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Comparison of manual and automated measures of walking speed: Distance and pace matter

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ABSTRACT

Background: Walking speed (WS) represents a global marker of individual health and provides a simple and objective measure of motor performances for use in clinical and research settings. WS is most often measured over relatively short distances at usual (UWS) or fast (FWS) pace, using manual (e.g., stopwatch) or automated methods (e.g., photoelectric cells). As the time needed to walk over these distances is very short, we hypothesized that measurement error related to manual compared to automated WS measures is more pronounced for shorter distances and FWS and investigated the reliability and agreement of WS in a subsample of the Constances cohort at two paces and over two distances.

Methods: We recruited 100 community-dwelling participants (50 % women) aged 45–70y (mean = 56.1y). WS was measured manually (stopwatches) and using photoelectric cells, at two paces (UWS/FWS) and over two distances (3 m/5 m). Agreement was examined using Bland and Altman plots and intraclass correlation coefficients (ICC).

Results: Participants were on average 169.8 cm tall, and their mean body mass index was 25.4 kg/m^2. Agreement between manual stopwatches and photoelectric cells was excellent (ICCs between 0.92 and 0.97), but it was lower for smaller distances, with significantly lower ICCs over 3 m compared to 5 m both for UWS ($difference_{ICC} = -0.04$) and FWS ($difference_{ICC} = -0.05$). Bias of manual measures was constant for UWS and increased with increasing FWS. There were inter-rater effects, with better agreement for UWS and 5 m compared to FWS and 3 m.

Conclusions: Both distance and pace have an influence on the reliability of WS measures using manual timing methods. Our findings also suggest the presence of rater effects and better agreement for 5 m and UWS. These findings are helpful for the design of studies that include manual measures of WS, especially FWS, in order to reduce measurement error and suggest that longer distances are preferable.

1. Introduction

Walking speed (WS) represents a global marker of individual health [1–3], and one of the main frailty criteria in the elderly [4]. WS provides a simple and objective measure of motor performances for use in clinical and research settings [5–7]. Slower WS and steeper WS decline are associated with increased risk of unfavorable health outcomes (disability, dementia, death) [7–10].

WS measurement protocols vary across studies, as WS can be measured over different distances, at different paces, and using different start/end protocols or timing methods [6,11]. A systematic review of the literature showed that the type of starting procedure and length of the test distance had an influence of average WS; there was no overall difference between manual and automated timing methods but individual studies showed significant differences in both directions [12]. Although some studies examined the reliability of WS measures [13–17], none investigated simultaneously the role of distance, pace, and timing methods. WS is most often measured over relatively short distances at usual (UWS) or fast (FWS) pace [18]. When WS is measured manually, measurement error may be higher over shorter distances and at a faster pace, as the time needed to walk over these distances is very short and the examiner needs to start and stop the stopwatch very fast. We

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hypothesized that measurement error related to manual compared to automated WS measures is more pronounced for shorter distances and FWS.

In a subsample of the Constances cohort [19,20], our aim was to compare at two paces (UWS/FWS) and over two distances (3 m/5 m) (*i*) the agreement between manual and automated (photoelectric cells) timing methods of WS, and (*i*) interrater agreement for manual measures.

2. Methods

2.1. Design and participants

Participants were recruited in the Constances cohort [19,20] between November 2015–February 2016. For the present substudy, we consecutively recruited a sex- and age-stratified (45–55 years; >55 years) sample of 100 volunteers at the Health Screening Center (HSC) of the city of Lille.

The French National Data Protection Authority and IRB of the National Institute for Medical Research approved the study protocol. All participants gave written informed consent.

2.2. Walking speed

WS was assessed using a dynamic protocol with a 1 m zone of acceleration/deceleration at each side of the test area. Participants performed 4 walks corresponding to the combination of two distances (3 m/5 m) and paces (UWS: "walk at your usual pace"; FWS: "walk as fast as you can without running"). The order was the same for all the participants (3 m-UWS; 3 m-FWS; 5 m-UWS; 5 m-FWS). Participants were invited to wear comfortable shoes and asked to remove them if wearing heels. Use of walking aids was allowed. Participants were allowed one trial before the actual measures.

