A SIMPLE METHOD TO DERIVE SPEED FOR THE ENDURANCE SHUTTLE WALK TEST

Short running title:

Determining the speed for the endurance shuttle walk test

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ABSTRACT

Background: The original method for determining endurance shuttle walk test (ESWT) speed involves components that are time consuming for clinicians. We sought to determine: (i) whether components described in the original method for determining ESWT speed held true and; (ii) the agreement between speeds derived using the original method and that equivalent to 85% of the peak speed achieved during the incremental shuttle walk test (ISWT).

Methods: Patients with chronic obstructive pulmonary disease (COPD) performed two ISWTs and one ESWT on separate days, wearing a calibrated portable gas analysis unit. A retrospective analysis of these data allowed us to determine whether: (i) the peak rate of oxygen uptake ($\dot{V}O_{2peak}$) can be accurately estimated from the incremental shuttle walk distance (ISWD) and; (ii) ESWTs performed at a speed derived using the original method elicited 85% of $\dot{V}O_{2peak}$. Agreement between walks speeds was determined using Bland-Altman analysis.

Results: Twenty-two participants (FEV_1 48±13% predicted, age 66±8 yr) completed the study. The $\dot{V}O_{2peak}$ estimated from the ISWD was less than that measured during the ISWT (mean difference -4.4; 95% confidence interval (CI), -6.0 to -2.9 $ml \cdot kg^{-1} \cdot min^{-1}$). The ESWT and ISWT elicited similar $\dot{V}O_{2peak}$ (mean difference -0.2; 95% CI, -1.5 to 1.2 $ml \cdot kg^{-1} \cdot min^{-1}$). The mean difference (± limits of agreement) between ESWT speeds was 0.15 (± 0.34) $km \cdot h^{-1}$.

Conclusions: Components of the original method for determining the ESWT speed did not hold true in our sample. ESWT speed can be derived by calculating 85% of the peak speed achieved during the ISWT.

INTRODUCTION

The endurance shuttle walk test (ESWT)[1] is an assessment of walking endurance that is appropriate for assessing the response to interventions in people with chronic obstructive pulmonary disease (COPD).[2] Its popularity as an outcome in clinical studies is increasing, largely as a result of its superior responsiveness when compared with other field based walking tests, such as the six-minute walk test (6MWT)[3,4] and the incremental shuttle walk test (ISWT).[1] The method for calculating the speed for the ESWT, as described in the original publication,[1] involves four components. First, an ISWT is performed and the distance walked (ISWD) is recorded. Second the ISWD is entered into a regression equation to estimate an individual's peak rate of oxygen uptake ($\dot{V}O_{2peak}$). Third, a value equivalent to 85% of the estimated $\dot{V}O_{2peak}$ is calculated. Fourth, a walk speed corresponding to 85% of the estimated $\dot{V}O_{2peak}$ is derived using a published figure that relates walk speed to the rate of oxygen uptake.[1] This four-component process can be time-consuming for clinicians and the reliance on the published figure during the final component may lead to imprecision when determining the speed for this test.

We recently compared the cardiorespiratory responses to the 6MWT, ISWT, ESWT with a ramp-based cycle ergometry test.[5] A secondary analysis of these data allowed us to determine the extent to which the components described in the original method for calculating an appropriate speed for the ESWT held true and whether the process for deriving the speed for the ESWT could be simplified. The specific aims for this study were to determine:

1. Whether $\dot{V}O_{2peak}$ can be accurately derived from ISWD.

2. Whether the rate of oxygen uptake during the ESWT was equivalent to 85% of $\dot{V}O_{2peak}$.

3. The agreement between ESWT speeds derived using the original four-component process and that equivalent to 85% of the peak speed achieved during the ISWT.

