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ORIGINAL REPORT

COMPARISON OF TWO 6-MINUTE WALK TESTS TO ASSESS WALKING CAPACITY IN POLIO SURVIVORS

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Objective: **To compare walking dynamics and test-retest reliability for 2 frequently applied walk tests in polio survivors: the 6-minute walk test (6MWT) to walk as far as possible; and the 6-minute walking energy cost test (WECT) at comfortable speed.**
Design: **Observational study.**
Participants: **Thirty-three polio survivors, able to walk ≥150 m.**
Methods: **On the same day participants performed a 6MWT and a WECT, which were repeated 1–3 weeks later. For each test, distance walked, heart rate and reduction in speed were assessed.**
Results: **The mean distance walked and mean heart rate were significantly higher in the 6MWT (441 m (standard deviation) (SD 79.7); 118 bpm (SD 19.2)) compared with the WECT (366 m (SD 67.3); 103 bpm (SD 14.3)); $p<0.001$. Furthermore, during the 6MWT, patients continuously slowed down (–6%), while during the WECT speed dropped only slightly during the first 2 min, by –1.8% in total. Test-retest reliability of both tests was excellent (intraclass correlation coefficient (ICC) ≥0.95; lower bound 95% confidence interval (95% CI) ≥0.87). The smallest detectable change for the walked distance was 42 m (9.7% change from the mean) and 50 m (13.7%) on the 6MWT and WECT, respectively.**
Conclusion: **Both the 6MWT and the WECT are reliable to assess walking capacity in polio survivors, with slightly superior sensitivity to detect change for the 6MWT. Differences in walking dynamics confirm that the tests cannot be used interchangeably. The 6MWT is recommended for measuring maximal walking capacity and the WECT for measuring submaximal walking capacity.**

Key words: poliomyelitis; walking; 6-minute walk test; walking energy cost test; reproducibility of results.

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Many people affected by paralytic poliomyelitis develop post-polio syndrome (PPS) later in life (1). PPS is characterized by a progressive decline in muscle strength, with or without abnormal muscle fatigability, muscle atrophy and/or joint pain (2). Increasing mobility limitations are the most frequently reported functional consequences of PPS (3).

In PPS, the estimated annual rate of decline in muscle strength is 1–2.5% (4–7). This decline in strength limits walking capacity, resulting in reduced walking distance or speed (8–10) and increased walking effort (8). In patients with PPS and symptomatic quadriceps weakness, walking capacity declined modestly over time as it decreased with 0.6% yearly in terms of the walked distance in 2 min (7, 11), and declined substatially by 2.7% yearly in one-fifth of the patients (11).

Field walking tests are used to evaluate changes in walking capacity, both in response to treatment and from natural course. Two frequently used tests are the 6-minute walk test (6MWT) (12) and the 6-minute walking energy cost test (WECT) (13). While both tests are commonly used in the field of polio and PPS (14–16), they have not been compared in terms of walking dynamics, exercise intensity or reliability.

The 6MWT measures the longest distance a patient can walk on a straight course in 6 min (12). The test is reliable (9, 17–18), easy to perform and strongly associated with walking ability outdoors (19). Therefore, the 6MWT is advocated as the test of choice for clinical and research purposes (20). A disadvantage of the 6MWT, however, is that motivation and adjusted self-pacing may influence the results, because patients may regulate their speed during the test. Also, other factors, such as inability to turn quickly at the ends of the course, may influence the results. In addition, subjects may perceive the test as fatiguing (21), even with allowable standing rests, considering the high intensity of effort that may be induced by the 6MWT (22).

The WECT may be less fatiguing in this respect, since it is performed at comfortable and not at maximal speed (13). This has the advantage of being less stressful for the patient, as was found in boys with Duchenne muscular dystrophy, by Kempen et al., who showed that the subjects' heart rate was considerably lower in the WECT than in the 6MWT (22). Based on this difference in exercise intensity, we hypothesized that differences in development of fatigue during the 6MWT and the WECT would be reflected by changes in speed and heart rate at different stages of the test. We also hypothesized that the WECT would be more reliable than the 6MWT, as it is less influenced by changes in speed. However, although the reliability of the

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6MWT (9, 17) and the WECT (8) have been previously established in polio, studies did not compare both tests and included small sample sizes (8), thus restraining the accuracy of the reliability estimates.

