials (Fig. 2). When conditions were compared within each lab to examine the condition × lab interaction, within-participant PWS were similar at both labs between the dynamic 4 and 6 m and between the 6 and 10 m conditions, as well as between the dynamic 6 and 10 m conditions and the covert condition (Table 1). All other conditions were different from each other at UMass, UMich, or both sites.

4. Discussion

The purpose of this study was to evaluate the PWSs of participants over a range of distances at two different testing sites. Overall, we

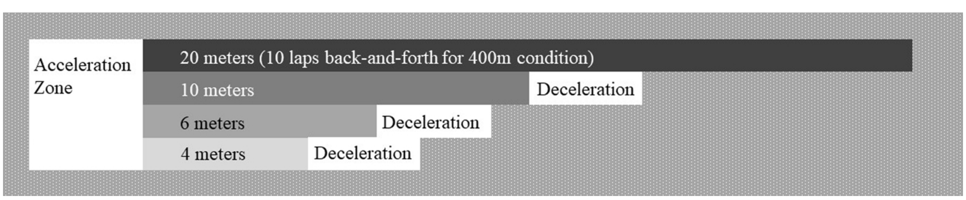

Fig. 1. Schematic diagram of the different conditions. White boxes show the 3 m acceleration or deceleration zones. The dynamic trials include the acceleration and deceleration zones for the 4, 6, 10, and 400 m zones (total distance = 10, 12, 16, and 406 m, respectively). The static trials for the 4 and 10 m conditions did not include the acceleration and deceleration zones. Trials were all evaluated with straightaway distances, with the exception of the 400 m trial, which consisted of 10 back-and-forth laps of a 20 m straightaway distance.

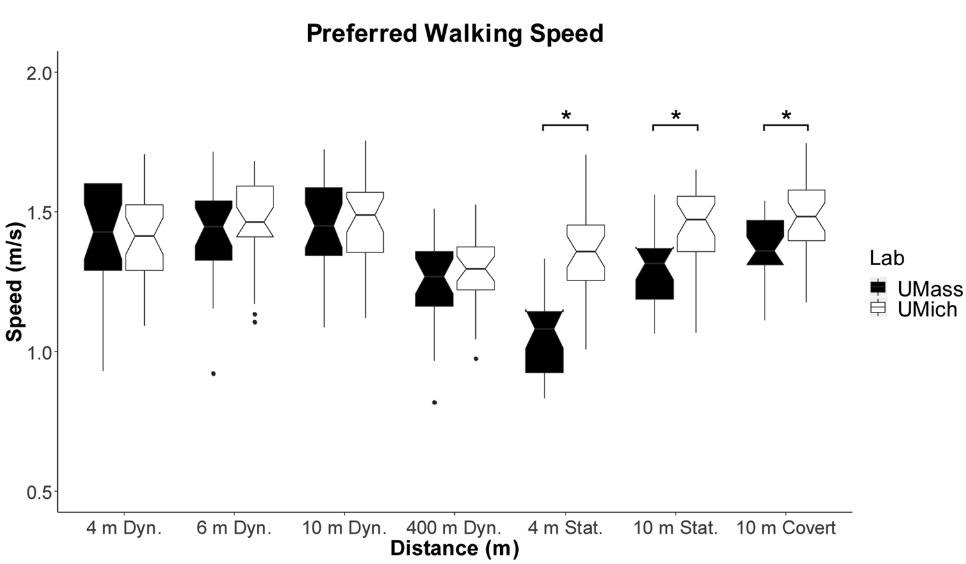

Fig. 2. Box plot showing walking speeds across all conditions for each of the two testing sites. Labels on the x-axis appended with "Dyn." indicate trials where the participants were walked the set distance plus 3 m to accelerate and 3 m to decelerate, "Stat." indicate trials with static starts and stops. The black boxes show data collected at the University of Massachusetts Amherst and the white boxes show data collected at the University of Michigan. Bars with asterisks indicate statistically significant differences between sites.
4 m stat.: faster at UMich than UMass (1.34 vs. 1.05, $p < 0.001$)
10 m stat.: faster at UMich than UMass (1.44 vs. 1.28, $p < 0.001$)
10 m Covert: faster at UMich than UMass (1.48 vs. 1.38, $p = 0.007$)
See Table 1 for a description of the statistical differences between conditions within labs.

