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Comparing a Portable and Standard Metabolic Measuring System during Rest and Exercise

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ABSTRACT

Winkle JM, Evans BW, Dilg P, Galparoli S. Comparing a Portable and Standard Metabolic Measuring System during Rest and Exercise. **JEPonline** 2011;14(2):80-87. The usefulness of a portable metabolic measuring system is dependent upon its ability to produce valid and reliable results when compared to standard laboratory equipment such as non-portable metabolic measuring systems. Results from studies comparing the VO2000 with non-portable systems have been inconsistent. The purpose of this study was to compare the metabolic and ventilatory values during exercise using a portable metabolic measuring system (VO2000) with a facemask (FM) and mouthpiece/ nose clip (MP) and a standard laboratory metabolic measuring system, CPX-Ultima (CPX/U). Eighteen volunteers (age = 25.7 ± 7.2 yrs) completed three 20 min exercise sessions (10 min walking/10 min jogging) using the CPX/U, FM, and MP. A counter-balanced design determined treatment order. Metabolic and ventilatory values were recorded at 20 sec intervals and averaged over the last 5 min of walking and jogging. A one-way ANOVA with repeated measures compared the mean values for each variable for the three conditions during walking and jogging. No significant difference ($p > 0.05$) in HR or VO_2 was found due to treatment order. The VO2000 produced similar metabolic and ventilatory values whether using the FM or MP ($p > 0.05$). However, significant differences ($p \leq 0.01$) were found for V_E, VO_2, VCO_2, and RER among the CPX/U, FM and MP during walking and jogging. The VO2000 overestimated VO_2 compared to the CPX/U by 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$ during walking and 6.9 $mL \cdot kg^{-1} \cdot min^{-1}$ during jogging.

Key Words: Oxygen Uptake, Portable Metabolic Measuring System

INTRODUCTION

Metabolic measuring systems have been used for decades in exercise physiology laboratories to determine physiological and ventilatory responses during exercise. With advances in technology, computerized metabolic measurement systems have been developed that not only produce valid and reliable results, but also provide sophisticated analyses such as estimates of ventilatory threshold and breath-by-breath sampling for oxygen uptake kinetics. Despite the advantages of computerized metabolic measuring systems, a disadvantage has been the lack of portability and, therefore, an inability to directly assess oxygen uptake (VO_2) and energy expenditure in the field.

In recent years portable metabolic measuring systems have been designed that enable researchers to obtain measurements during an activity performed outside of a laboratory environment. One portable system, the MedGraphics VO2000, has been used successfully in the field to obtain energy expenditure values for disabled and non-disabled skiers and snow boarders (13), during orienteering (15), and during racquetball competition (3). The usefulness of a portable metabolic measuring system is dependent upon its ability to produce valid and reliable results when compared to standard laboratory equipment such as non-portable metabolic measuring systems. Researchers have reported similar values for basal metabolic rate (BMR) using the VO2000 and a non-portable system specifically designed to measure BMR (17), and also when BMR was measured with the VO2000 using a low flow pneumotach in series with a non-portable metabolic measuring system, the MedGraphics CPX/D (12). During exercise, researchers who compared the VO2000 and the CPX/D in series found no significant differences between the two systems for ventilation (V_E), VO_2 ($L \cdot min^{-1}$), and VCO_2 ($L \cdot min^{-1}$) values while cycling at different workloads (4).

On the other hand, when measured during separate exercise sessions, the VO2000 has been reported to be less accurate and less reliable compared to the CPX/D and Douglas bag, overestimating V_E, VO_2, and VCO_2 values over a range of cycling workloads (5). Significantly lower VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$) and VCO_2 ($L \cdot min^{-1}$) values have been reported during treadmill exercise when using the VO2000 compared to the CPX/D (8). Anderson (2), however, found the VO2000 to be reliable during submaximal and maximal treadmill exercise, but valid for VO_2 only at 3.5 mph and at peak intensities (2). The VO2000 was found to overestimate VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$) compared to the CPX/D during exercise in sedentary pregnant women (20).

Results from studies comparing the VO2000 with standard, non-portable systems during exercise are not consistent and may indicate methodological problems or possible mechanical and technological errors. The over-estimation of values measured in the field by the VO2000 could result in a misrepresentation of actual energy expenditure and VO_2 values, resulting in errors in exercise prescription and physical training programs. More research is needed to determine the ability of the VO2000 and similar portable metabolic measuring systems to accurately assess metabolic demands in the field. The purpose of this study was to compare values from a non-portable metabolic measuring system, the MedGraphics CPX Ultima (CPX/U), and a portable metabolic measuring system, the MedGraphics VO2000, during rest, walking, and jogging.

