Validation of the CardioCoachCO$_2$ for Submaximal and Maximal Metabolic Exercise Testing

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Abstract

Dieli-Conwright, CM, Jensky, NE, Battaglia, G, McCauley, S, and Schroeder, ET. Validation of the CardioCoachCo$_2$ for submaximal and maximal metabolic exercise testing. *J Strength Cond Res* 00(0): 1–5, 2009—This study examined the validity of the CardioCoachCO$_2$ metabolic system to measure oxygen capacity by comparison to a previously validated device. Fourteen subjects (8 men and 6 women; 25.9 $\pm$ 6.6 years of age) completed 2 maximal graded exercise tests on a cycle ergometer. Subjects were randomly tested on the CardioCoachCO$_2$ and Medical Graphics CardiO2/CP (MedGraphics) system on 2 separate visits. The exercise test included 3 submaximal 3-minute stages (50, 75, and 100 W for women; 50, 100, and 150 W for men) followed by incremental, 25 W, 1-minute stages until volitional fatigue ($\dot{V}O_2max$). There was no significant difference between the CardioCoachCO$_2$ and MedGraphics except at the 100 W stage (22.4 $\pm$ 4.8 and 20.3 $\pm$ 3.7 ml·kg^{-1}·min^{-1}, $p = 0.048$, respectively). Spearman correlations demonstrated a strong correlation between the 2 devices at maximal $\dot{V}O_2$ ($R = 0.94$). Bland-Altman plots demonstrated small limits of agreement, indicating that the 2 devices are similar in measuring oxygen consumption. This study indicates that the CardioCoachCO$_2$ is a valid device for testing $\dot{V}O_2$ at submaximal and maximal levels. Validation of this device supports the CardioCoachCO$_2$ as a feasible and convenient method for testing participants and may be useful in the field or clinic.

Key Words ergometer, oxygen consumption, fitness levels, endurance athletes

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Introduction

Metabolic exercise testing is traditionally performed in a laboratory environment with cumbersome expensive equipment. Over the last several decades, oxygen consumption, expressed as $\dot{V}O_2$, has been measured exclusively with stationary systems in laboratories equipped with a treadmill or cycle ergometer. However, exercise testing is commonly performed in applied settings with athletes (8,12) and thus should be available in a portable and inexpensive device. Exercise measurements during field conditions are not possible using stationary metabolic devices. With the development of portable metabolic units, metabolic gas measurement systems have become easier to use and allow testing to be performed in a variety of settings (5). This is important for athletes and clinicians interested in cardiorespiratory fitness.

CardioCoachCO$_2$ is a portable, lightweight, and economical metabolic testing device that may be practical for use in non-laboratory environments. It is a self-contained, single-unit, metabolic measuring system that self-calibrates and requires minimal technique or training to operate. It is important to validate portable metabolic testing measurement systems that can be operated in the clinic because many metabolic devices differ in calibration, gas analyzers, masks, and sampling of O_2 and CO_2 (5). The validity of the CardioCoachCO$_2$ has been minimally investigated. Previous studies determined that the CardioCoach (model without the CO_2 analyzer) was an accurate and useful device for exercise testing (4,7,9). However, one study recently determined that the CardioCoach was not a valid measure to detect changes in $\dot{V}O_2$ over 14 weeks of training (13). We analyzed data to determine the accuracy of the CardioCoachCO$_2$ values for submaximal and maximal workloads.

The purpose of this study was to validate the CardioCoachCO$_2$ with the Medical Graphics CardiO2/CP system (MedGraphics), a dependable and widely used gas analyzer system (6,11,14), during submaximal and maximal metabolic exercise testing. We hypothesized that the CardioCoachCO$_2$ would provide similar results to the Medical Graphics

Table 1. Subject characteristics.*

	Men ($n = 8$)	Women ($n = 6$)	Combined ($n = 14$)
Age (y)	26.5 ± 8.2	25.2 ± 4.2	25.9 ± 6.6
Height (cm)	180.1 ± 5.6	164.6 ± 7.1	173.5 ± 10.2
Weight (kg)	74.2 ± 10.5	63.7 ± 9.8	69.7 ± 11.2

*Values are mean ± *SD*.

CardiO2/CP during submaximal and maximal metabolic exercise testing. It is important to validate these portable units for clinicians, physicians, scientists, fitness trainers, and athletes who may be interested in purchasing a CardioCoachCO_2 system for metabolic testing.