The time taken to perform the test was recorded simultaneously by photoelectric cells (Racetime2 kit light radio, MicroGate®) and by three trained neuropsychologists who used manual stopwatches. Two neuropsychologists recorded the time for approximatively half of the participants each (raters 1A and-1B), while the third (rater 2) recorded the time for all participants. We divided the distance (300–500 cm) by the time recorded at the nearest centisecond to estimate WS in cm/s.

2.3. Statistical methodology

We used paired *t*-tests to test for differences in mean WS. Agreement was examined using Bland and Altman plots [21] and intraclass correlation coefficients (ICC) [22].

Bland and Altman plots allow a graphical visualization and quantification of agreement between two methods. The plot includes a scatter plot of the difference (Y-axis) and average of the two measures (X-axis). Limits of agreement (LoA) delimit the interval in which 95 % of the differences are found. A smaller range between the two limits indicates better agreement. The plot also includes the average difference (or bias) and its 95 % confidence interval (CI). If two measures are on average concordant, bias is not significantly different from 0; if bias is different from 0, one method provides higher/lower values than the other.

One limitation of this approach, however, is that it assumes that bias is constant across all the values of the measure [21,23]. We tested this assumption by regressing the difference on the mean of the measures modelled using restricted cubic splines with three knots located at the percentiles; we tested whether splines improved model's fit compared to linear regression (P_{Spline}). If this test was not significant ($P_{Spline} > 0.05$), we then tested whether there was a linear relation between the difference and the mean (P_{Linear}); if not ($P_{Linear} > 0.05$), we concluded that bias was constant.

ICCs were computed using a 2-way random effects model for absolute agreement [24]. We compared two ICCs by computing their difference and 2.5th and 97.5th percentiles using the bootstrap ($n = 5000$). If the 2.5th–97.5th percentiles interval did not include 0, we concluded that there was a significant difference between two ICCs.

We used the methods described above to assess: (*i*) agreement between timing methods (manual vs. photoelectric cells): we compared WS measures taken by the photoelectric cells and rater 2; and (*ii*) interrater variability: we compared measures taken by rater 2 to those taken by raters 1A and 1B.

In sensitivity analyses, we repeated these analyses in two age groups (45-55y, >55y). Due to the lower number of participants in each group, we used a less stringent significant threshold of $P \leq 0.10$ for P_{Spline} and P_{Linear}.

According to our calculations of statistical power (Supplementary Methods), our sample size was sufficient for assessing agreement between automated and manual timing methods by the Bland−Altman method with statistical power of 80 % [25].

Statistical analyses were performed using SAS 9.4 (Institute Inc., Cary, NC, USA).

3. Results

One hundred adults (50 % women) aged 45-70y (mean age = 56.1y, standard deviation [SD] = 7.5) participated in the study; their characteristics are shown in Supplementary Table S1. Older participants tended to be in poorer health than younger ones. One participant used a cane.

Mean (SD) WS is shown in Table 1. Overall, participants walked slower over 3 m compared to 5 m at usual pace ($P < 0.001$), while they walked faster over 3 m compared to 5 m at fast pace (P between < 0.001 and 0.030). As expected, older participants walked slower than younger ones.

The average times needed to cover 3 m and 5 m were small (<4 s). For instance, for photoelectric cells, the average time needed to cover 3 m was 2.36 s (SD = 0.57) for UWS and 1.57 s (SD = 0.34) for FWS, compared to 3.69 s (SD = 0.86) for UWS and 2.69 s (SD = 0.60) for FWS for 5 m.

3.1. Agreement between manual stopwatches and photoelectric cells

Table 2 presents the agreement between WS measured with manual stopwatches (rater 2) and photoelectric cells. All combinations of distance and pace showed excellent agreement (ICCs between 0.92 and 0.97). However, agreement was lower for smaller distances, with significantly lower ICCs over 3 m compared to 5 m, both for UWS ($difference_{ICC} = -0.04$) and FWS ($difference_{ICC} = -0.05$). For a given distance, agreement was similar for UWS and FWS (3 m-$difference_{ICC}$ = 0.01; 5 m-$difference_{ICC}$ = 0.00).