The aim of the current study was to compare the reliability of the 6MWT and the WECT in polio survivors and to evaluate differences in walking dynamics and exercise intensity between these tests.

METHODS

Participants

Participants were recruited from our rehabilitation outpatient clinic at the Academic Medical Center (AMC), Amsterdam, The Netherlands. Between April 2012 and December 2013, medical records from patients who had visited the outpatient clinic in the previous 9 months were screened for eligibility according to the following criteria: a confirmed history of paralytic polio; age ≥ 18 years; able to walk ≥ 150 m as reported by the patient; and no existent pulmonary, cardiovascular or other disease that could influence the outcome of the walk tests. The study was approved by the ethics committee of the AMC and informed consent was obtained from all included participants. In order for the study to be considered fair according to COSMIN (**CO**nsensus-based **S**tandards for the selection of health **M**easurement **IN**struments) standards (23), it was intended to include 30 participants.

Procedures

In accordance with COSMIN standards (23), participants were tested twice, with a minimum of 1 week and a maximum of 3 weeks between visits. Test (T1) and re-test (T2) visits were scheduled during the same part of the day and were performed by the same experienced research assistant. On each visit, weight and height were determined, followed by performance of the 6MWT and the WECT. To control for the influence of fatigue, at T1 the test order underwent computer randomization and a 30-min rest period was provided between tests. The same test order was applied at T1 and T2.

Measurements

The 6MWT is a self-paced walking capacity test at fast speed. The test and encouragements were performed according to American Thorax Society guidelines (12). Subjects were instructed to walk as far as possible along a 30-m indoor straight course for 6 min and were permitted to slow down, stop, and rest as necessary. During the test, heart rate (HR) was recorded with a Polar RS400 heart rate monitor (Polar Electro Oy, Kempele, Finland). Furthermore, the minute-split distances ($6MWT_{D1}$ through $6MWT_{D6}$) were recorded with tape flags. After the test, the total distance walked was noted, and the subjects' rate of perceived exertion (RPE) was scored with the Borg Scale (range 6–20, where 20 = "extremely exhausting") (24).

The WECT is a self-paced walking capacity test at comfortable speed. For this test, patients were instructed to walk continuously (i.e. not to slow down or speed up) and not to stop or rest, so as to allow subjects to achieve a steady state, which is required for the assessment of walking effort measures, in addition to the walked distance (13). Subjects first sat on a chair for an 8-min rest test, and then performed a 6-min walk test along an indoor oval course. During the test, HR and the minute-split distances ($WECT_{D1}$ through $WECT_{D6}$) were recorded, and pulmonary gas exchange was assessed with an telemetric gas analysis device (Cosmed K4b^2, Rome, Italy), consisting of a face-mask, a volume transducer, a gas-sample line, and a battery-operated unit worn on the back (13). After the test, the total distance walked and subjects' RPE were scored. If necessary, subjects could use their habitual assistive device(s) during both tests.

Data analysis

From the minute-split distances, walking speed dynamics for the 6MWT and WECT were determined by calculating the percentage change in speed for each consecutive minute covered compared with the first minute, starting from the second minute ((speed min_n–speed min_1/speed min_1) × 100%).

The mean heart rates during the 6MWT and WECT were determined over the final 3 min of the tests ($HR_{3–6}$). Furthermore, heart rate values for each consecutive minute covered were computed (HR_1 through HR_6). $HR_{3–6}$ and $HR_{1–6}$ values were expressed as percentage of: (*i*) age-predicted HR_{max}, calculated according to Fairbarn et al. (25); and (*ii*) heart rate reserve (HRR), calculated as (220–age)–HR_{rest}.

For the WECT, energy consumption ($Jkg^{-1}min^{-1}$) and energy cost ($Jkg^{-1}m^{-1}$) were also determined from the mean steady-state respiratory exchange ratios and oxygen-uptake over the last 3 min of the test.

Statistical analysis

Patient characteristics and outcomes on the 6MWT and WECT were analysed with descriptive statistics. Differences in the mean walked distance and $HR_{3–6}$ between the 6MWT and WECT were analysed by paired *t*-tests and by Wilcoxon signed-rank tests for RPE. Walking speed and heart rate dynamics during each test were plotted.