METHODS

Patients with stable COPD were recruited from referrals to pulmonary rehabilitation programs and respiratory medicine clinics. Individuals were excluded if they had evidence of a co-morbid condition that may have adversely affected their capacity to complete field-based walking tests such as severe lower back pain or required a gait aid or supplemental oxygen during exercise. As the American Thoracic Society / American College of Chest Physicians statement on cardiopulmonary exercise testing[6] indicates that a decrease in arterial oxygen saturation (SpO_2) to ≤ 80%, when accompanied by symptoms and signs of severe hypoxaemia is a criterion that clinicians should use to terminate an exercise test, we chose to exclude any individual who desaturated to this extent during any of the tests. Approval was obtained from the Research Ethics Board at our facility and written informed consent was obtained from every participant. Age, gender, height and weight were recorded and recent spirometric measures of lung function were extracted from the medical notes. Data collection pertaining to the main study[5] was completed over four assessment sessions, each separated by at least one day. During a session, participants completed either two 6MWTs, two ISWTs, two ESWTs or one incremental cycle ergometry test wearing a calibrated portable gas analysis unit (Cosmed™, $K4b^2$, Italy). To meet the aims of the current study, data were used for the test that yielded the best ISWD and the first of the two ESWTs. The speed for the ESWT was determined according to the method originally described.[1] Standard protocols were used for both tests,[1,7] and participants were instructed to increase their walking speed when they first lagged behind the pace dictated by the audio-signal.[5]

Data analysis

Data analyses were performed using the Statistical Package for Social Sciences (version 19.0, SPSS Inc., Chicago, IL, USA) and data are expressed as mean ± standard deviation unless otherwise stated. We estimated $\dot{V}O_{2peak}$ using the following published regression equation:[8]

$$\text{Estimated } \dot{V}O_{2peak}\,(\text{ml}\cdot\text{kg}^{-1}\cdot\text{min}^{-1}) = 4.19 + (\text{ISWD} \times 0.025)$$

and determined if it was different from the $\dot{V}O_{2peak}$ measured directly during the ISWT using a paired t-test. Agreement between the estimated and measured $\dot{V}O_{2peak}$ was examined using the methods described by Bland-Altman.[9]

To determine the extent to which the rate of oxygen uptake measured during the ESWT corresponded to 85% of the $\dot{V}O_{2peak}$ achieved during the ISWT, we compared the $\dot{V}O_{2peak}$ achieved during the two tests using a paired t-test. Further, the pattern of change in the rate of oxygen uptake between the ISWT and ESWT was compared by; (i) grouping data into deciles of the total test duration using a two-dimensional data transformation (Sigmaplot®, version 12.0) and, (ii) fitting a curve to the profile of the mean data for each test. Data collected during the 90 second warm-up that preceded the ESWT were excluded from these analyses.

We determined whether the speed equivalent to 85% of the peak speed achieved during the ISWT differed from that derived using the original four-component process using a paired t-test and the methods described by Bland-Altman.[9]

Sample size calculations

The results of this study arise from the retrospective analyses of an existing dataset. Therefore, sample size calculations were not undertaken to meet the specific aims of this study. Nevertheless, our sample size yielded adequate power ($\alpha = 0.05$, $1-\beta = 0.8$) to detect a difference in speeds for the ESWT (i.e. that equivalent to 85% of the peak speed achieved during the ISWT and that derived using the original four-component process) of 0.17 ± 0.27 $km \cdot h^{-1}$ (or 2.8 $m \cdot min^{-1}$). This difference is the smallest difference in pre-recorded speeds available for the ESWT.

RESULTS

Characteristics of the 22 participants (14 men) are summarised in Table 1 and have been described in detail elsewhere.[5]

The ISWD was 343 ± 104 m (range 180 to 550 m). The speed for the ESWT was 4.29 ± 0.64 $km \cdot h^{-1}$ (range 3.27 to 5.54 $km \cdot h^{-1}$) and the time to symptom limitation was 378 ± 298 s (range 115 to 1156 s).

