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Validity and Reliability of the KORR Metabolic System During Submaximal and Maximal Exercise

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ABSTRACT

This study compared the KORR CardioCoach Pro metabolic system to the COSMED clinical-research system during submaximal steady-state exercise and maximal aerobic capacity. Eighteen adults (50.3 ± 11.9 yrs old, 78.6 ± 10.6 kg, 25.6 ± 8.0 % body fat, and cardiovascular fitness rank equaled 83rd percentile) completed the validation phase, while nine subjects were randomly assigned to the test-retest phase. Metabolic data were collected simultaneously with both systems. VO2 max (mls • kg • min-1) was not significantly different between systems (COSMED = 40.3 ± 5.7; KORR = 41.5 ± 5.8; ES = 0.21). There were no between-system differences for max ventilation, tidal volume, respiration rate, carbon dioxide production, or respiratory exchange ratio. The intra-class correlation (ICC) and regression slope between the two systems showed excellent agreement (ICC: 0.95; r-squared = 0.94; p = 0.0001; SEE = 1.4 mls • kg-1 • min-1). During submaximal exercise, no statistical differences between systems were observed. The intra-class correlation (ICC) and regression slope between the two systems showed excellent agreement (ICC: 0.92; r-squared = 0.937; p = 0.0001; SEE = 0.058 mls • kg-1 • min-1). These results indicate the KORR metabolic system accurately measured metabolism during both submaximal and maximal cycling.

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I. INTRODUCTION

Over the last several years, more affordable metabolic testing systems have been used to monitor a person's fitness and wellness programming outcomes (Montoye et al., 2020; Tsekouras et al., 2019). These systems simplify the calibration and setup process, so testing is easily performed in fitness, wellness, and nutritional centers. In the past, assessments of resting metabolic rate, maximal oxygen uptake, and metabolic efficiency were done in either university-based research or medical center labs.

With advances in technology, newer systems may provide cost-effective and accessible testing options for general fitness/wellness clients wanting to improve cardio-respiratory capacity (i.e., VO2 max), energy efficiency profiles (fat versus carbohydrate use at rest and/or exercise), or understanding metabolic needs during exercise at various training zones. Additionally, these systems, through post-testing data processes, are focused on helping practitioners customize a client's fitness and preventive health goals while at the same time easily evaluating the client's real-time progress for personalized adjustments, i.e., improvement in fitness leading to changes in a person's training zone targets (Capostagno et al., 2021). From a health perspective, individuals interested in losing weight or improving body composition, metabolic testing may help fitness/health experts provide a more individualized exercise and dietary intake program that fine tunes the balance between macronutrient intake, dietary composition, and the person's energy expenditure patterns like current trends in personalized medical treatments (Abul-Husn & Kenny, 2019; Braig, 2022; Goetz & Schork, 2018). Finally, maximal oxygen uptake testing provides clients with important information about their current cardiovascular disease risk based on their maximal metabolic equivalent level achieved (METS) at the time of testing. Previous research shows that maximal oxygen uptake values are strong predictors of premature cardiovascular events and death (Ross et al., 2016; Swainson et al., 2019). Correspondingly, previous exercise behavioral research suggests that providing individuals real-time health and physical activity information may be a powerful positive motivator of current and future health behaviors (Ferguson et al., 2022; Singh et al., 2022). However, it is equally important that the use of this information needs to come via accurate and reliable testing so that the information is properly actionable for the client (Shei et al., 2022).

While metabolic testing can provide valuable fitness and health information, the data collected is only valuable if the metabolic system and process are accurate and reliable. We previously showed that when compared to standardized research-based oxygen uptake testing results, initially, affordable metabolic testing systems in fitness clubs produced very inconsistent results (Broeder, 2014). However, more recent research with affordable metabolic systems suggests that when testing follows proper population-specific protocols (Tsekouras et al., 2019) and proper graded exercise testing guideline procedures (ACSM, 2021), newer systems can provide accurate and reliable data. Additionally, other lower-cost systems specifically designed to measure resting metabolic rate have also been shown to be reliable and valid (Nieman et al., 2006; Nieman et al., 2005; Vandarakis et al., 2013).