Test-retest reliability was assessed with the intraclass correlation coefficient ($ICC_{2,1}$) and 95% confidence intervals (95% CI) of the ICC. A 2-way random effects model was used to calculate the ICC (26). Test-retest reliability was considered excellent if the lower bound of the 95% CI of the ICC was ≥ 0.75 (27). Systematic differences between assessments were analysed with paired *t*-tests. Measurement error was expressed with the standard error of measurement (SEM), calculated as $\sqrt{(var_o + var_e)}$, where var_o is the variance due to systematic differences between assessments and var_e is the random error variance. From the SEM, the smallest detectable change (SDC), i.e. the amount of change between 2 repeated assessments for an individual that is reliably detectable above measurement error, was derived, calculated as 1.96 × √2 × SEM (26). Analyses were performed with SPSS for Windows, version 22. For all tests, the level of significance was set at $p < 0.05$.

RESULTS

Participant characteristics

Thirty-three patients with prior polio were included. All included participants performed the T1 assessment, although one participant was not able to complete the 6MWT and WECT due to the severity of muscle paresis. Three other participants did not perform the T2 assessment; one due to time constraints and 2 due to injury unrelated to the study. Thus, data from

Table I. Baseline characteristics of 29 participants

Variables	
Demographic characteristics, mean (SD) [range]	
Sex, male/female	13/16
Age, years	60 (11.5) [29–72]
Weight, kg	77 (14.2) [48–112]
Height, cm	172 (9.6) [154–189]
Polio characteristics	
Affected legs (unilateral/bilateral), *n*	24/5
MMT sum score legs[a], median [range]	67.0 [20–78]
Walking device, *n* (%)	
None	15 (51.7)
Cane/crutch	2 (6.9)
Ankle-foot orthosis	5 (17.2)
Knee-ankle-foot orthosis	7 (24.1)
Walking ability, *n* (%)	
Around house only	2 (6.9)
Rarely > 1 km	15 (51.7)
Regularly > 1 km	9 (31.0)
Unlimited	3 (10.3)

[a]Sum score for leg muscle strength was calculated by adding the scores of 16 muscle groups. Each muscle group had a score between 0 and 5, sum score ranged from 0 to 80 (28).
MMT: manual muscle testing; SD: standard deviation.

29 patients (13 males) were available for analyses. Socio-demographic and disease characteristics of these participants are shown in Table I.

Walking dynamics

Walking dynamics for each test at T1 and T2 are described in Table II. The mean walked distance over T1 and T2 was 441 m (standard deviation (SD) 79.7 m) on the 6MWT vs 366 m (SD 67.3 m) on the WECT. Walking speed dynamics during both tests (available in the 17 last enrolled patients) are shown in Fig. 1.

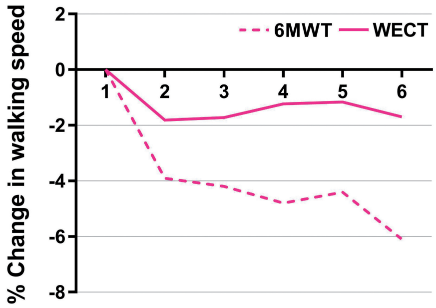

Fig. 1. Mean percentage change in walking speed for each consecutive minute covered compared with the first minute (based on 17 patients). Negative values represent a decrease.

All patients were able to complete the 6MWT without stopping, although they slowed down continuously, as was most pronounced in the sixth minute (–6.1% compared with the first minute). During the WECT, speed reduced slightly from the first to the second minute (–1.8%) and remained constant from the third minute onwards.

The mean HR_{3-6} and median (IQR) RPE on the 6MWT were 118 bpm (SD 19.2) and 13.0 (IQR 5.0), respectively (Table II). These values were significantly higher compared with values on the WECT (HR_{3-6}: 103 bpm (SD 14.3) and RPE: 12.0 (IQR 3.0), $p<0.001$). Heart rate dynamics are shown in Table III and Fig. 2, showing that during the 6MWT, the relative heart rate increased from 31%HRR to 58%HRR. During the WECT, the relative heart rate increased from 23%HRR to 40%HRR.