Methods

Experimental Approach to the Problem

Two maximal graded exercise tests were performed over 2 laboratory visits. All exercise tests were performed on a cycle ergometer (SensorMedics Ergometer 800; VIASYS Healthcare, Inc., Conshohocken, PA). Heart rate was measured using a heart rate monitor (Polar T31; Polar, Inc., Lake Success, NY) worn by the subject. The CardioCoachCO_2 or MedGraphics was used to measure $\dot{V}O_2$ during each exercise test. Results of the 2 exercise tests were compared to determine if the CardioCoachCO_2 accurately measures oxygen consumption.

Subjects

Fourteen volunteers visited the University of Southern California's Clinical Exercise Research Center on 2 separate occasions, performing submaximal and maximal exercise tests on a cycle ergometer (Table 1). Before participation, all subjects read and signed informed consent approved by University of Southern California's Institutional Review Board for human subjects' protection. All subjects were classified as low risk according to the risk stratification by the American College of Sports Medicine (1).

Procedures

During the first visit to the Clinical Exercise Research Center, the subjects were randomized to begin testing with either the CardioCoachCO_2 (Figure 1) or MedGraphics. The exercise test included 3 submaximal 3-minute stages (50, 75, and 100 W for women; 50, 100, and 150 W for men) followed by incremental, 25 W, 1-minute stages until volitional fatigue ($\dot{V}O_2$max). Before the start of each exercise test, height and weight were recorded for each subject using a Healthometer balance beam scale. Oxygen consumption, expressed as $\dot{V}O_2$ (milliliters per kilogram per minute), was collected using the CardioCoachCO_2 model (Korr Medical Technologies, Inc., Salt Lake City, UT) or the MedGraphics (BreezeSuite software version 6.1B; Medical Graphics Corporation, St. Paul, MN). A Hans Rudolph one-way valve and silicone face mask was used for gas collection with the CardioCoachCO_2. A PreVent neoprene mask was used for gas collection with the MedGraphics device (10).

Subjects were instructed to maintain a pedal rate of 65 rpm; therefore, maximal $\dot{V}O_2$ was achieved during the stage at which the subject could not maintain 65 rpm at the given workload. Both heart rate and $\dot{V}O_2$ were recorded manually at the beginning of each stage and at volitional fatigue during the exercise test. Heart rate was assessed using a Polar T31 heart rate monitor (Polar, Inc). During the second visit to the laboratory, which occurred approximately 1 week after the first visit, the subjects repeated the procedures from the first visit using either CardioCoachCO_2 or MedGraphics, depending on randomization.

CardioCoachCO_2 values were measured from expired air using a 5 L mixing chamber technique, which samples every

Table 2. Submaximal and maximal exercise testing $\dot{V}O_2$ values.

Workload (W)	CardioCoachCO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	MedGraphics CardiO2/CP ($ml \cdot kg^{-1} \cdot min^{-1}$)	*R*	*p* values	Percentage of error*
50 ($n = 14$)	13.6 ± 2.3†	13.4 ± 2.5	0.47	0.83	12.5
75 ($n = 6$)	17.4 ± 2.6	17.5 ± 3.2	0.54	0.93	49.5
100 ($n = 14$)	22.4 ± 4.8	20.3 ± 3.7	0.68‡	0.05§	41.2
150 ($n = 8$)	28.9 ± 5.7	28.0 ± 6.1	0.60‡	0.50	14.8
$\dot{V}O_2$max ($n = 14$)	50.6 ± 12.4	48.4 ± 12.2	0.94‡	0.08	3.0

*Percentage of error = (1 − coefficient of reliability).
†Values are mean ± *SD*.
‡Significant correlation between CardioCoachCO_2 and Medical Graphics CardiO2/CP.
§Significant difference between CardioCoachCO_2 and Medical Graphics CardiO2/CP.

Figure 1. The CardioCoachCO_2 metabolic testing device.

15 seconds. A 6-ft breathing tube connects the non-breathing valve to the mixing chamber inlet. $\dot{V}O_2$ is calculated using modified Haldane equations, whereas CO_2 is directly measured by the CO_2 analyzer within the device. The MedGraphics detects breath-by-breath gas analysis that was averaged in 15-second intervals. The devices were calibrated before each test.