Results addressing aim 1

The $\dot{V}O_{2peak}$ estimated using the ISWD was 12.8 ± 2.6 $ml \cdot kg^{-1} \cdot min^{-1}$ and the $\dot{V}O_{2peak}$ measured during the ISWT was 17.2 ± 4.7 $ml \cdot kg^{-1} \cdot min^{-1}$. The mean difference between these measures was

-4.4 ml·kg^{-1}·min^{-1} (95% confidence interval (CI), -6.0 to -2.9 ml·kg^{-1}·min^{-1}). The published regression equation underestimated $\dot{V}O_{2peak}$ in 19 (86%) participants. Significant heteroscedasticity was observed as the difference between estimated and measured $\dot{V}O_{2peak}$ increased as $\dot{V}O_{2peak}$ increased (slope = -0.683; p = 0.001) (Figure 1).

Results addressing aim 2

The $\dot{V}O_{2peak}$ measured during the ESWT was 17.4 ± 4.4 ml·kg^{-1}·min^{-1}. The difference between the $\dot{V}O_{2peak}$ achieved during the ESWT and ISWT was not significant (mean difference -0.2; 95% CI, -1.5 to 1.2 ml·kg^{-1}·min^{-1}). The profiles of $\dot{V}O_{2peak}$ measured during the ISWT and ESWT are shown in Figure 2. The oxygen uptake at the beginning of the ISWT was less than that observed for the ESWT because the ISWT was initiated from a stationary standing position, whereas, the ESWT commenced after a 90 second warm-up walk and data collected during this warm-up were excluded from the analyses. The increase in the rate of oxygen uptake with increasing time during the ISWT could be described by the following linear function:

$$\dot{V}O_2 = 5.34 + (2 \times t); t = \text{time (min)}$$

Consistent with previous work that has explored the cardiorespiratory responses to a constant power test,[10] the increase in the rate of oxygen uptake with increasing time during the ESWT could be described by the following three-parameter single exponential function:

$$\dot{V}O_2 = 9.90 + [7.29 \times (1-e^{-0.62 \cdot t})]; t = \text{time (min)}.$$

During the ESWT, every participant exceeded 85% of the $\dot{V}O_{2peak}$ estimated from the ISWD. Of note, in Figure 2, the shaded area, which indicates the 95% CI for values equivalent to 85% of $\dot{V}O_{2peak}$ estimated using the ISWD, was achieved within the first 0.5 ± 0.5 min of the ESWT.

Results addressing aim 3

The speed equivalent to 85% of the peak speed achieved during the ISWT was 4.44 ± 0.67 $km \cdot h^{-1}$ (range 3.09 to 5.69 $km \cdot h^{-1}$).The mean difference between this speed and that derived using the original method was 0.15 $km \cdot h^{-1}$ (95% CI, 0.07 to 0.22 $km \cdot h^{-1}$). The two methods resulted in identical speeds for 8 (36%) participants and a difference of one speed (of those available for the ESWT) in 14 (64%) participants (Figure 3).

DISCUSSION

This study explored whether the peak rate of oxygen uptake ($\dot{V}O_{2peak}$) can be accurately estimated from the ISWD and whether ESWTs performed at a speed derived using the original four-component process elicited 85% of $\dot{V}O_{2peak}$. In addition, it determined whether a simple process for calculating the speed for the ESWT produced similar speeds as the original four-component process. An important finding of this study was that the regression equation used to derive $\dot{V}O_{2peak}$ from the ISWD resulted in a significant underestimation of the directly measured $\dot{V}O_{2peak}$. Further, our data indicate that the $\dot{V}O_{2peak}$ achieved during the ESWT approached the $\dot{V}O_{2peak}$ directly measured during the ISWT thereby exceeding a value equivalent to 85% of the $\dot{V}O_{2peak}$ estimated from the ISWD. Nevertheless, on average, the speed for the ESWT derived using the original four-component process resulted in a desirable duration for time to symptom limitation of between 4 and 7 min.[11] Our data suggest that using 85% of the peak walk speed achieved during the ISWT produced similar speeds for the ESWT when compared with that derived using the original four-component process. These findings indicate that components of the original method described to calculate the speed for the ESWT may not hold true in patients with COPD and are unnecessary when calculating the speed for the ESWT. We propose that the speed for this test can be simply determined by calculating 85% of the peak speed achieved during the ISWT.