Table II. Descriptive data for 6-minute walk test (6MWT) and walking energy cost test (WECT) outcomes based on 29 patients

	6MWT			WECT		
	T1	T2	T1/T2	T1	T2	T1/T2
Distance, m, mean (SD)	438 (79.3)	444 (81.3)	441* (79.7)	361 (64.2)	372 (71.0)	366 (67.3)
HR_{3-6}, bmp, mean (SD)	118 (19.7)	117 (19.0)	118* (19.2)	102 (14.0)	103 (14.7)	103 (14.3)
RPE, median (IQR)	13.0 (4.0)	15.0 (4.0)	13.0* (5.0)	11.0 (2.8)	13.0 (4.0)	12.0 (3.0)
Gross ECS				312 (56.6)	314 (63.6)	313 (59.6)
Gross EC				5.29 (1.19)	5.26 (1.20)	5.28 (1.19)

*Significantly higher compared with the mean value on the WECT ($p<0.001$). To test for differences between the 6MWT and WECT, paired *t*-tests were used for continuous data (distance and HR_{3-6}), and Wilcoxon singed-rank tests for ordinal data (RPE).
6MWT: 6-minute walk test; WECT: walking energy cost test; T1: first assessment; T2: second assessment; HR_{3-6}: mean heart rate over minute 3–6 (bpm); RPE: rate of perceived exertion (range 6–20); ECS: energy consumption ($Jkg^{-1}min^{-1}$); EC: energy cost ($Jkg^{-1}m^{-1}$); IQR: interquartile range.

Table III. Absolute and relative heart rate during the 6-minute walk test (6MWT) and walking energy cost test (WECT) based on 29 patients

	HR_{rest} Mean (SD)	HR_{3-6} Mean (SD)	HR_1 Mean (SD)	HR_2 Mean (SD)	HR_3 Mean (SD)	HR_4 Mean (SD)	HR_5 Mean (SD)	HR_6 Mean (SD)
6MWT								
HR, bpm	69 (7)	119 (19)	96 (13)	112 (17)	116 (18)	117 (18)	118 (19)	120 (20)
$\%HR_{max}$, %	44 (5)	75 (12)	61 (8)	71 (11)	74 (11)	74 (11)	75 (12)	76 (12)
%HRR, %		57 (19)	31 (11)	50 (17)	54 (17)	55 (18)	56 (19)	58 (20)
WECT								
HR, bpm	69 (7)	103 (13)	88 (10)	98 (12)	101 (13)	102 (13)	103 (14)	103 (15)
$\%HR_{max}$, %	44 (5)	65 (9)	56 (6)	62 (7)	64 (8)	65 (8)	65 (9)	65 (9)
%HRR, %		40 (12)	23 (7)	35 (10)	38 (11)	39 (12)	40 (12)	40 (13)

6MWT: 6-minute walk test; WECT: walking energy cost test; HR_{rest}: steady state heart rate during rest; HR_{3-6}: steady state heart rate during the walk test; HR_1: mean heart rate over minute 1 of the walk test, etc; $\%HR_{max}$: HR as percentage of age-predicted maximal heart rate, calculated according to Fairbarn et al. (25)); % HRR: HR as percentage the heart rate reserve, calculated as ((220–age)–HR_{rest}).

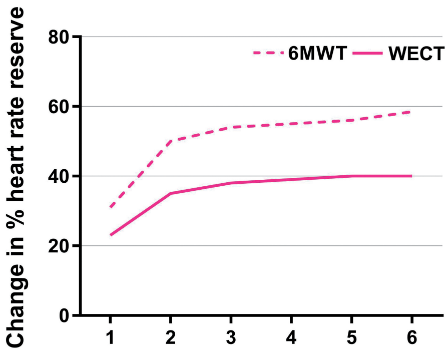

Fig. 2. Mean heart rate during walking for each consecutive minute covered expressed as percentage of the heart rate reserve (based on 29 patients).

Test-retest reliability

Table IV shows the results for reliability. Outcomes on the 6MWT and WECT did not differ significantly between T1 and T2, except for the walked distance on the WECT (mean difference: 11.9 m (95% CI 3.1–20.6). The ICCs (95% CI) for the walked distance on the 6MWT and WECT were 0.97 (0.94–0.99) and 0.95 (0.87–0.98), respectively. ICCs for walking effort outcomes, derived from the WECT, were 0.86 (0.72–0.93) for energy consumption and 0.94 (0.88–0.98) for energy cost. Measurement errors, expressed by the SDC, were 42 m (9.7% change from the mean) and 50 m (13.7%) for the walked distance on the 6MWT and WECT, respectively. The SDC for energy consumption was 22.9 $Jkg^{-1}min^{-1}$ (20.4%) and for energy cost 0.36 $Jkg^{-1}m^{-1}$ (18.4%).