This study, in a healthy active adult population, compared the KORR CardioCoach Pro metabolic system to a previously validated medical research system (Nieman et al., 2013) developed by the COSMED corporation (Chicago, IL) during submaximal steady-state exercise and for maximal aerobic capacity determination. The COSMED comparison system was recently used in a similar metabolic system comparison study (Tsekouras et al., 2019). Although the KORR metabolic systems are currently used in many fitness centers, weight loss facilities, and even universities, there has not been an independent external CardioCoach Pro study conducted comparing this system to a research-grade validated device.

II. METHODS

Participants

Subject participation was conducted following the ethical principles stated in the Declaration of Helsinki (World Medical, 2013), which includes ethics approval obtained before initiating the study, consent forms taking into consideration the well-being, free will, and respect of the participants, and respect of privacy. Prior to starting the study, all study protocol items were approved by Pearl IRB, which is an independent, accredited Institutional Review Board by the Association for the Accreditation of Human Research Protection Programs. This research was carried out in accordance with the ethical standards of the International Journal of Exercise Science (Navalta et al., 2019). Each subject completed the study's consent form and a medical and physical activity history form. If a subject met all inclusion criteria, they then received a trial-testing schedule.

To participate in the study, all subjects were classified as low risk for coronary artery disease according to the American College of Sports

Medicine (ACSM) Graded Exercise Testing guidelines between 18 and 65 years of age (ACSM, 2021). Subjects were required to be currently active (exercise 3-5 times per week on a regular basis over the 6-months prior to starting the study). All subjects were free of metabolic disease (e.g., diabetes), acute infection (e.g., flu), COVID-19, chronic inflammatory conditions (e.g., rheumatoid arthritis), lung disease (e.g., COPD or restrictive lung), and were currently not taking medications to treat hypertension. Pregnant females were excluded from the study. Because initial subject screening items included bioelectric impedance body composition assessment, individuals with implanted electronic devices were excluded from participating in the study. Subjects were recruited from the local area population. Twenty-one subjects volunteered to participate in the study. Of those, 18 subjects (9 females; 9 males) completed the validation portion of the study. Two subjects did not complete the study due to schedule changes (i.e., lack of time), and one subject did not meet all pre-screening criteria. Ten subjects were randomly selected to participate in the test-retest reliability aspect of the study. One subject did not complete this portion of the study due to a schedule change and lack of time, leaving nine for the reliability analysis.

III. PROTOCOL

Body composition was assessed using InBody's 570 multi-frequency bioelectrical impedance (BIA) system (InBody, Cerritos, CA). Each subject was instructed to abstain from solid food for 4 hours prior to testing. Subjects were instructed to drink 12-16 oz of water two hours before testing to ensure proper hydration status as recommended by the manufacturer. If testing took place in the morning, subjects did not strenuously exercise the evening prior. For afternoon or evening testing, subjects did not perform any strenuous exercise the day of testing.

Maximal aerobic capacity was determined using a standardized linear ramp cycling protocol with 3-minute stages, hereafter referred to as the VO2 max test. The starting workload was 75 watts (Stage 1). With each subsequent stage, the workload increased by 25 watts every 3 minutes until each subject reached volitional fatigue. All testing was performed using a Tacx Smart Bike system, which was controlled by an ANT+ ergometer mode computer system. The Tacx Bike (Garmin, USA) testing protocol was controlled using a computer program designed by Rouvy (Czech Republic) that automatically adjusts the force required based on a subject's individual cadence pattern (i.e., low versus high cadence subject), target power independent of a person's preferred cadence.

Submaximal workload determinations were established using the VO2 max protocol data results. The submaximal workloads consisted of three 6-minute stages set at 60%, 75%, and 90% of each person's max watts achieved during the VO2 max test. Maximal watts were determined using a weighted mean that included the last stage a cyclist completed and the fraction of the next stage up to the final end point (e.g., Stage 7–225 W at 180s and Stage 8–250 W at 30s = 229 W at VO2 max). As with the VO2 max test, submaximal workloads were programmed and controlled through the Rouvy cycling software as described above.

Exercise testing trial data were collected each day using identical testing set-up procedures and methods. Testing occurred at the same time of the day ± 30 minutes across all submaximal and maximal trials to avoid diurnal effects on metabolic rate. Subjects were asked to avoid strenuous exercise 24 hours prior to testing and maintain the same dietary intake pattern on the days prior to and the day of testing. These procedures allowed us to minimize the effects that diet and exercise can have on metabolic measurements 18-24 hours prior to exercise measurements (Broeder et al., 1991). Prior to starting the specific trial protocol for a given day, each subject completed a 20-minute standardized cycle ergometer warm-up based on their respective fitness.