Fig. 1 and Supplementary Table S2 show results of Bland and Altman analyses. There was no significant relation between the difference and mean for UWS, suggesting that bias was constant as UWS increased. UWS measures with the manual stopwatch tended to be lower than those taken with photoelectric cells, with a more pronounced average bias for 3 m (1.6 cm/s, 95 % CI = −0.1, 3.4) than 5 m (0.9 cm/s, 95 % CI = −0.3, 2.1). Limits of agreement were wider for 3 m than 5 m.

Alternatively, the difference and mean of both 3 m- and 5 m-FWS were significantly associated (Fig. 1, Supplementary Table S2). For 3 m-FWS, the relation between the difference and mean was not linear ($P_{Spline} = 0.038$). The average bias appeared to be null before 200 cm/s; after this threshold, the stopwatch overestimated WS and the difference increased with increasing FWS (Fig. 1-B). Although the scatterplot suggests a similar pattern for 5 m-FWS (Supplementary Fig. S1), a linear relation between the mean and difference was not rejected ($P_{Spline} = 0.27$) and we used linear regression for our main analyses showing that the stopwatch underestimated FWS at slower speed and overestimated FWS at faster speed ($P_{Linear} = 0.007$; Fig. 1-D).

A similar pattern of increasing bias with increasing FWS was present

Table 1
Description of walking speed measured by photoelectric cells and stopwatches.

Method	N	Usual walking speed (cm/s)			Fast walking speed (cm/s)		
		3 m Mean (SD)	5 m Mean (SD)	P-paired *t*-Test	3 m Mean (SD)	5 m Mean (SD)	P-paired *t*-test
Overall							
Photoelectric cells	99	132.7 (24.3)	140.7 (24.3)	<0.001	198.0 (32.4)	192.0 (31.5)	<0.001
Stopwatch							
Rater 1A	49	131.8 (26.9)	139.1 (27.7)	<0.001	204.1 (37.7)	191.7 (34.5)	<0.001
Rater 1B	51	134.4 (22.3)	140.5 (22.1)	<0.001	198.1 (32.2)	191.1 (29.9)	0.008
Rater 2	100	131.1 (24.7)	139.8 (24.6)	<0.001	197.4 (35.3)	192.8 (33.5)	0.030
	49[a]	128.1 (25.4)	135.7 (26.0)	<0.001	199.7 (38.6)	189.0 (34.6)	<0.001
	51[b]	134.0 (23.9)	143.7 (22.7)	<0.001	195.1 (32.1)	196.5 (32.3)	0.65
45–55 years							
Photoelectric cells	52	138.1 (19.3)	145.3 (19.3)	<0.001	204.6 (22.8)	200.2 (25.0)	0.003
Stopwatch							
Rater 1A	30	140.6 (22.7)	145.5 (23.3)	0.032	211.7 (26.0)	201.8 (25.7)	0.019
Rater 1B	23	137.2 (19.1)	143.7 (17.3)	0.031	204.2 (23.3)	199.5 (24.2)	0.23
Rater 2	53	136.1 (19.4)	144.3 (19.9)	<0.001	205.6 (26.6)	199.0 (25.7)	0.009
	30[a]	136.2 (21.3)	142.0 (21.0)	0.033	209.0 (28.6)	197.2 (26.6)	<0.001
	23[b]	136.0 (17.2)	147.3 (18.4)	0.001	201.1 (23.7)	201.2 (24.9)	0.97
>55 years							
Photoelectric cells	47	126.7 (27.9)	135.6 (28.2)	<0.001	190.7 (39.5)	182.9 (35.5)	<0.001
Stopwatch							
Rater 1A	19	117.8 (27.7)	129.0 (31.6)	<0.001	192.1 (49.5)	175.9 (41.0)	0.002
Rater 1B	28	132.1 (24.8)	138.0 (25.4)	0.002	193.1 (37.7)	184.2 (32.6)	0.013
Rater 2	47	125.4 (28.6)	134.7 (28.3)	<0.001	188.1 (41.5)	185.9 (39.7)	0.52
	19[a]	115.3 (26.4)	125.7 (30.4)	0.004	185.0 (47.8)	176.0 (42.0)	0.086
	28[b]	132.3 (28.4)	140.8 (25.6)	0.002	190.2 (37.4)	192.6 (37.3)	0.62

SD, standard deviation. Fast walking speed was always greater than usual walking speed (all $P < .0001$).
[a] Participants with WS measured by rater 1A.
[b] Participants with WS measured by rater 1B.

in younger and older participants, except for 5 m-FWS in younger participants for which bias was constant (Supplementary Table S3, Supplementary Fig. S2).