DISCUSSION

This study evaluated differences in walking dynamics, exercise intensity and test-retest reliability between 2 commonly used 6-minute walk tests (6MWT and WECT) in polio survivors. Walking dynamics, in terms of the walked distance, was significantly higher on the 6MWT than on the WECT. In addition, during the 6MWT, speed declined gradually, while during the WECT speed remained constant. Based on mean heart rate, exercise intensity was significantly higher for the 6MWT compared with the WECT. Test-retest reliability of both tests was excellent, and for evaluating individual change, the 6MWT was slightly superior to the WECT.

Despite the frequent use of the 6MWT and WECT in the evaluation of walking capacity in polio survivors (14–16), the current study is the first to compare walking dynamics and exercise intensities between both tests in this population. The results show that the exercise intensity in terms of the heart rate response and perceived exertion rate were significantly greater during the 6MWT compared with the WECT, indicating that the 6MWT is more demanding. This is in line with Kempen et al., who reported a similar finding in boys with Duchenne muscular dystrophy (22).

Regarding the 6MWT, the mean absolute heart rate of 118 bpm in our sample was noticeably higher than that of 96 bpm reported in polio survivors by Vreede et al. (21). However, patients in that study might have been more severely affected, for example as reflected by the lower walked distance and speed on the test. It is likely that this led to a lower heart rate; since the heart rate during walking is speed dependent. The lower heart rate in the Vreede study (21) may also be due to the higher age of participants: walking speed declines with age (29), which inherently results in a lower heart rate. Yet, to allow a direct comparison of heart rate values across studies, especially in patients of different ages, application of the relative heart rate is needed, which was, however, not reported in Vreede's study.

In patients with MS, the relative heart rate during the 6MWT increased from 64% to 69% of age-predicted HR_{max} (30). A slightly higher relative heart rate of 76% was found at the end of the 6MWT in our study. A higher relative heart rate was also found on the 6MWT compared with the WECT (mean 75%HR_{max} and 57%HRR vs 65%HR_{max} and 40%HRR), and besides, heart rate during the 6MWT increased throughout the test, while during the WECT it remained constant from the third minute onwards. Although this was partly expected, exercise intensity of the 6MWT appeared to be rather high, and even substantially high, i.e. >57%HRR in a proportion of subjects (40%), which corresponds

Table IV. Test-retest reliability and measurement error for 6-minute walk test (6MWT) and walking energy cost test (WECT) outcomes based on 29 patients

	6MWT				WECT			
	ICC[a] [95% CI]	ΔT2–T1 [95% CI]	SEM[b] (%)	SDC[c] (%)	ICC [95% CI]	ΔT2–T1 [95% CI]	SEM (%)	SDC (%)
Distance	0.97 [0.94–0.99]	6.6 [−1.18–14.5]	15 (3.5)	42 (9.7)	0.95 [0.87–0.98]	11.9 [3.1–20.6]	18 (4.9)	50 (13.7)
Gross ECS					0.86 [0.72–0.93]	0.241 [−12.3–12.8]	22.9 (7.4)	64 (20.4)
Gross EC					0.94 [0.88–0.98]	−0.14 [−0.33–0.05]	0.36 (6.6)	0.99 (18.4)

T1: first assessment; T2: second assessment; ECS: energy consumption ($Jkg^{-1}min^{-1}$), EC: energy cost ($Jkg^{-1}m^{-1}$); ICC: intraclass correlation coefficient; SEM: standard error of measurement; SDC: smallest detectable change; 95% CI: 95% confidence interval. [a]ICC was calculated as varp/(varp+varo+vare), where varp is the variance due to systematic differences between "true" scores of patients; varo is the variance due to systematic differences between assessments (i.e. occasions); vare is the random error variance. [b]SEM was calculated as √ (varo + vare) and expressed in absolute units and as percentage of the mean of the 2 assessments. [c]SDC was calculated as 1.96 × √2 × SEM and expressed in absolute units and as percentage of the mean of the 2 assessments.

well to exercise intensities used for aerobic training in patients with PPS (31, 32).