METHODS

Subjects

Eighteen apparently healthy volunteers (10 males and 8 females), who met the American College of Sports Medicine criteria as low risk (1), were exercising a minimum of three times each week participated in the study. The research procedures used to collect the data were approved by the University Institutional Review Board. Each participant completed a medical history questionnaire, physical activity readiness questionnaire (PAR-Q), and provided written informed consent prior to testing. All subjects were familiar with treadmill exercise and the laboratory procedures. Physical characteristics (mean ± SD) of the subjects were: age = 25.7 ± 7.2 yrs; height = 173.8 ± 9.5 cm; and body mass = 74.0 ± 16.5 kg.

Equipment

The CPX/U is a non-portable metabolic measuring system that uses a zirconia O_2 analyzer with a response time of <0.80 msec and accuracy of ±0.03% and a non-dispersive infrared (NDIR) CO_2 analyzer with response time of <130 msec and accuracy of ±0.1%. A bi-directional differential pressure preVent™ pneumotach with 39 ml dead space and accuracy of ±3% or 50 ml measures ventilation from expiratory volumes over an exercise range of 20 to 200 $L \cdot min^{-1}$. The BreezeSuite software is used for data collection and manipulation (9).

The VO2000 is a portable metabolic measuring system that uses a three-point harness system or single belt configuration for data collection in a field setting. The unit with the battery pack, harness, and cables weighs 1.5 kg. The O_2 analyzer is a galvanic fuel cell with accuracy of ±0.1% and the CO_2 analyzer is a NDIR analyzer with an accuracy of ±0.2%. The preVent™ pneumotach measures ventilation from expiratory flow volumes and the BreezeSuite software package is used for data collection and manipulation (10,11).

A neoprene facemask used during data collection has an aluminum nosepiece that is adjusted at the bridge of the nose, a silicone coupler in front of the mouth for attaching the pneumotach, and two strips of neoprene with Velcro to secure the facemask to the crown and nape of the head. The facemask comes in four sizes including extra small, small, medium, and large. The correct fit allows for approximately 1 inch of neoprene material under the chin (10).

Procedures

Each participant completed three test sessions separated by a minimum of 24 hrs. The three test sessions included measurements using the non-portable CPX/U, VO2000 with facemask (FM), and the VO2000 with mouthpiece and nose clip (MP). Each session consisted of 5 min of seated rest, 10 min of walking at 1.33 $m \cdot s^{-1}$, and 10 min of jogging at a self-selected speed (2.46 ± .28 $m \cdot s^{-1}$) on a Trackmaster TMX 425CP treadmill. The three sessions were assigned using a counter-balanced treatment order.

Prior to beginning each test session, participants were fitted with a Polar telemetry heart rate (HR) monitor and either a facemask or mouthpiece and nose clip. The facemask was fitted per manufacturer's instructions and the same mask size was used for the CPX/U and FM trials. Gas exchange and pulmonary ventilation values were recorded using the breath x breath mode with 20 sec average values printed during testing. Values for variables assessed during the test sessions are reported as the mean value for the last 2 min of rest and for the last 5 min of walking and jogging. Heart rate (HR) was recorded at the end of each min for rest and exercise, respectively. The mean HR for the 5 min of rest and for the last 5 min of exercise was used in data analyses. Rating of perceived exertion (RPE) was recorded at min 4, 5, 9, and 10 during exercise. The mean RPE for the last 2 min of exercise was used in data analyses.

Prior to each test, the CPX/U and VO2000 were calibrated according to manufacturer's instructions. The CPX/U analyzers were calibrated using medical grade gases and air volume calibrated using a calibrated 3-liter syringe over 5 flow rates. The VO2000 uses an auto-calibration mode that calibrates the analyzers using room air and proprietary software. Since manual calibration was not an option with the VO2000 a manual check of the analyzers and the air flow volume was performed prior to and after the FM and MP trials. The analyzers were checked using medical grade gases and a 3-liter rebreathing bag attached to the CAL port of the VO2000. Oxygen and CO_2 values were similar to the gas tank values and were not significantly different prior to and after trials (%O_2, t =.87, p = .40 and %CO_2, t =.25, p = .81, respectively). The air flow check was completed using a calibrated 3-liter syringe by designating the total volume that would be completed during 20 sec. The value was accepted if it was within 10% of the factory set default value. No volume check was rejected.

Statistical Analysis

Values for all variables are reported as the mean ± SD. Each dependent variable was analyzed by a one-way repeated measures analysis of variance (ANOVA), using an alpha level of $p \leq .05$. If the sphericity assumption was violated, the p value was adjusted using the Huyn-Feldt correction to determine significance. If significant differences were found, pairwise comparisons using the Bonferroni adjustment determined which trials were different.