The two metabolic systems (COSMED and KORR) were calibrated as recommended by each manufacturer just prior to the start of each subject's trial. The COSMED system calibrations required the flow sensor and gas sensors to use a semi-automated process to accurately measure volume, O2, and CO2 values during the trials based on known calibration volume (3-liter syringe X 6 full breath simulations) and a gas standard calibration process using O2 = 16% & CO2 = 4% concentrations. In contrast, the KORR system uses a totally automated calibration process. The flow sensor was pre-calibrated at the factory, while the gas sensors were pre-calibrated at the factory and were then automatically pre-test calibrated using a room air sensor zeroing process for both the flow and gas sensors. Once the calibration process was completed, the metabolic collection masks for both systems were secured on each person as shown in Figure 1. Next, each subject sat on the cycle ergometer at rest for 2-3 minutes to ensure metabolic variables stabilized prior to starting the exercise protocol. Heart rate, ventilation, tidal volume, respiratory rate, watts, oxygen consumption (VO2), carbon dioxide production (VCO2), and respiratory exchange ratio (RER; VCO2/VO2) data were continuously recorded on both systems simultaneously for each stage during both the submaximal and maximal exercise trials.

Figure 1 - Mask Set-Up For Simultaneous Data Collection on Both Systems

For the submaximal exercise trials, based on previous pilot data, the mean of minutes 4-6 (steady-state values) was used at each respective workload for the between (validity data) and within (reliability) system comparisons. For the maximal oxygen uptake trials, VO2 max was defined as achieving the three following criteria: a plateau in oxygen uptake (≤ 1-2 ml/kg) with increasing workloads, RER ≥ 1.05, and a maximal heart rate ± 5 beats/minute of each subject's age-predicted maximal heart rate (Tanaka et al., 2001).

IV. STATISTICAL ANALYSIS

Data are presented as mean ± standard deviation (SD) in all tables and within the Results section. All summary figures are presented as the mean ± SEM. For maximal effort data, metabolic and pulmonary data were analyzed using t-test procedures. Submaximal data were analyzed using two-way repeated-measures ANOVA. Tukey's post-hoc procedures were used to determine where statistical differences occurred (i.e., VO2 at 60% vs. 75% of max). For the test-retest comparisons, a repeated measures ANOVA model was used to compare within and between systems at each respective submaximal measurement period. Cohen's d effect size (ES) procedures were used to determine the magnitude of the difference for each respective comparison when appropriate. Cohen's d measures the difference between two means divided by the pooled standard deviation of each mean. The effect size descriptors used were very small = 0.01, small = 0.20, medium = 0.50, large = 0.80, large = 1.20, and very large = 2.0. In addition, to compare the two systems, intra-class correlation and regression analyses, Bland-Altman plots with bias and limits of agreement (LOA) analyses were performed. A power analysis was performed to find a significant correlation coefficient between systems, ranging from 0.80 to 0.95, p-value = 0.05, power value (1-ß) = 80%, and sample size = 16 subjects. Finally, the data were analyzed using Prism 9.4.1.

V. RESULTS

Subject and fitness performance characteristics (Tables 1 & 2) are presented for all subjects and compared to a randomly assigned test-retest subject group. There were no statistical differences observed in physical or performance-related characteristics between the groups.

