



Original Article

The reliability of VO_2 kinetics during a 6-minute walking test is influenced by walk speed

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Abstract. [Purpose] This study aimed to investigate the reliability of time constant measurements of oxygen intake at fast and comfortable speeds during a 6-min walking test. [Participants and Methods] The study included 10 healthy young males who walked at 4.5 km/h and 6.0 km/h twice for 6 min each in speed treadmill. Breath-by-breath gas exchange data were continuously measured and used to calculate the time constant of oxygen uptake. The reproducibility and variability of the variables were verified using the limit of agreement, inter-class correlation coefficient, coefficient of variation, and standard error of measurement. [Results] The limit of agreement was -8.5 to 2.3 s and -3.9 to 2.1 s for speeds 4.5 km/h and 6.0 km/h, respectively. The inter-class correlation coefficient, coefficient of variation, and standard error of measurement of the time constant for both speeds were 0.52 and 0.83, 11.2% and 6.4%, and 5.3 s and 1.8 s, respectively. [Conclusion] The results of this study suggested that the cardiopulmonary response, in terms of oxygen uptake, was more consistent during fast walking than during comfortable walking in a 6-min walking test with constant speed.

Key words: Reliability, Oxygen uptake, 6-minute walking test

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INTRODUCTION

The assessment of an individual's physical response to aerobic exercises provides a wealth of valuable clinical information for the early detection of abnormalities in healthy individuals and in those at risk of cardiovascular diseases. Among tests to assess aerobic capacity, the 6-minute walk test (6MWT) is validated, cost-effective, easy to perform, and well-tolerated by patients¹⁾. It is used as an outcome measure to determine activity of daily living in patients with chronic obstructive pulmonary disease²⁾ and to assess the quality of life outcomes of patients with peripheral artery disease³⁾ and predict frailty and risk in patients with heart failure⁴⁾.

As the 6MWT is a constant-load exercise, the cardiopulmonary response is based on the oxygen uptake kinetics. The kinetics of the transition from rest to exercise in terms of oxygen uptake (VO_2) is categorized into three phases⁵⁾. Oxygen uptake during the primary phase (phase I) is due to the response of increased blood flow to the lung caused by exercise. The time constant (TC) of VO_2 in Phase II is equal to the time it takes to reach 63% of steady-state VO_2 during exercise, and it assesses cardiopulmonary response⁶⁾. Factors such as aging⁷⁾, chronic heart failure⁸⁾, type II diabetes mellitus⁹⁾, and stroke¹⁰⁾ can prolong TC of VO_2 due to abnormal responses result in re-hospitalization and high mortality rate, particularly from chronic heart failure¹¹⁾. The oxygen uptake reached a steady state in phase III.

The 2002 ATS guidelines¹⁾ stated that the 6MWT should be explained to “as far as possible”. However, the previous study reported that patients with respiratory failure were instructed to “walk as fast as possible” and increase the walking distance¹²⁾. Therefore, not considering walking speed in the 6MWT may lead to an incorrect assessment of the cardiopulmo-

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nary response as TC of oxygen uptake. However, walking speed affected the reproductivity of oxygen uptake kinetics has not been investigated in 6MWT.

This study aimed to investigate the reliability of oxygen uptake kinetics at comfortable and fast walking speed in healthy young men. We hypothesise that fast walking speed can be used to more accurately measure TC of oxygen uptake during 6MWT compared to comfortable walking.

PARTICIPANTS AND METHODS

The participants were recruited intentionally among a population of university students with no cardiovascular and respiratory diseases to exclude the effect of different walking speed and physical conditions on TC of each participant. Ten healthy individuals (age, 20.3 ± 0.8 years; height, 168.0 ± 7.5 cm; weight, 62.7 ± 10.8 kg; body mass index, 22.2 ± 3.1 kg/m²) participated in four consecutive exercise sessions that lasted for 3 h in 1 day. The participants had not exercised within the previous 24 h and had not consumed caffeine or alcohol 12 h before the study. The institutional research ethics board of Health Science University approved this study (approval number 11), and it was conducted following the principles of the 1964 Declaration of Helsinki; all participants provided written and verbal informed consent before data collection.

From each constant-load exercise test, we collected 5-min resting data followed by a 6-min steady-state treadmill ambulation at 4.5 km/h (comfortable) and then at 6.0 km/h (fast) with a 1-min cool-down period. Each measurement at 4.5 km/h and 6.0 km/h was performed twice with a 30-min interval.

Blood pressure measurements were taken manually before each session. The heart rates of the participants were recorded using an electrocardiogram, with one lead in a standard CM5 configuration and the three electrodes were placed on the chest during all sessions. Oxygen uptake was measured using a breath-by-breath gas measurement system (Aero Monitor AE-300S, Minato Medical Science, Osaka, Japan).