When determining the speed for the ESWT, VO_{2peak} is estimated in order to relate the intensity of the test to an individual's aerobic capacity[1] and to achieve a baseline endurance time within the responsive range.[11] The equation published to estimate $\dot{V}O_{2peak}$ included ISWD as the sole independent variable and $\dot{V}O_{2peak}$ measured during an incremental symptom-limited treadmill test as the dependent variable.[8] Our data demonstrated that this equation produced values that were significantly less than those directly measured during the test. The reasons for this do not appear to be related to differences in the samples between the studies. That is, compared with our sample, the participants in the original study had similar disease severity (forced expiratory volume in one second; 1.1 ± 0.4 L vs. 1.4 ± 0.5 L) and functional impairment (ISWD; 343 ± 104 m vs. 375 ± 137 m).[8] Further, both studies used the same ISWT protocol.[8] However, in contrast with our study which measured $\dot{V}O_{2peak}$ using a portable gas analysis system during the ISWT, the original paper measured the $\dot{V}O_{2peak}$ during a laboratory-based treadmill test.[8] Compared to ground walking with frequent turns back and forth around a 10 m course, treadmill walking requires less energy and is more efficient.[1] When walking at similar speeds, these differences produced a consistent tendency to walk for longer on a treadmill compared with ground walking.[1] The reduced efficiency associated with ground walking around a 10 m course is likely to have increased the rate of oxygen uptake for any given ISWD when compared with measurements made during treadmill walking. The weight of the portable gas analysis unit worn by the participants in our study would also have contributed a small amount to the higher rate of oxygen uptake. We speculate these to be the reasons why the published regression equation underestimated the measured $\dot{V}O_{2peak}$ achieved during the ISWT in our sample.

The original paper describing the ESWT investigated the appropriateness of treadmill walk speeds corresponding to 75%, 85% and 95% of the $\dot{V}O_{2peak}$ measured during a symptom-limited incremental treadmill test.[1] They concluded that a speed corresponding to 85% of $\dot{V}O_{2peak}$ was most appropriate as; (i) unlike the test performed at 95% of $\dot{V}O_{2peak}$, it did not provoke a similar response as the ISWT, (ii) compared with the test performed at 75% of $\dot{V}O_{2peak}$, a smaller proportion of tests were terminated by the investigator as the patients reached the upper limit of 20 min and, (iii) the exercise times were of an appropriate duration (i.e. 10.2 ± 2.5 min). In the original study, the $\dot{V}O_{2peak}$ elicited whilst walking on a treadmill at this speed corresponded to 87 ± 13% of $\dot{V}O_{2peak}$.[1] In contrast with this study which evaluated responses during treadmill walking,[1] we compared the $\dot{V}O_{2peak}$ achieved during the ESWT with that achieved during an ISWT, both of which necessitated ground walking around a 10 m course. Our data demonstrated that the rate of oxygen uptake achieved during the ESWT, performed at a speed derived using the original four-component process, was similar to the $\dot{V}O_{2peak}$ measured during the ISWT. This is consistent with previous data showing that patients with COPD achieved a similar $\dot{V}O_{2peak}$ cycling at 85% of peak power when compared with that measured during an incremental cycle ergometry test.[12] Figure 2 demonstrates that, on average, patients with COPD have achieved a rate of oxygen uptake equivalent to 85% of the $\dot{V}O_{2peak}$, estimated using the published regression equation, within the first 0.5 min of the ESWT. These data do not suggest that the speed chosen for the ESWT was inappropriate. In fact, the time to symptom limitation measured in our study (378 ± 298 s) is likely to be highly responsive to change,[11,13] and suggests that the speed was close to 120% of the maximum sustainable walking speed.[13] Rather, these data simply highlight that an ESWT performed at a speed derived using the original four-component process will elicit a $\dot{V}O_{2peak}$ that exceeds 85% of the $\dot{V}O_{2peak}$ estimated from the ISWD.