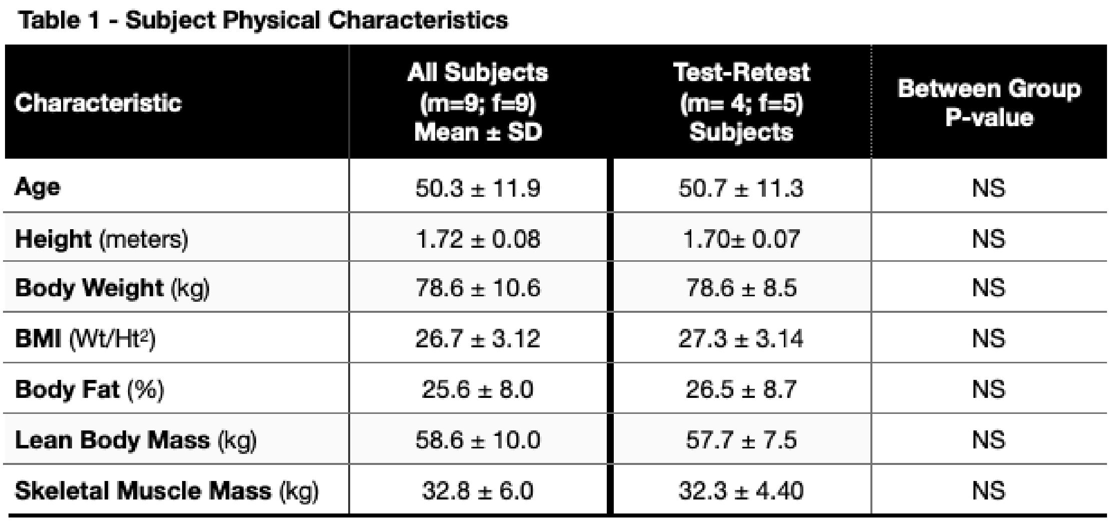


Table 1 - Subject Physical Characteristics

Characteristic	All Subjects (m=9; f=9) Mean ± SD	Test-Retest (m= 4; f=5) Subjects	Between Group P-value
Age	50.3 ± 11.9	50.7 ± 11.3	NS
Height (meters)	1.72 ± 0.08	1.70± 0.07	NS
Body Weight (kg)	78.6 ± 10.6	78.6 ± 8.5	NS
BMI (Wt/Ht^2)	26.7 ± 3.12	27.3 ± 3.14	NS
Body Fat (%)	25.6 ± 8.0	26.5 ± 8.7	NS
Lean Body Mass (kg)	58.6 ± 10.0	57.7 ± 7.5	NS
Skeletal Muscle Mass (kg)	32.8 ± 6.0	32.3 ± 4.40	NS