The resting oxygen uptake corresponded to the average value of the 5-min resting data obtained in the sitting position before and in between each exercise session. To measure the oxygen uptake during exercise, the average oxygen uptake from the beginning to the end of the exercise was measured at 10-s intervals. Steady-state oxygen uptake was the average value obtained within 4 min after the commencement of the exercise. Steady-state oxygen uptake was defined as the average value obtained from 4 minutes after the commencement of the exercise to the end.

The initial increase in oxygen uptake at the onset of a steady-state exercise was due to an increase in pulmonary perfusion, and not due to an increase in skeletal muscle metabolism. The initial increase in oxygen uptake did not fit in the commonly used monoexponential kinetic equation. Therefore, to account for the cardiopulmonary component of the oxygen uptake response, exercise data for the first 20 s were not included in the final analysis.

The TC was determined by fitting the resting zero and 10-s average data to a curve using the Microsoft Excel Solver optimization tool, according to this equation.

$$VO_2(t) = VO_{2(b)} + A(1 - e^{-(t-TD)/TC})$$

The values included in this equation were the oxygen uptake at any time ($O_2(t)$), the average value of oxygen uptake at rest (t), the average increase in oxygen uptake after the rest and during the last 2 min of exercise (O_2), natural logarithmic base (e), and O_2 uptake TC¹³. Thus, TC is the time required to reach 63% of the steady-state O_2 uptake. Moreover, the TC properties vary among individuals with different physiological traits.

The $VO_{2\text{ rest}}$, the $VO_{2\text{ amplitude}}$, and the TC in the constant-speed treadmill test₁ and test₂ were confirmed by performing a paired t-test on the values measured in each condition at 4.5 km/h and 6.0 km/h. The Bland-Altman analysis as reproducibility was calculated as the product of 1.96 and the standard deviation of the difference between test₁ and test₂ at treadmill speeds of 4.5 km/h and 6.0 km/h, assessed at the 95% limit of agreement (LOA), suggesting the calculation of upper and lower limits at which a 95% difference should occur in the same units measured¹⁴. Inter-class correlation coefficients (ICCs) were used to assess the reliability of the TC in the two exercise sessions at 4.5 km/h and 6 km/h. The use of coefficient of variation (CV) values is the most common method for determining within-subject variability, and this method was used in this study as well. The standard error of measurement (SEM) provided a measure of the variability value, and this was calculated as follows: $SEM = SD \times \sqrt{1 - ICC}$, with SD representing the standard deviation of the measure¹⁵.

Statistical analysis was performed using Bellcurve for Excel (Social Survey Research Information Co., Ltd. Tokyo, Japan) and Microsoft Excel 2013 (Microsoft Corp., Redmond, WA, USA). Statistical tests with a p-value of <0.05 were considered significant.

RESULTS

No significant differences were observed in the resting VO_2 , steady-state VO_2 , 4-min active VO_2 , and TC between test₁ and test₂ at 4.5 km/h and 6.0 km/h (Table 1). Furthermore, no significant difference was noted in the TC between the means of the two tests performed on the same day, both at 4.5 km/h and 6.0 km/h.

The difference in variance between test₁ and test₂ was confirmed by a qualitative analysis using the Bland-Altman plots

for the TC at 4.5 km/h and 6.0 km/h. The grand means, with the 95% LOA bias between test₁ and test₂, were -8.5 to 2.3 s at 4.5 km/h and -3.9 to 2.1 s at 6.0 km/h (Fig. 1). Fixed and proportional biases were not observed in the TC of any of the treadmill-walking speed test.

The values of intraclass correlation coefficient (ICC), CV, and standard error of the mean (SEM) were 0.52, 11.2%, and 5.3 s at 4.5 km/h, respectively, and 0.83, 6.4%, and 1.8 s at 6.0 km/h, respectively.

DISCUSSION

This study showed that fixed and proportional biases of 6MWT in both speed settings are unobserved. However, the TC measurement obtained at 6.0 km/h is more reproducible and more accurate than that at 4.5 km/h in a treadmill-walking exercise. Therefore, the interpretation of the TC results in the 6.0 km/h setting offers a more feasible option, as compared to that of results in the 4.5 km/h setting. The results of this study suggest that cardiopulmonary responses, such as oxygen uptake, are more consistent with fast walking during a constant speed 6-min walk test compared to tests at comfort speed.