Statistical Analyses

Data were analyzed using SPSS (SPSS software version 14.0; SPSS, Inc., Chicago, IL). All assumptions of linear statistics were met before performing analyses. Spearman correlations were used to study correlations between variables. *R* values of 0.7 or greater were taken as indicating a strong correlation with the level of significance set to an alpha of 0.05. Bland-Altman plots were used for validating $\dot{V}O_2$ values at different loads using MedCalc (MedCalc for Windows, version 9.2.0.0;

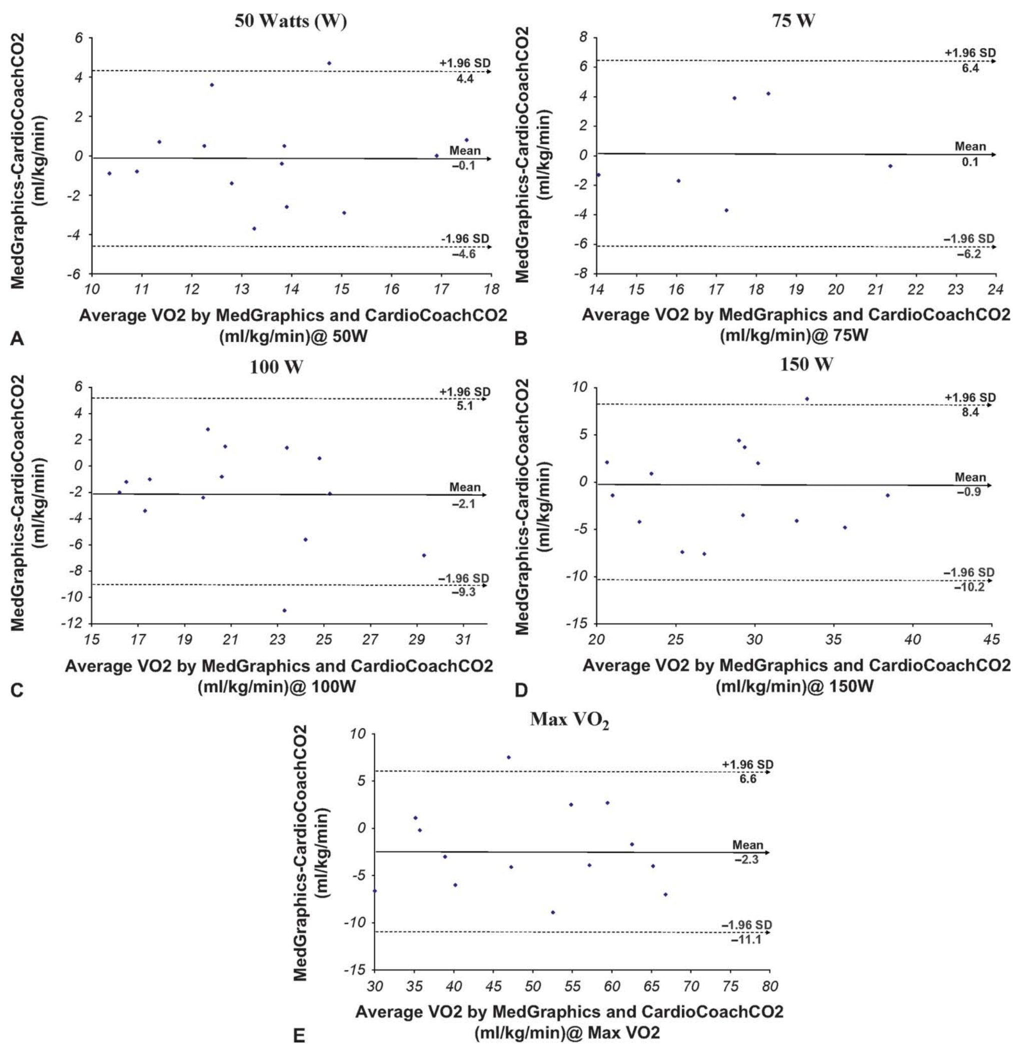

Figure 2. Bland-Altman plots for (a) 50 W, (b) 75 W, (c) 100 W, (d) 150 W, and (e) max $\dot{V}O_2$.