Table 1
Means, standard errors, and 95 % confidence intervals (CI; lower bound – higher bound) for each condition from each lab. Labels appended with "Dyn." indicate trials where the participants were walked the set distance plus 3 m to accelerate and 3 m to decelerate, "Stat." indicate trials with static starts and stops. UMass n = 24, UMich n = 30. For pairwise comparisons within labs: UMass: condition is different from A = 4 m Dyn; B = 6 m Dyn; C = 10 m Dyn; D = 400 m Dyn; E = 4 m Stat.; F = 10 m Stat.; G = 10 m Covert. UMich: condition is different from I = 4 m Dyn; II = 6 m Dyn; III = 10 m Dyn; IV = 400 m Dyn; V = 4 m Stat.; VI = 10 m Stat.; VII = 10 m Covert.

	Lab	Condition	Mean ± SE (m/s)	95 % CI (LB–HB; m/s)	Pairwise comparisons						
A	UMass	4 m Dyn.	1.40 ± 0.04	1.36–1.44	–			D	E	F	
B	UMass	6 m Dyn.	1.42 ± 0.04	1.38–1.46		–		D	E	F	
C	UMass	10 m Dyn.	1.44 ± 0.03	1.41–1.47			–	D	E	F	
D	UMass	400 m Dyn.	1.25 ± 0.04	1.21–1.29	A	B	C	–	E		G
E	UMass	4 m Stat.	1.05 ± 0.03	1.02–1.08	A	B	C	D	–	F	G
F	UMass	10 m Stat.	1.28 ± 0.03	1.25–1.31	A	B	C		E	–	G
G	UMass	10 m Covert	1.38 ± 0.02	1.36–1.40				D	E	F	–
I	UMich	4 m Dyn.	1.41 ± 0.03	1.38–1.44	–		III	IV			VII
II	UMich	6 m Dyn.	1.45 ± 0.03	1.42–1.48		–		IV	V		
III	UMich	10 m Dyn.	1.45 ± 0.03	1.42–1.48	I		–	IV	V		
IV	UMich	400 m Dyn.	1.29 ± 0.02	1.27–1.31	I	II	III	–		VI	VII
V	UMich	4 m Stat.	1.34 ± 0.03	1.31–1.37		II	III		–	VI	VII
VI	UMich	10 m Stat.	1.44 ± 0.03	1.41–1.47				IV	V	–	
VII	UMich	10 m Covert	1.48 ± 0.03	1.45–1.51	I			IV	V		–

Statistical p-values for pairwise comparisons within labs are available in Supplementary Table 1.

found that for both laboratory sites, the PWS for the 6 m dynamic condition was not different from the 4 m or 10 m dynamic conditions, or the covert 10 m condition.

Despite static starts/stops being included in common clinical tests like the Short Physical Performance Battery and Dynamic Gait Index, our finding that acceleration and deceleration zones provide faster and more consistent gait speeds is in line with previous research [13,14]. Our results add to these previously reported data by including between-site comparisons. Using acceleration and deceleration zones is also likely consistent with the methods used to collect steady-state overground gait data in the lab, and is therefore recommended to allow for consistent results across studies.

Previous researchers have reported differences in gait speed when measured in a covert versus overt way [10,11]. Our study did not find differences in gait speed between covert trials and the straight-away short-distance trials. However, our overt and covert trials were different from previous research, as participants were informed the purpose of the study was to validate an accelerometer.

We recommend using a 6 m distance with acceleration and deceleration zones (with subject's awareness) when measuring PWS for overground gait analysis to facilitate comparisons between studies, because the 6 m dynamic condition was not statistically different from the 4 or 10 m conditions and gave similar PWSs between sites. However, speeds measured over shorter distances may be faster than a subject feels comfortable walking over longer distances (like 400 m), so researchers should carefully select the distance to measure PWS such that it aligns with their purpose and methods. Some labs may not have a 12 m straightaway distance within their lab space to perform this recommended distance; our results suggest it may be reasonable to perform the measurements in a long hallway instead, as was done at UMich. Due to the influence of protocol on PWSs found in this study and others [10,11,13–15], we recommend that researchers fully describe the methods used to estimate PWS to enable replication of studies. Future studies could examine whether a 6 m test is most appropriate for other populations, especially those with endurance or mobility limitations.

CRediT authorship contribution statement

Russell T. Johnson: Conceptualization, Data curation, Investigation, Methodology, Project administration, Visualization, Writing - original draft, Writing - review & editing. **Jocelyn F. Hafer:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing - review & editing. **Ryan D. Wedge:** Conceptualization, Data curation, Investigation, Methodology, Writing - review & editing. **Katherine A. Boyer:** Conceptualization, Methodology, Supervision, Writing - review & editing.

Declaration of Competing Interest

None.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.gaitpost.2020.01.007.

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