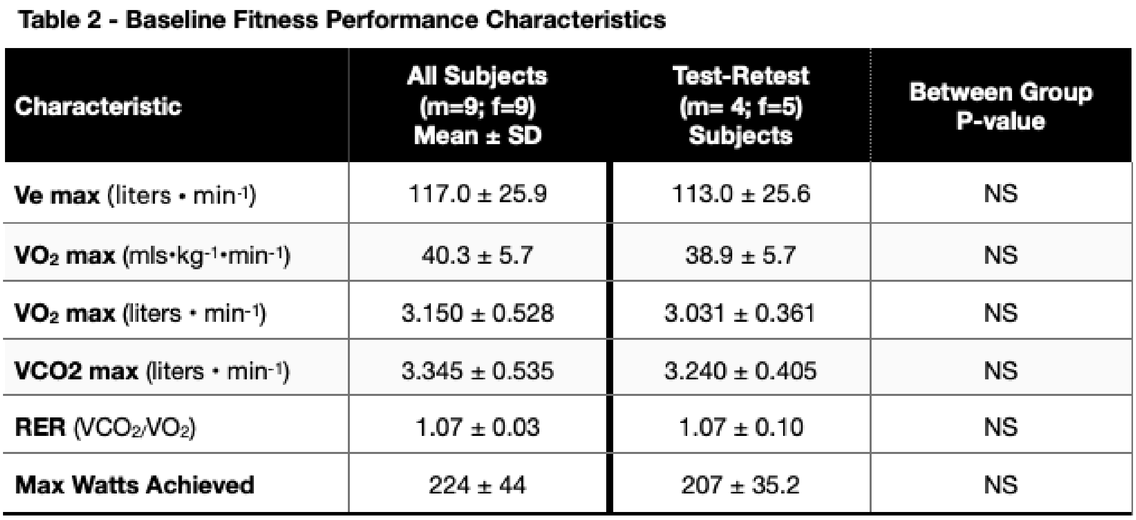


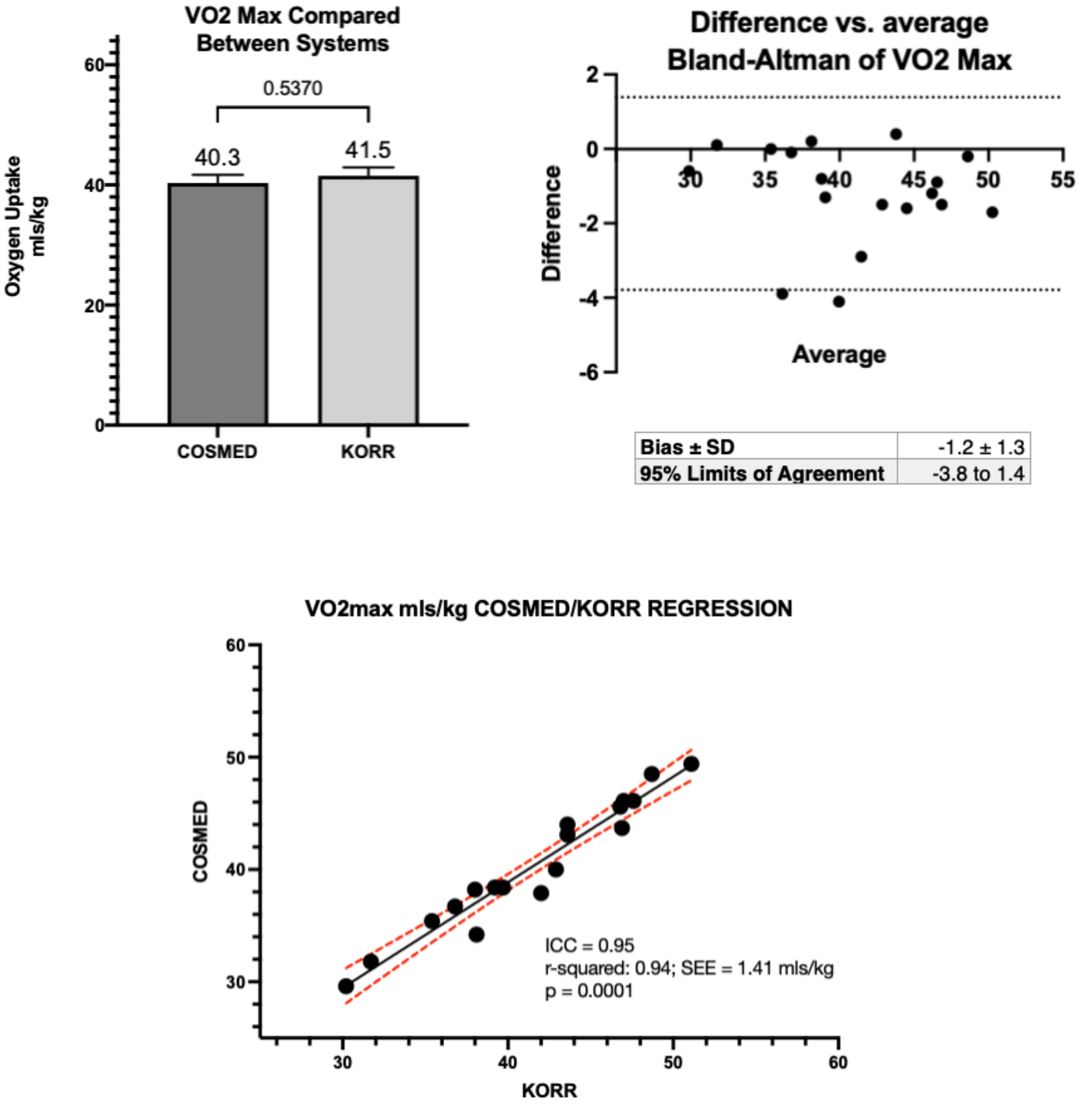
Table 2 - Baseline Fitness Performance Characteristics

Characteristic	All Subjects (m=9; f=9) Mean ± SD	Test-Retest (m= 4; f=5) Subjects	Between Group P-value
Ve max (liters • min^{-1})	117.0 ± 25.9	113.0 ± 25.6	NS
VO$_2$ max (mls•kg^{-1}•min^{-1})	40.3 ± 5.7	38.9 ± 5.7	NS
VO$_2$ max (liters • min^{-1})	3.150 ± 0.528	3.031 ± 0.361	NS
VCO2 max (liters • min^{-1})	3.345 ± 0.535	3.240 ± 0.405	NS
RER (VCO$_2$/VO$_2$)	1.07 ± 0.03	1.07 ± 0.10	NS
Max Watts Achieved	224 ± 44	207 ± 35.2	NS

Maximal exercise comparisons (Figures 2) between systems showed there were no significant differences in oxygen uptake for all subjects combined (COSMED = 40.3 ± 5.7; KORR = 41.5 ± 5.8; ES = 0.21) The intra-class correlation (ICC) and regression slope between the two systems showed excellent agreement (ICC: 0.95; r-squared = 0.94; p = 0.0001; SEE = 1.4 mls • kg−1 • min−1).