RESULTS

Trial Order

No significant differences related to order of testing were found for VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$ and HR values during rest, walking, and jogging, indicating that the counter-balanced treatment design did not influence the test results (p > .05).

Correlation Coefficients for FM and MP

Significant correlations were found during walking between the FM and MP for V_E (r = .87, p = .000), VO_2 $L \cdot min^{-1}$ (r = .83, p =. 000), VCO_2 $L \cdot min^{-1}$ (r = .75, p = .000), and VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$ (r = .53, p = .02). During jogging the correlation coefficients for the FM and the MP were significant for V_E (r =.92, p = .000), VO_2 $L \cdot min^{-1}$ (r = .78, p = .000), VCO_2 $L \cdot min^{-1}$ (r = .74, p = .000), and VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$ (r = .80, p = .000).

Comparison of Three Conditions during Walking and Jogging

Mean physiological and ventilatory values and significant paired differences for walking and jogging for the three conditions are shown in Tables 1 and 2, respectively. No significant differences were found among the three conditions for HR and RPE values during walking and jogging (p > .05).

Table 1. Metabolic and ventilatory values for the three trials during walking (Mean ± SD).

Variable	CPX/U	FM	MP
V_E ($L \cdot min^{-1}$)	22.1 ± 4.5^{a}	23.7 ± 6.2^{b}	28.2 ± 4.5^{ab}
Fb ($breaths \cdot min^{-1}$)	21.4 ± 4.2^{ab}	26.3 ± 7.3^{ac}	32.8 ± 9.2^{bc}
T_V ($mL \cdot breath$)	1053.9 ± 243.6	1020.1 ± 323.0	945.6 ± 297.6
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	12.0 ± 1.1^{ab}	14.4 ± 2.4^{a}	15.6 ± 2.6^{b}
VO_2 ($L \cdot min^{-1}$)	$0.879 \pm .182^{ab}$	$1.074 \pm .268^{a}$	$1.150 \pm .190^{b}$
VCO_2 ($L \cdot min^{-1}$)	$0.789 \pm .184^{a}$	0.859 ± .215	$0.933 \pm .170^{a}$
RER	$0.90 \pm .07^{ab}$	$0.80 \pm .05^{a}$	$0.80 \pm .07^{b}$

*Similar letters denote significant differences between conditions.

Walking

Significant differences among the three conditions were found during walking for VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$ ($F_{2,16}$ = 18.58, p = 000), VO_2 $L \cdot min^{-1}$ ($F_{2,16}$ = 24.55, p = .000), VCO_2 $L \cdot min^{-1}$ ($F_{2,16}$ = 8.30, p = .000), RER ($F_{2,16}$ = 25.24, p = .000), V_E ($F_{2,16}$ = 29.79, p = .000), and Fb ($F_{2,16}$ = 24.79, p = .000). No significant difference among the three conditions was found for T_V ($p \geq .05$). VO_2 values were significantly lower for the CPX/U trial compared to the FM and MP trials, but significantly higher for RER ($p \leq .05$). Significantly lower VCO_2 and V_E values were found for the CPX/U trial compared to the MP trial ($p \leq .05$). In addition, V_E and Fb were significantly higher for the MP trial compared to the FM trial ($p \leq .05$) (Table 1).

Jogging

Significant differences among the three conditions were found VO_2 $mL \cdot kg^{-1} \cdot min^{-1}$ ($F_{2,16}$ = 29.29, p = .000), VO_2 $L \cdot min^{-1}$ ($F_{2,16}$ = 8.47, p = .000), VCO_2 $L \cdot min^{-1}$ ($F_{2,16}$ = 5.98, p = .006), RER ($F_{2,16}$ = 25.23, p = .000), V_E ($F_{2,16}$ = 14.39, p = .000), and Fb ($F_{2,16}$ = 5.16, p = .01). The CPX/U values were significantly lower compared to the MP values for VO_2 results, VCO_2, V_E, and Fb, but significantly higher for RER ($p \leq .05$). In addition, a significantly higher RER was found for the CPX/U trial compared to the FM and MP trials ($p \leq .05$) (Table 2).

Table 2. Metabolic and ventilatory values for the three trials during jogging (Mean ± SD).