3.2. Inter-rater agreement between manual stopwatches

Table 2 presents inter-rater agreement for manual stopwatches (raters 1A and 1B compared to rater 2). Agreement between raters 1A and 2 was excellent (ICCs between 0.91 and 0.95); it tended to be lower for 3 m than 5 m-WS, but differences were not statistically significant. ICCs between raters 1B and 2 were lower (ICCs between 0.83 and 0.93). The ICC for 5 m-UWS was significantly higher than that for 5 m-FWS.

Supplementary Table S2 and Supplementary Figs. S3 and S4 present results of Bland and Altman analyses. The difference and mean of WS were not correlated for all combinations of distance and pace, thus suggesting that biases were constant. Compared to rater 2, rater 1A provided significantly faster WS measures for all combinations (mean differences between 2.7 and 4.4 cm/s). Compared to rater 2, rater 1B provided significantly slower 5 m-WS (UWS: −3.2 cm/s; FWS: −5.3 cm/s), and tended to provide faster 3 m-WS but the difference was not significant. For both raters, the interval between LoAs was smaller for UWS than FWS, and for 5 m compared to 3 m for both paces, thus suggesting better agreement for UWS and 5 m.

Results tended to be similar in younger and older participants; however, bias was related to mean WS for 5 m-UWS in younger participants and 3 m-UWS in older ones (Supplementary Fig. S5, Supplementary Fig. S6).

4. Discussion

In this study, we examined the reliability and agreement of WS measures in community-dwelling participants aged 45–70y while taking into account distance (3 m/5 m) and pace (UWS/FWS). There was an excellent agreement between WS measured with photoelectric cells and stopwatches, but agreement was lower for 3 m than 5 m, both for UWS and FWS. For FWS, reliability decreased with increasing speed, thus suggesting that measurement error is higher for those who walk faster. Our findings also suggest the presence of rater effects and better agreement for 5 m and UWS. Age-stratified analyses tended to show similar patterns in younger and older participants.

Manual timers are an inexpensive and simple method to measure WS [6]. However, their use introduces an error attributable to raters' effects [16,26]. This error exists despite training and explicit protocols [16], and is likely due to differences in stopwatch triggering [12,16]. The shorter the distance and the faster WS, the faster the tester needs to press the stopwatch. We therefore hypothesized that agreement would be lower for shorter distance and faster pace, and our findings are consistent with this hypothesis.

Although agreement between stopwatches and photoelectric cells was excellent, consistent with previous studies [6,13,15,16], it was lower for 3 m than 5 m independently of pace. Furthermore, Bland and Altman analyses showed that bias increased with FWS. This pattern was more pronounced for 3 m- than 5 m-FWS, likely due to a larger variability of differences as reflected by a wider interval between LoAs. A similar pattern was described in 34 cognitively impaired individuals, in

Table 2
Intraclass correlation coefficients (ICC).

WS test	ICC (95 % CI)	Difference between ICCs (95 % CI)[a]	
Comparison between timing methods: photoelectric cells vs. stopwatch by rater 2 (*N* = 99)			
3 m UWS	0.93 (0.90, 0.95)	**3 m UWS–3 m FWS**	0.01 (−0.03, 0.05)
3 m FWS	0.92 (0.88, 0.95)	**3 m UWS–5 m UWS**	**−0.04 (−0.07, −0.02)**
5 m UWS	0.97 (0.96, 0.98)	**3 m FWS–5 m FWS**	**−0.05 (−0.09, −0.02)**
5 m FWS	0.97 (0.95, 0.98)	**5 m UWS–5 m FWS**	0.00 (−0.01, 0.02)
Comparison between raters using a stopwatch			
Raters 1A and 2 (N = 49)			
3 m UWS	0.92 (0.88, 0.95)	**3 m UWS–3 m FWS**	0.01 (−0.05, 0.06)
3 m FWS	0.91 (0.87, 0.94)	**3 m UWS–5 m UWS**	−0.03 (−0.09, 0.02)
5 m UWS	0.95 (0.91, 0.97)	**3 m FWS–5 m FWS**	−0.02 (−0.07, 0.02)
5 m FWS	0.93 (0.90, 0.95)	**5 m UWS–5 m FWS**	0.02 (−0.02, 0.06)
Raters 1B and 2 (N = 51)			
3 m UWS	0.88 (0.83, 0.92)	**3 m UWS–3 m FWS**	0.06 (−0.05, 0.18)
3 m FWS	0.83 (0.75, 0.88)	**3 m UWS–5 m UWS**	−0.05 (−0.12, 0.01)
5 m UWS	0.93 (0.89, 0.95)	**3 m FWS–5 m FWS**	−0.01 (−0.14, 0.14)
5 m FWS	0.84 (0.76, 0.89)	**5 m UWS–5 m FWS**	**0.09 (0.00, 0.22)**