Our data demonstrate similarity between the speeds derived for the ESWT using the original four-component process and that calculated to be 85% of the peak speed achieved during the ISWT. Of note, these two methods differed, on average, by 0.15 $km \cdot h^{-1}$ (i.e. 2.5 $m \cdot min^{-1}$). An increase in walking speed of this magnitude has the potential to reduce the time to symptom limitation by approximately one minute.[13] However, given that performance improves with familiarisation by an average of 50 to 60 sec,[1,5] any reduction in time to symptom limitation reduction is likely to be offset, at least in part, by repeating the test. This suggests that the speed for the ESWT can be derived by simply calculating 85% of the peak speed achieved during the ISWT rather than completing a more complicated four-component process.

Limitations

The main limitation of this study was that we did not measure the time to symptom limitation achieved during the ESWT performed at a speed equivalent to 85% of the peak speed achieved during the ISWT and further research is needed in this area. Notwithstanding this, we estimated the difference in time to symptom limitation during the ESWT performed at this slightly faster speed using our previously published data demonstrating the power-endurance relationship during walking tasks in COPD.[13] As patients who use gait aids and supplemental oxygen were excluded, it is possible that our results do not extend to these sub-groups. Further, as the study sample was characterised by moderate to severe COPD, it is unclear if our results extend to individuals with mild or very severe disease.

Conclusions

In a sample of participants with stable COPD, our data suggest that the regression equation used to derive $\dot{V}O_{2peak}$ from the ISWD resulted in a significant underestimation of the directly measured value and that the $\dot{V}O_{2peak}$ achieved during the ESWT exceeded a value equivalent to 85% of the $\dot{V}O_{2peak}$ estimated from the ISWD. Further, speeds equivalent to 85% of the peak walk speed achieved during the ISWT were similar to that derived using the original four-component process. Taken together, these results suggest that components described in the original method for determining the speed for the ESWT did not hold true and are unnecessary. We propose that speeds for the ESWT can be simply derived by calculating 85% of the peak speed achieved during the ISWT.