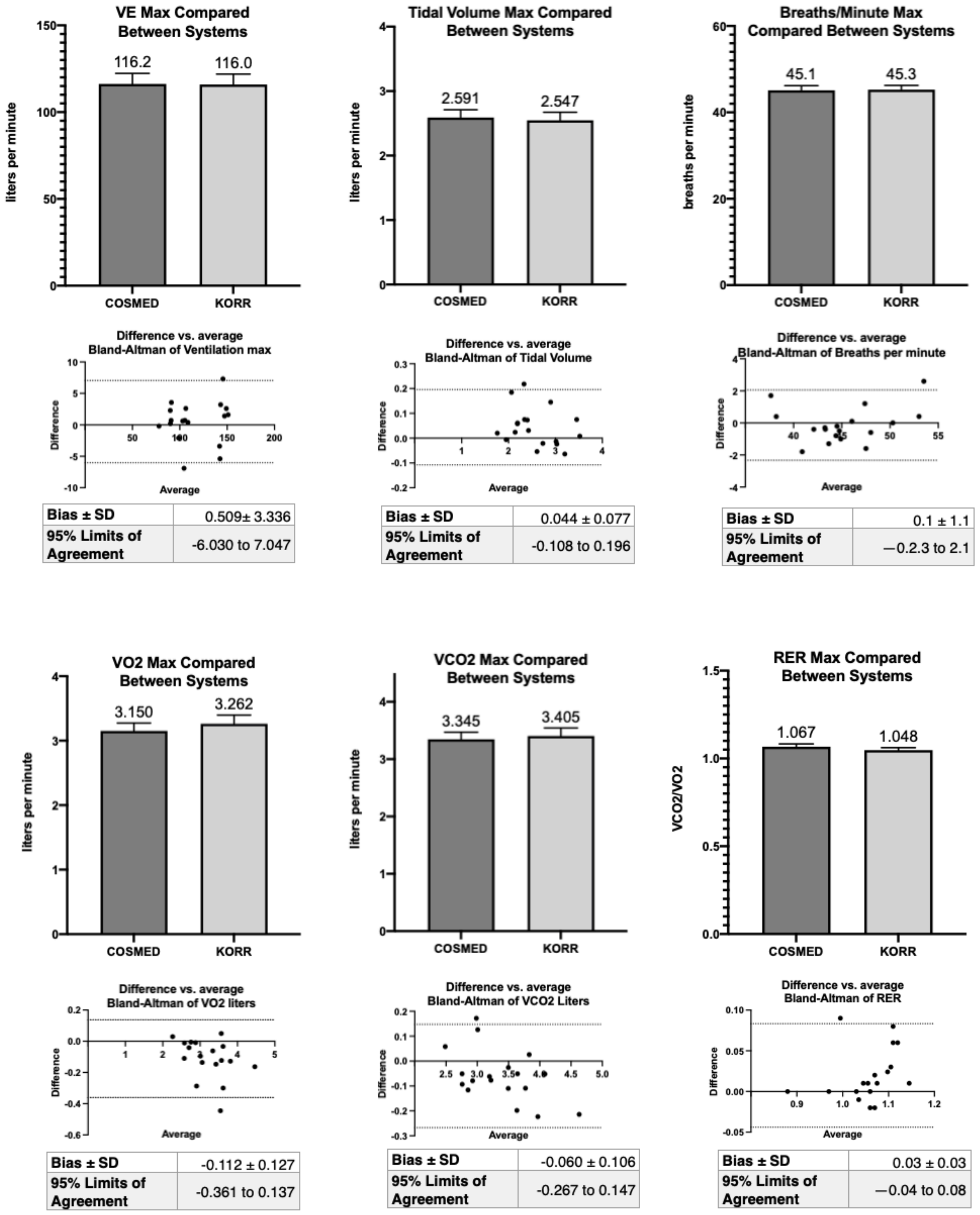
The Bland-Altman analysis showed a Bias ± SD equaled -1.2 to 1.3 with a 95% LOA = to -3.8 to 1.4. Furthermore, there were no significant differences observed between the systems for maximal ventilation in liters • minute-1, tidal volume in liters • minute-1, maximal respiratory rate in breaths • minute-1, and VO2 max & VCO2 max in liters • minute-1, or RER values (Figure 3).