There are a few previous studies that have investigated the reliability of oxygen uptake kinetics using walking tests, such as the 6MWT. One of these previous studies reported that ICC measured using the steady-state treadmill walking test of TC and the SEM was 0.84, 5.3 s in healthy participants¹⁶). Cycle ergometry measurement methodologies of TC from a previous study showed a CV of 11.5%¹⁷) and 11.0%¹⁸). We showed that TC measurement in the 6.0-km/h treadmill-speed walking test in ICC, SEM, and CV had a more reliable value and acceptable set speed than that of the 4.5-km/h test and those reported in a previous study. Fixed and proportional bias were not shown in 4.5-km/h test; however, it appears that combined biases increased the measurement error and led to low ICC and SEM. These results suggest that fast walking during a 6MWT of on-kinetics has a higher reproductivity than comfortable walking.

Reliability of on-kinetics in ICC, SEM, and CV among fast and comfortable 6MWT is related to the mechanisms underlying the relationship between phase I of oxygen uptake kinetics and muscle pump function. This phase is characterized by the muscle pump at the start of the exercise¹⁹). The previous study has shown that errors in the analysis of phase II affects the accuracy of that of phase I²⁰). Therefore, venous return to the lungs due to muscle pumping may have an effect variance in the measured oxygen uptake kinetics during the 6MWT. Specifically, as the treadmill starts slowly, it is not possible to take stable steps at the beginning of 6MWT. Hence, the increase in oxygen uptake in phase I was considered to have been unstable

Table 1. Descriptive statistics for TC of VO₂ measured at 4.5 km/h and 6.0 km/h

Parameter	4.5 km/h		6.0 km/h	
	Test ₁	Test ₂	Test ₁	Test ₂
VO ₂ rest (mL/min)	288.5 ± 34.5	286.6 ± 32.6	289.9 ± 34.0	284.8 ± 47.4
VO ₂ steady-state (mL/min)	829.3 ± 124.4	846.7 ± 126.7	1,160.2 ± 134.7	1,125.7 ± 166.0
VO ₂ amplitude (mL/min)	556.9 ± 103.2	553.5 ± 95.2	892.0 ± 92.5	869.2 ± 102.2
TC (s)	36.7 ± 5.9	39.8 ± 9.6	42.6 ± 6.9	43.5 ± 7.0

Mean ± standard deviation.

TC: time constant of VO₂.

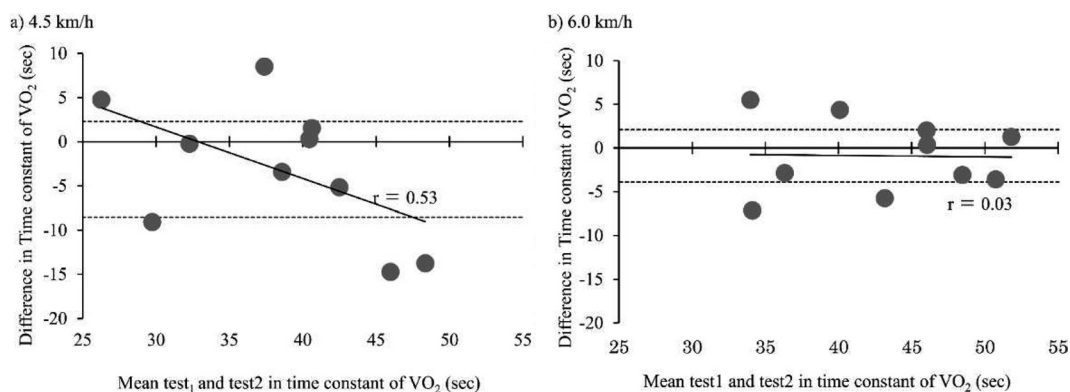


Fig. 1. Bland-Altman plots shows 95% LOA of constant speed treadmill test for a) 4.5 km/h and b) 6.0 km/h.

at 4.5 km/h. Additionally, this fact is supported by a larger amplitude of oxygen uptake that has been reported to increase the accuracy of exponential curves²¹⁾.

This study had a few limitations. First, the characteristics of the study group. In particular, the participants were young and had a low risk for cardiovascular diseases. Hence, it is not recommended that the results be applied to those who have been diagnosed with heart failure or a chronic obstructive pulmonary disease. Second, the sample size was small. Future research should focus on establishing the reliability of oxygen uptake kinetics using treadmill walking in groups diagnosed with cardiovascular and pulmonary diseases with large sample size before drawing a sound conclusion.

In conclusion, this study reveals a reproducible measure of fast walking in 6MWT of the oxygen uptake kinetics. It shows that 6MWT conducted at a slower speed induce inaccurate results during an exercise test. Since only healthy individuals were included in this study, future clinical trials involving patients with other health conditions should be conducted to verify the reliability of the method.

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Conflict of interest

None.

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