In addition to differences in heart rate dynamics, we also found differences in walking speed dynamics between the 6MWT and WECT. During the 6MWT, walking speed gradually declined throughout the test, as was also previously reported in polio survivors (21), in other neuromuscular disorders (33) and in patients with MS (30, 34), whilst during the WECT, speed decline remained constant. The observation that walking speed decreased during the 6MWT, is contrary to trends seen in healthy individuals, who have been observed to display a stereotypical U-shaped pattern of walking speed during timed walking, characterized by a relatively high speed during the initial phase, followed by slowing down and final acceleration (35). Probably in response to the high exercise intensity of the 6MWT, patients slowed down, so as to minimize increases in heart rate and exertion, in accordance with the energy minimization hypothesis, which refers to the ability of organisms to naturally adopt a movement pattern that minimizes metabolic energy expenditure (36). That the 6MWT is fatiguing for polio patients, as indicated by the high RPE of 13, is underlined by findings that the slowing down of patients during the 6MWT was accompanied by alterations in gait kinematics (21). The development of fatigue during the 6MWT and WECT, in relation to concomitant changes in gait biomechanics should be studied further to identify underlying mechanisms of slowing down during timed walking in polio.

The use of walk tests to evaluate changes in walking capacity requires information about reliability. Based on the ICC, we confirmed earlier findings that the test-retest reliability of the 6MWT (9, 17) and WECT (8) were excellent. However, the observed learning effect for the walked distance on the WECT indicates that at least 2 tests are required for accurate assessment. In addition, both tests were found to be sufficiently sensitive to detect changes in the walked distance, where differences of at least 9.7% for the 6MWT and of 13.7% for the WECT can be interpreted as a real change. Considering the WECT, a similar smallest real change was reported by Horemans et al. (37) and Stolwijk-Swüste et al. (38) for the 2MWT, which is also performed at comfortable speed. Taken together, these findings indicate slightly inferior sensitivity to detect individual changes for walk tests at comfortable speed (such as the WECT and 2MWT) compared with tests performed at fast speed (6MWT), which was also found by Kempen et al. in boys with Duchenne muscular dystrophy (22).

Walking effort measures, as assessed with the WECT, were found to be less sensitive to detect individual change. For example, it appeared that the change in walking energy cost should exceed 18.4%, which is larger than we found previously (9.4%) (8). This may be due to the fact that, in the current study, patients were more severely affected (indicated by the higher energy cost), which, as shown in other patient populations (39), leads to greater variability. Another explanation may be a difference in measurement protocol (2 instead of 4 repeated measurements) and the larger number of participants ($n=29$ vs $n=14$ as previously reported (8)) to more accurately estimate reliability, which may have led to the distinct reliability outcomes. Future studies should focus on differences in responsiveness between the 6MWT, WECT and 2MWT evaluated longitudinally in the same study sample, to determine how adequately they can detect meaningful changes in temporal, cardiac and energetic walking dynamics over time. This may provide valuable understanding of the discrepancy that walking capacity declines less in comparison with strength over time (11, 40).

A limitation to this study is that we selected individuals who were expected to walk at least 150 m. Therefore, generalizability of the results to more severely affected persons with prior polio may be compromised. A strength of this study is that, for the first time, in patients with polio, temporal and cardiac walking dynamics of 2 commonly used walk tests were explored in the same study sample, which provided information that may be useful for future trials investing therapeutic interventions aimed at improving walking capacity in PPS.

In conclusion, this study of polio survivors with a minimum self-reported walking distance of 150 m shows that both the 6MWT and the WECT are reliable and can be used to evaluate changes in walking capacity, with the 6MWT showing slightly superior sensitivity to detect change. The study also shows a significantly higher heart rate (57%HRR on average) at the expense of a reduction in walking speed at this heart rate during the 6MWT compared with the WECT. These findings indicate distinct patterns of walking dynamics between the 6MWT and WECT, where the 6MWT is more likely a measure of maximal walking capacity (i.e. what a person can do) and the WECT of submaximal walking capacity (i.e. what a person does do). The difference in walking dynamics confirms that these tests cannot be used interchangeably, and that the choice to use either test should be tailored to the construct to be measured. Responsiveness to change in this patient population should be further investigated for both tests.

The authors declare no conflicts of interest.

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