Figure 2 - Maximal Oxygen Uptake (mls · kg^{-1}) Comparisons Between Systems



Bias ± SD	-1.2 ± 1.3
95% Limits of Agreement	-3.8 to 1.4

Figure 3 - Maximal Pulmonary and Oxygen Uptake System Comparisons



Bias ± SD	0.509± 3.336
95% Limits of Agreement	-6.030 to 7.047

Bias ± SD	0.044 ± 0.077
95% Limits of Agreement	-0.108 to 0.196

Bias ± SD	0.1 ± 1.1
95% Limits of Agreement	—0.2.3 to 2.1

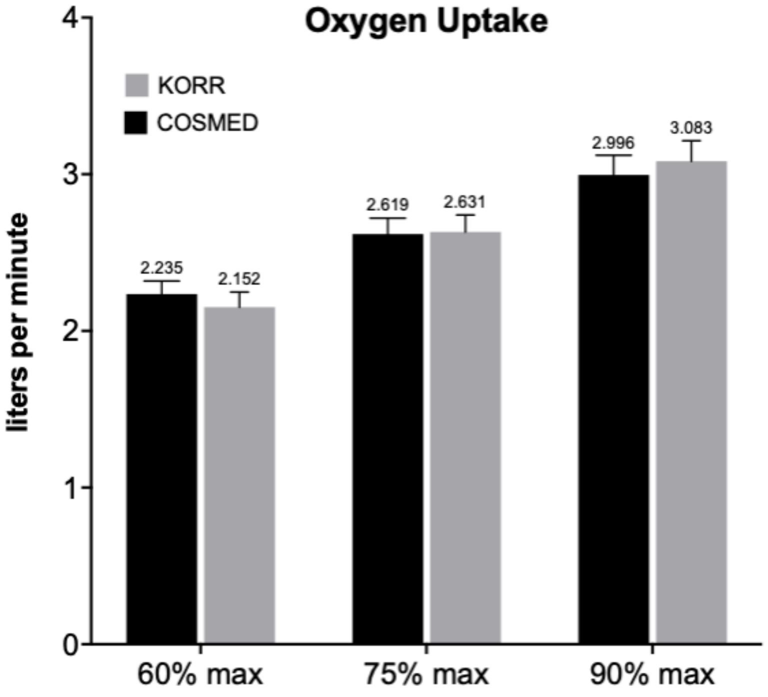
Bias ± SD	-0.112 ± 0.127
95% Limits of Agreement	-0.361 to 0.137

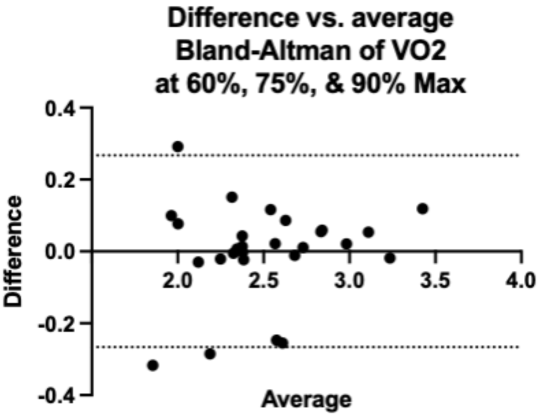
Bias ± SD	-0.060 ± 0.106
95% Limits of Agreement	-0.267 to 0.147