MedCalc Software, Mariakerke, Belgium). These plots are commonly used to assess agreement between 2 methods of clinical measurements (3,2). The Bland-Altman plots were supported by paired *t*-tests at each workload and at $\dot{V}O_2$max using the 0.05 level of significance. Coefficients of reliability (*R*) (ratio of the variances of the MedGraphics device to the CardioCoachCO_2) were calculated to estimate the amount of variance attributable to variation in the population. From these calculations, we determined the amount of excess error (determined by $1 - R$) by the CardioCoachCO_2, expressed as percentage. This percentage is interpreted as the amount of error attributed to the CardioCoachCO_2.

Results

All 14 subjects completed both exercise tests. Gender differences did not exist between the devices; therefore, the data were collectively analyzed. Average $\dot{V}O_2$ values with Spearman correlations and paired *t*-test results are presented in Table 2 from both devices. Spearman correlations determined that the devices are moderately correlated at workloads of 100 and 150 W. At workloads of 50 and 75 W, no correlations existed; however, a strong correlation existed between the devices for $\dot{V}O_2$max ($R = 0.94$). The paired *t*-tests demonstrated that the devices were not significantly different except at the workload of 100 W.

Bland-Altman plots (Figure 2) were used to determine mean differences between the devices and the directionality of those differences. The plots displayed in Figure 2 use the difference of CardioCoachCO_2 from MedGraphics. Therefore, a mean difference less than zero results in an overestimation by the CardioCoachCO_2, and a mean difference greater than zero translates to an underestimation by the CardioCoachCO_2. For $\dot{V}O_2$ at 50, 75, and 150 W, small physiological differences were evident between the 2 methods. At 50 W, a negligible mean difference of -0.1 was present with small limits of agreement (4.4, -4.6 $ml \cdot kg^{-1} \cdot min^{-1}$). At 75 W, a negligible mean difference was 0.1 with small limits of agreement (6.4, -6.2 $ml \cdot kg^{-1} \cdot min^{-1}$).

At 150 W, there was a small mean difference of -0.9 with larger limits of agreement (8.4, -10.2 $ml \cdot kg^{-1} \cdot min^{-1}$). In this case, the data points are randomly dispersed throughout the plot, indicating random error. However, at 100 W, the physiological differences seem to be higher with a mean of -2.1 (limits of agreement [5.1, -9.3 ml·kg·min]), indicating that the CardioCoachCO_2 is underestimating $\dot{V}O_2$ values in comparison to MedGraphics. Furthermore, the data points are tightly clustered above the mean between 16 and 25 $ml \cdot kg^{-1} \cdot min^{-1}$, indicating that random error is not likely. For $\dot{V}O_2$max, the mean difference is larger at -2.3 (limits of agreement [6.6, -11.1 ml·kg·min]), again indicating an underestimation by the CardioCoachCO_2. However, the dispersion of the data points is random, whereas the data points for 100 W are clustered above the mean difference.

To further support the validity of the CardioCoachCO_2, we examined percentage of excess error from the CardioCoachCO_2 using coefficient of reliability (Table 2). As indicated in the table, percentage of error at 75 and 100 W was approximately 40–50%, whereas 50 and 150 W demonstrated less error between the devices. More profoundly, 3% error was determined for $\dot{V}O_2$max between the devices.

Discussion

The purpose of this study was to validate the CardioCoach-CO_2 with the MedGraphics device during submaximal and maximal metabolic exercise testing. The results of this study supported our hypothesis that the CardioCoachCO_2 provides similar results to the MedGraphics during submaximal and maximal metabolic exercise testing. However, our results demonstrate some exceptions during particular submaximal stages (i.e., 100 W).

As expected, the devices are correlated; however, the extent of the correlation depends on the exercise stage. Moderately strong correlations were found at 100 and 150 W ($R = 0.68$, 0.60, respectively), whereas a strong correlation was found at maximal $\dot{V}O_2$ between the 2 devices ($R = 0.94$). At 50 and 75 W, moderate correlations were found (R = 0.47, 0.54, respectively). Small sample size and variation in individual fitness level may explain the more moderate correlations at 50 and 75 W. At 75 W, a sample size of 6 resulted because only the women participated in this stage by study design, which may have altered our results. Both stages may have been affected by differences in individual fitness levels, which were not controlled.