WS: walking speed; ICC: intraclass correlation coefficient; CI: confidence interval; UWS: usual walking speed; FWS: fast walking speed.
Bold values represent differences that were significantly different from 0.
[a] Confidence intervals of differences were estimated by bootstrapping

analyses combining results of several 6 m-WS measures (UWS/FWS, single/dual-task) [15]. Another study of 1177 community-dwelling Korean adults aged 70-84y assessed for 4 m-UWS showed that the difference between automated and manual measures increased with increasing WS, and that manual measures tended to increasingly underestimate, rather than overestimate, WS at the highest values; however, non-linear effects were not examined in that study [17].

When WS is only measured once, the excellent agreement between stopwatches and photoelectric cells, as already reported [6,13,15], suggests that manual WS measures are reliable. However, there appeared to be some differences across raters, as in previous studies [16,26], with better agreement for UWS and 5 m. These results support

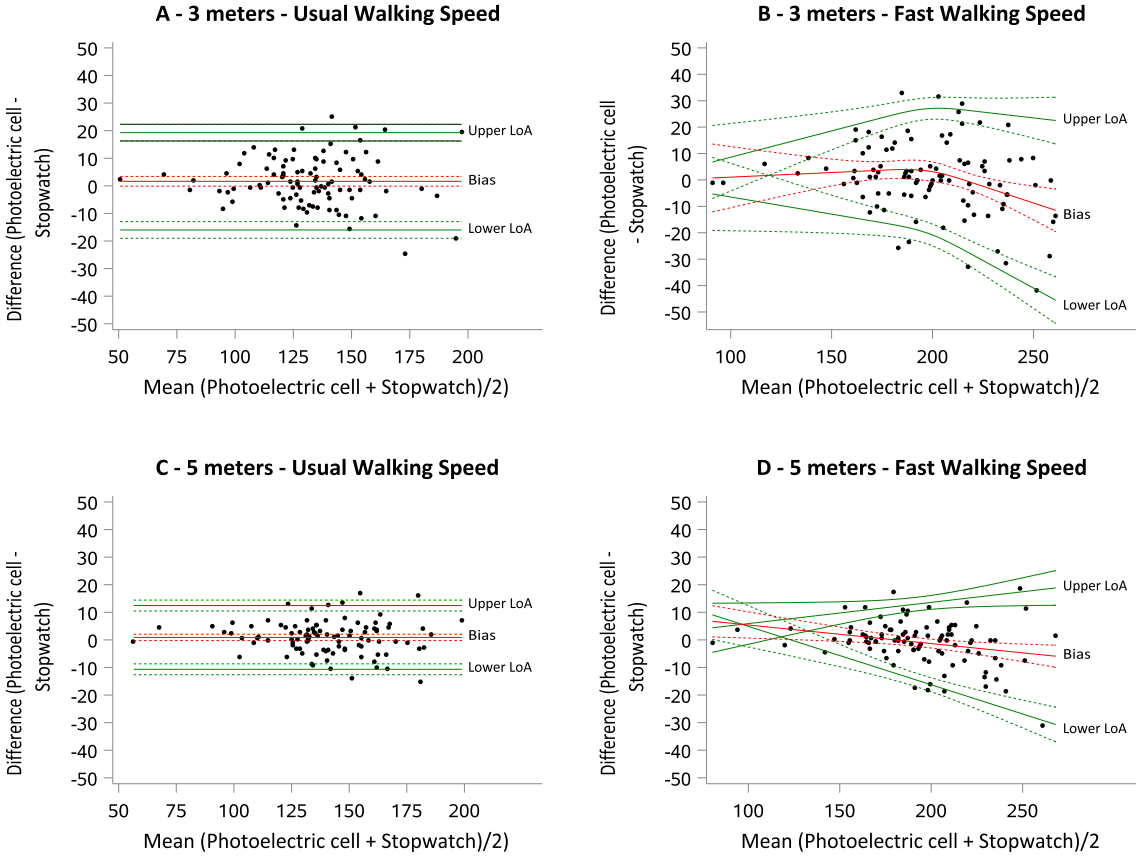

Fig. 1. Bland-Altman plots for the agreement between measures of walking speed taken with a stopwatch (rater 2) and photoelectric cells.
The red line corresponds to the average bias (solid line) together with its 95 % confidence interval. The green lines correspond to the lower and upper limits of agreement (LoA, solid line), together with their 95 % confidence intervals.
Bias is constant for panels A and C, while it depends on mean walking speed in panels B and D. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

using longer distances for manual WS measures. Moreover, a reduced number of highly experienced testers and standardized protocols should be preferred.

When WS is measured repeatedly using manual measurements to estimate WS decline in longitudinal studies, our findings suggest that measurement error may bias estimates of WS decline, in particular for FWS over short distances; this is because decline is steeper in those with faster baseline WS [8], so that measurement error will be more pronounced at baseline than over the follow-up. Therefore, longer distances are preferable in studies with repeated manual WS measures, in particular for FWS. Our study does not allow to determine the best distance, but suggests that distances ≥5 m are recommended. Alternatively, if only short distances are available, automated methods should be preferred.

To our knowledge, our study is the only one to have examined reliability and agreement of WS measurements with manual and automated timing methods over two distances at different paces. Previous studies mainly involved older and predominantly female populations [14,26,27], while our stratified sample included younger participants and as many men as women. Given their younger age, participants from our study walked faster than those included in previous studies; however, age-stratified