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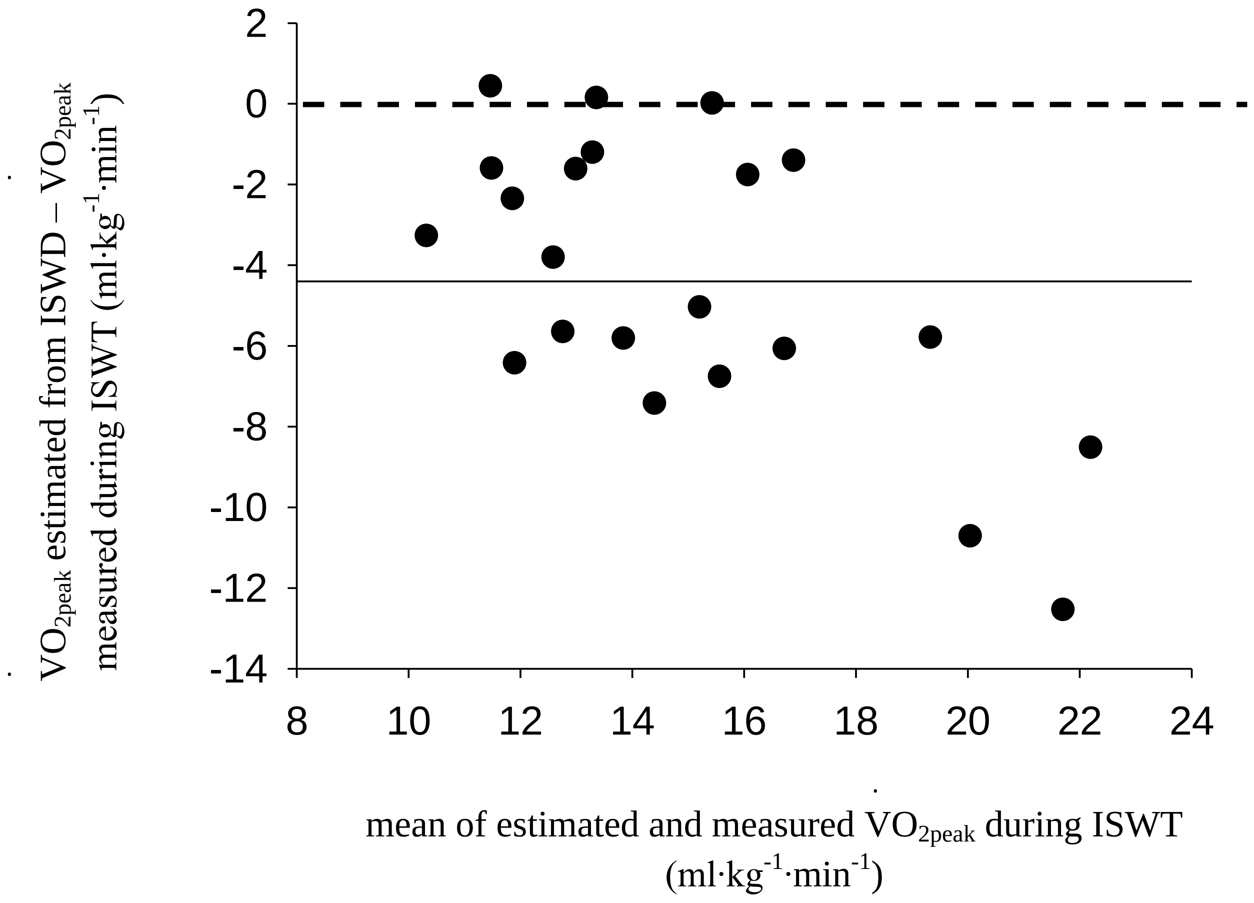

Figure 1: Bland-Altman plot demonstrating agreement between $\dot{V}O_{2peak}$ estimated using the published regression equation and $\dot{V}O_{2peak}$ directly measured during the ISWT. Solid black line indicates bias (mean difference) of -4.4 $ml \cdot kg^{-1} \cdot min^{-1}$. Limits of agreement were not calculated as the difference between the measures was systematic. The dashed line indicates no difference between the measures. Note that 19 (86%) data points are located below the dashed line indicating that the regression equation underestimated $\dot{V}O_{2peak}$ for most participants.