Variable	CPX/U	FM	MP
V_E ($L \cdot min^{-1}$)	59.1 ± 15.5[a]	63.8 ± 19.2	67.9 ± 17.5[a]
Fb ($breaths \cdot min^{-1}$)	35.0 ± 6.0[a]	36.4 ± 6.3	38.1 ± 7.8[a]
T_V ($mL \cdot breath$)	1723.7 ± 505.5	1781.8 ± 582.6	1870.2 ± 514.3
VO_2 ($mL \cdot kg^{-1} \cdot min^{-1}$)	30.5 ± 4.4[ab]	37.4 ± 8.0[a]	37.7 ± 6.3[b]
VO_2 ($L \cdot min^{-1}$)	2.194 ± .572[a]	2.566 ± 1.071	2.761 ± .718[a]
VCO_2 ($L \cdot min^{-1}$)	2.212 ± .615[a]	2.390 ± .708	2.417 ± .661[a]
RER	1.0 ± .06[ab]	0.88 ± .05[a]	0.89 ± .07[b]

*Similar letters denote significant differences between conditions.

DISCUSSION

Several researchers have reported reliable values for the VO2000 and FM during rest (17) and during submaximal and maximal treadmill exercise (2). In this study the VO2000 produced similar VO_2, VCO_2, and RER values during walking and jogging when using either a FM or MP. No studies were found that reported results using the MP. Though VO_2, VCO_2, and RER values were similar in this study, some significant differences occurred in V_E as a result of differences in T_V and Fb. These results were not surprising, as previous researchers have shown that breathing apparatus affects breathing patterns. In particular, the use of MP increases V_E due to an increase in Fb (16). In this study Fb was slightly higher for MP compared to FM during walking and jogging, while T_V was higher during jogging for MP. The differences that occur in breathing patterns due to breathing apparatus may reflect differences in breathing assembly dead space, resistance to air flow during inspiration and expiration, leaks in the FM as well as mechanical or neural factors. As with previous studies that compared FM and MP, the differences in V_E due to breathing pattern did not translate into statistically significant differences in VO_2 values (6). Even though a majority of the participants found the MP to be uncomfortable and unappealing, they perceived the exercise sessions to be similar in intensity, reporting the same RPE values for FM and MP.

The validity of the VO2000 has been in question. Several studies have indicated that the VO2000 produces valid measurements during rest (12,17) and in series with a CPX/D (4). Other studies have found an overestimation of V_E, VO_2, VCO_2, and RER values when using the VO2000 and FM compared to the CPX/D or other portable units (5,20). This study found the FM overestimated VO_2 and RER values compared to the laboratory standard CPX/U, while MP overestimated all values except T_V. During walking, the overestimation of VO_2 values was 2.4 $mL \cdot kg^{-1} \cdot min^{-1}$ higher using the FM compared to the CPX/U. Typically, 2 to 3 $mL \cdot kg^{-1} \cdot min^{-1}$ difference or a difference of approximately 3 to 5% between tests is acceptable due to biological and day-to-day variability (18). Therefore, the VO2000 with FM appears to be within industry standards for use during lower intensity exercise such as walking.

On the other hand, the significant difference in VO_2 values between the CPX/U and the VO2000 during jogging was 6.9 $mL \cdot kg^{-1} \cdot min^{-1}$. This difference is troubling, yet it supports the findings of Anderson (2) who reported valid results for the VO2000 at 3.5 mph, but not for 5 and 6 mph. The mean speed for jogging in this study was 5.5 mph. The differences reported between walking and jogging combined with the finding by Anderson (2) that the VO2000 was valid at peak exercise suggests a non-systematic error in the VO2000.

One area for concern mentioned in previous studies has been the measurement of V_E. Errors that occur in V_E translate directly into errors in VO_2 but in this study no significant difference was found between CPX/U and FM for V_E. However, the significantly lower RER values for the VO2000 compared to the CPX/U could indicate a problem with lag time during gas analysis. A difference in gas transport time and the response time of the analyzers as well as other default settings for the computerized systems could result in differences in reported values between measuring systems (7,14,19). The factory default settings on the VO2000 are not adjustable. Future studies should focus attention on comparing the factory settings between units to determine if they present a possible source of error prior to testing.

The importance of calibration and verification of systems is critical when using different metabolic measuring systems. The autocalibration system of the VO2000 has been suggested as a possible source of error (8). In this study a manual check was completed that verified the analyzer readings before and after testing using medical grade gases and checked air flow volume using a calibrated 3-liter syringe. Therefore, differences between measuring systems in this study appear to be related to some of the technical issues described previously.

CONCLUSIONS

The VO2000 was reliable during walking and jogging when using either FM or MP. The small difference in VO_2 values between the CPX/U and FM during walking indicate the VO2000 is within industry standards, even though statistically different, and may be considered valid for this type of low intensity exercise. However, the difference in VO_2 values between systems during jogging indicates the VO2000 was not valid at the average speeds used in this study. Continued research is needed to better understand and address problems that may be encountered when using portable metabolic measuring systems in the field or when comparing values from multiple metabolic measuring systems.

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