analyses showed similar findings in older and younger participants. One limitation of our study is that the order of the tests was not randomized; this likely explains our observation of faster 5 m-UWS compared to 3 m-UWS, while 3 m-FWS was faster than 5 m-FWS. A previous study that randomized the order of the walks found no difference in FWS or UWS over 4 m and 8 m [14]. In our study, participants walked over 3 m (UWS then FWS) and then over 5 m (UWS then FWS). Returning to UWS after FWS could have induced faster 5 m-UWS compared to 3 m-UWS. For FWS, fatigue or reduced motivation may have led to slower 5 m-FWS compared to 3 m-FWS. In addition, age-stratified analyses were based on a smaller number of participants than our main analyses, and may have failed to show small differences between the two age groups.

In conclusion, in agreement with our working hypothesis, our findings suggest that both distance and pace have an influence on measurement error of WS using manual timing methods. These findings have implications for the design of studies aimed at measuring WS.

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Why does this matter?

Our findings are helpful for the design of studies that include manual measures of walking speed, especially fast walking speed, in order to reduce measurement error.

Impact statement

We certify that this work is novel. Our study is the first to examine reliability and agreement of walking speed measurements with manual and automated timing methods over two distances at different paces in community-dwelling subjects.

Credit authorship contribution statement

FS, FA, and AE conducted the analyses. AE designed the study. AO and ML contributed to the recruitment of subjects, and coordinated data collection. MZ obtained funding and coordinates the CONSTANCES study. All authors contributed to the interpretation of data and to the preparation of the manuscript.

Sponsor's role

The sponsors had no role in the design, methods, subject recruitment, data collections, analysis and preparation of paper.

Declaration of competing interest

FS is the recipient of a doctoral grant from Université Paris-Saclay, France.

AO reports no conflicts of interest.

ML reports no conflicts of interest.

MZ reports no conflicts of interest.

FA reports no conflicts of interest.

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Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary material include the characteristics of the participants (Supplementary Tables S1), Bland and Altman analyses (Supplementary Tables S2 and S3) and plots, including agreement between the stopwatch and photoelectric cells for 5 m-FWS using splines (Supplementary Figs. S1 and S2) and agreement between two raters (Supplementary Figs. S3 to S6). Supplementary data to this article can be found online at https://doi.org/10.1016/j.exger.2022.111987.

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