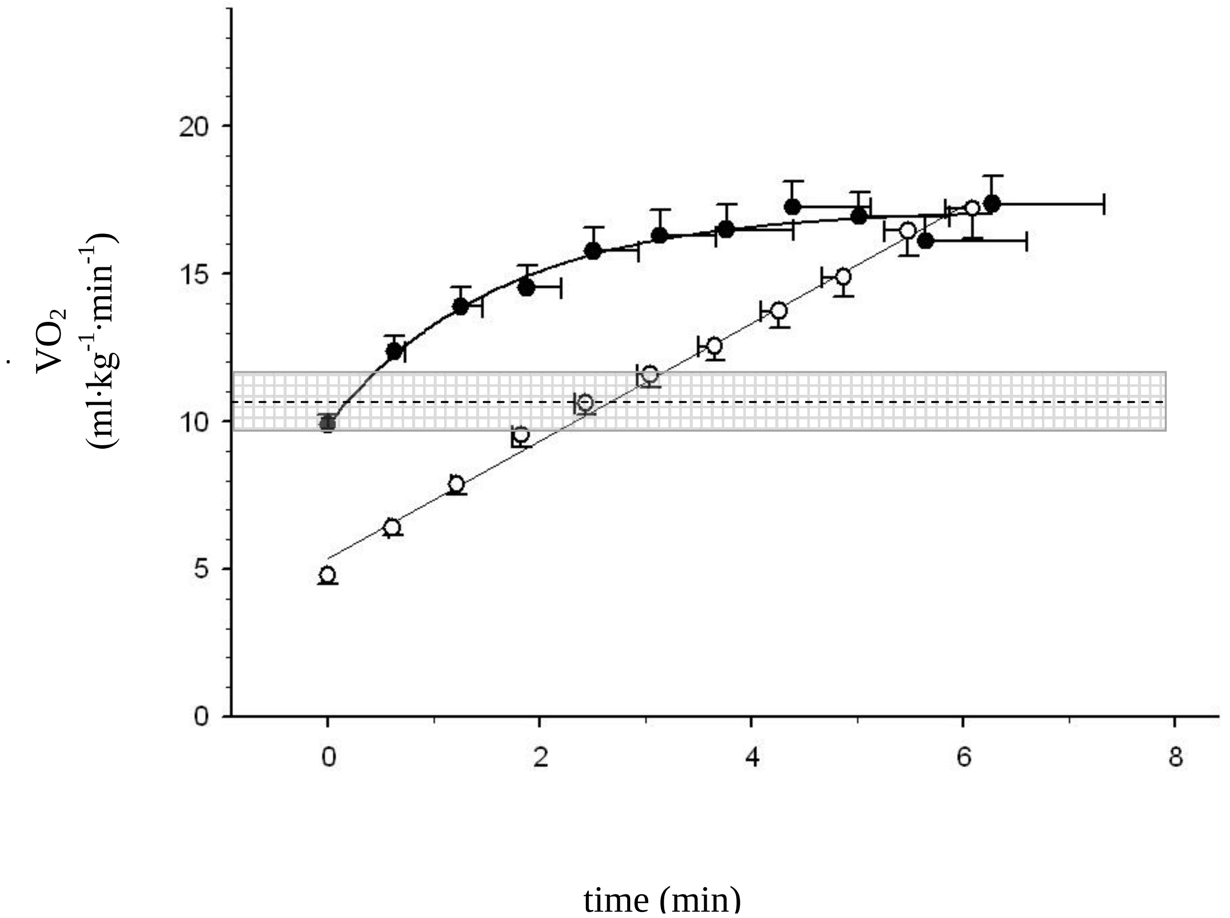

Figure 2: Change in $\dot{V}O_2$ during the incremental shuttle walk test (open circles) and endurance shuttle walk test (closed circles) plotted using the functions reported in the text. Data are mean ± SEM. Dashed black line represents the mean value equivalent to 85% of the $\dot{V}O_{2peak}$ estimated from the ISWD. The grey box represents the 95% confidence interval around this mean value. Of note, the $\dot{V}O_{2peak}$ achieved during the ESWT exceeded 85% of the $\dot{V}O_{2peak}$ estimated during the incremental shuttle walk test in every participant.