Our results indicate, based on paired *t*-tests, that the $\dot{V}O_2$ values from the 2 devices did not significantly differ during the submaximal stages at 50, 75, and 150 W and at maximal $\dot{V}O_2$. At 100 W, there were significant differences in $\dot{V}O_2$ values between the CardioCoachCO_2 and the MedGraphics. However, various factors may have affected the results. For instance, the women in the study progressed through the stages differently than the men. At 100 W, the men were in the second stage, whereas the women were in the third and final stage; therefore, the women were exercising for a longer period. The women may have been more fatigued at the 100 W stage, which may have altered the results. Additionally, differences in intensity between men and women may explain why the percentage of error was large for this stage (41%). Future studies may warrant exercise stages consistent across both genders; however, body mass, leg strength, and training history should be considered when choosing the appropriate intensities.

The Bland-Altman plots demonstrate findings consistent with the paired *t*-tests, which overall demonstrate that the devices differed significantly at 100 W with the Cardio-CoachCO_2 overestimating $\dot{V}O_2$ values. These plots reinforce the similarity in the devices based on small mean differences between the 2 devices. Again, the opposing results at 100 W may be due to study deign with exercise testing. The large mean difference at $\dot{V}O_2$max is less of a concern because the data points are randomly dispersed, indicating that random error is present. In regard to percentage of error by CardioCoachCO_2, these percentages were determined based on variation in the sample. Thus, because our sample comprised subjects with various fitness levels, it is understandable that the error would be high at certain stages (i.e., 75 and 100 W). Of significant importance is the low error at $\dot{V}O_2$max, which further supports this device to be used for maximal exercise testing.

The previous study by Vehrs et al. (13), including data collected several years ago, is the only published study to use the CardioCoach (model without the CO_2 analyzer) for exercise testing. Our results differed from this study, which reported that the CardioCoach did not accurately measure $\dot{V}O_2$. As described, we report that the CardioCoachCO_2 is accurate for measuring submaximal and maximal $\dot{V}O_2$. There are some obvious differences between the 2 studies, which may have affected the outcome such as type of exercise mode, target population, and the "gold standard" device for comparison. Of notable importance is the fact that our study was designed to validate the CardioCoachCO_2, whereas the purpose of the study of Vehrs et al. (13) was to monitor $\dot{V}O_2$max before and after training.

Our study presents several limitations that need to be considered when interpreting the findings. First, the study population varied by fitness level and this was not controlled for in the study design. Some participants were competitive cyclists, whereas others were recreational athletes. Further, participants who were more accustomed to cycling innately performed better on the test. Second, our sample size was relatively small and had differing numbers of men and women. Additional studies should involve a larger sample size of participants with various fitness levels or a sample with less variance in athletic ability. Last, to rule out the possibility that the MedGraphics CardiO2/CP system was not underestimating $\dot{V}O_2$ values, we performed a pilot study with 10 subjects (5 men and 5 women) that performed the same protocol as for this study. The subjects completed 1 test on the CardiO2/CP system used in this study and a second test on a different CardiO2/CP system for comparison. The results for each stage did not differ between the MedGraphics systems, suggesting that the CardiO2/CP used in the current study was accurate.

In conclusion, the CardioCoachCO_2 provides similar results to the MedGraphics during submaximal and maximal metabolic exercise testing. The CardioCoachCO_2 is a valid device to measure $\dot{V}O_2$ during submaximal and maximal exercise testing. This device provides an inexpensive and portable method to test patients and athletes in the clinical setting.

Practical Applications

This study supports the use of the CardioCoachCO_2 for metabolic exercise testing. The CardioCoachCO_2 device provides a method for clinicians to perform submaximal and maximal exercise testing without expensive and bulky devices. The CardioCoachCO_2 is self-calibrating and easy to use. Although the device is self-contained and allows collection of data without a computer interface, the software is user friendly and provides additional analyses beyond the $\dot{V}O_2$ data presented in this article. Endurance athletes may benefit by having a readily available assessment of their fitness as measured by maximal oxygen consumption using the CardioCoachCO_2 that seems to be a valid measuring device. Of equal importance is the need to assess submaximal oxygen consumption in clinics and rehabilitation centers where the energy cost of movement is important. The CardioCoachCO_2 is a user-friendly device that may serve as an efficient and accurate method for metabolic testing by health professionals, trainers, and coaches.

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