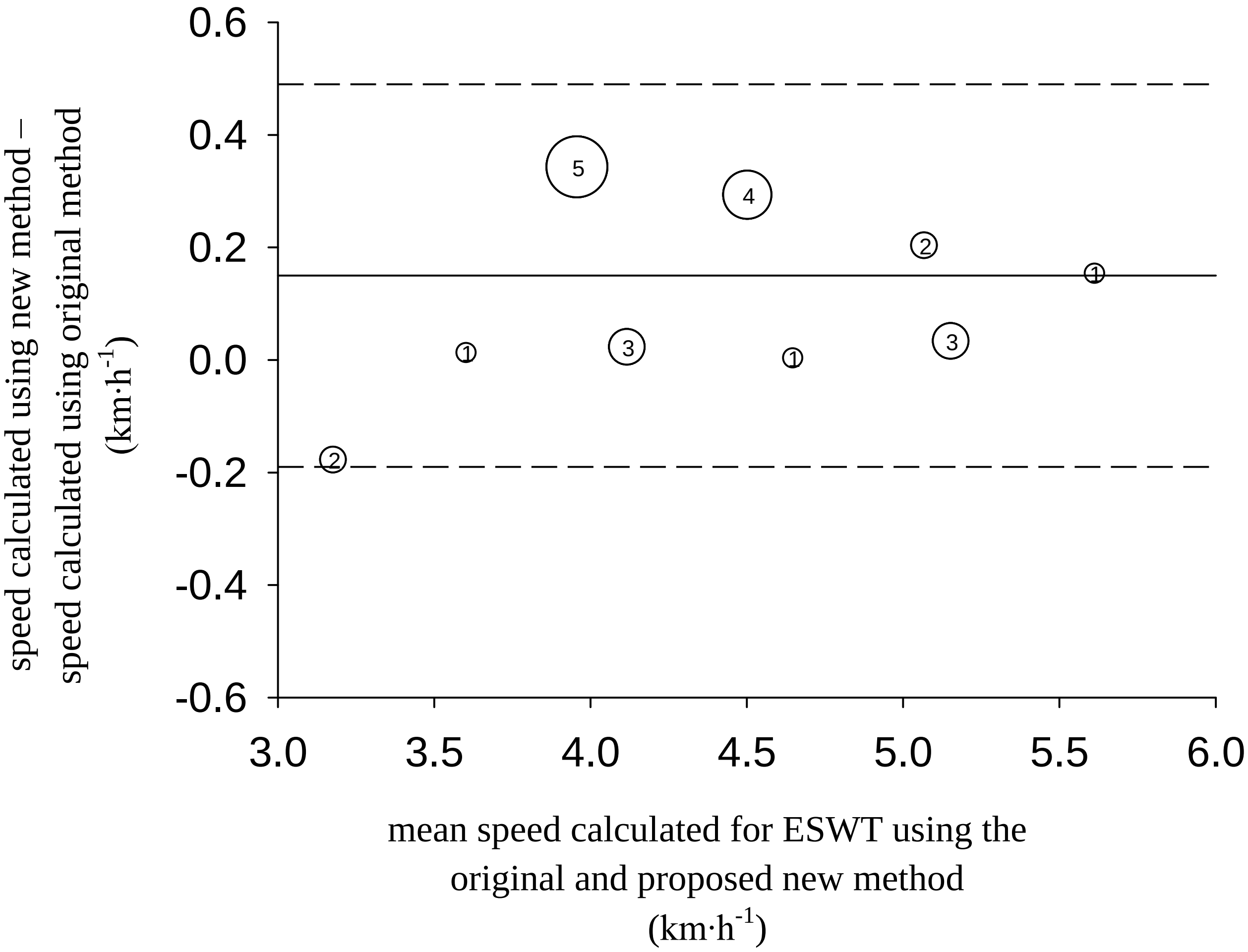

Figure 3: Bland-Altman plot demonstrating agreement between the speed determined for the endurance shuttle walk test (ESWT) using the original method and that equivalent to 85% of the peak speed achieved during the incremental shuttle walk test (new method). Solid black line indicates bias (mean difference) equal to 0.15 $km \cdot h^{-1}$. Dashed lines represent limits of agreement equal to 0.34 $km \cdot h^{-1}$. The size of each point (and the number written inside) represents the number of data points with that x,y coordinate.

Table 1: Characteristics of the participants

Variable	Mean ± SD
Age (yr)	66 ± 8
BMI (kg/m^2)	27.2 ± 5.5
Height (m)	1.63 ± 0.10
Weight (kg)	71.9 ± 13.6
FEV_1 (L)	1.13 ± 0.35
FEV_1 % predicted	48.5 ± 13.0

BMI: body mass index; FEV_1: forced expiratory volume in one second