Bias ± SD	0.03 ± 0.03
95% Limits of Agreement	—0.04 to 0.08

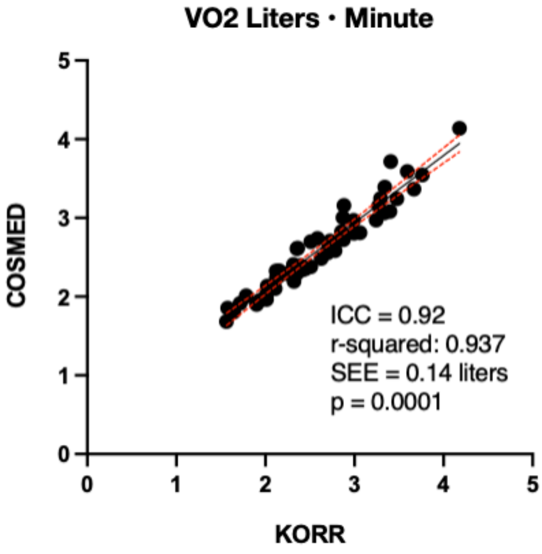
Submaximal exercise comparisons (Figure 4) between system comparisons showed there were no significant differences observed in oxygen uptake in liters per minute. The intra-class correlation (ICC) and regression slope between the two systems showed excellent agreement (ICC: 0.92; r-squared = 0.937; p = 0.0001; SEE = 0.058 mls • kg-1 • min-1). The Bland-Altman analysis showed a Bias ± SD equaled 0.00 to 0.14 with a 95% LOA = to - .27 to 0.27.

Figure 4 - Submaximal Oxygen Uptake (liters • min-1) Between System Comparison





Bias ± SD	0.00 ± 0.14
95% Limits of Agreement	-0.27 to 0.27



Submaximal test-retest results (Table 3) within and between each of the system comparisons showed no significant differences observed at any of the three exercise workloads for VO2 in mls • kg-1 • or liters • min-1, VCO2 in liters • min-1, or RER values. Using the overall submaximal test day VO2 (mls • kg-1 • min-1) mean of each trial and system, the within-system mean difference during submaximal effort day 1 versus 2 was 2.5% and 1.9% for the COSMED and KORR systems, respectively. For VCO2 (liters • min-1), the within-system difference was 0.3% (COSMED) and 1.9% (KORR) while RER (VCO2/VO2) was 1.0% (COSMED) and 0.3% (KORR).

Table 3 - Sub-maximal Metabolic Data Within and Between System Comparisons

Percent of VO2 Max Watts Achieved @ Baseline †	COSMED System		KORR System		Significance Between Days Within Each System	Significance Between Systems Across Days Tested
	Day 1	Day 2	Day 1	Day 2		
	VO2 ($\text{mls}^{-1} \cdot \text{kg}^{-1} \cdot \text{min}^{-1}$)					
60% max	27.3 ± 3.3	26.4 ± 4.0	27.4 ± 2.2	26.3 ± 3.1	NS	NS
75% max	32.0 ± 3.1	32.4 ± 4.0	32.0 ± 2.9	32.3 ± 3.6	NS	NS
90% max	35.4 ± 5.5	38.2 ± 5.0	36.7 ± 3.7	38.2 ± 4.7	NS	NS
	VO2 ($\text{liters} \cdot \text{min}^{-1}$)					
60% max	2.137 ± 0.208	2.071 ± 0.340	2.150 ± 0.221	2.067 ± 0.297	NS	NS
75% max	2.505 ± 0.224	2.539 ± 0.377	2.508 ± 0.275	2.536 ± 0.353	NS	NS
90% max	2.873 ± 0.307	3.000 ± 0.444	2.858 ± 0.365	2.997 ± 0.428	NS	NS
	VCO2 ($\text{liters} \cdot \text{min}^{-1}$)					
60% max	1.946 ± 0.252	1.886 ± 0.365	1.973 ± 0.247	1.931 ± 0.337	NS	NS
75% max	2.423 ± 0.256	2.437 ± 0.388	2.433 ± 0.340	2.477 ± 0.432	NS	NS
90% max	2.955 ± 0.370	3.024 ± 0.484	2.933 ± 0.477	3.070 ± 0.583	NS	NS
	RER (VCO2/VO2)					
60% max	0.91 ± 0.06	0.91 ± 0.06	0.92 ± 0.05	0.93 ± 0.05	NS	NS
75% max	0.97 ± 0.06	0.96 ± 0.05	0.97 ± 0.05	0.97 ± 0.05	NS	NS
90% max	1.03 ± 0.06	1.00 ± 0.05	1.02 ± 0.06	1.02 ± 0.06	NS	NS

† *(60% of max watts = 131 ± 24 watts; 75% of max watts = 164 ± 30 watts; 90% of max watts = 195 ± 36 watts)*

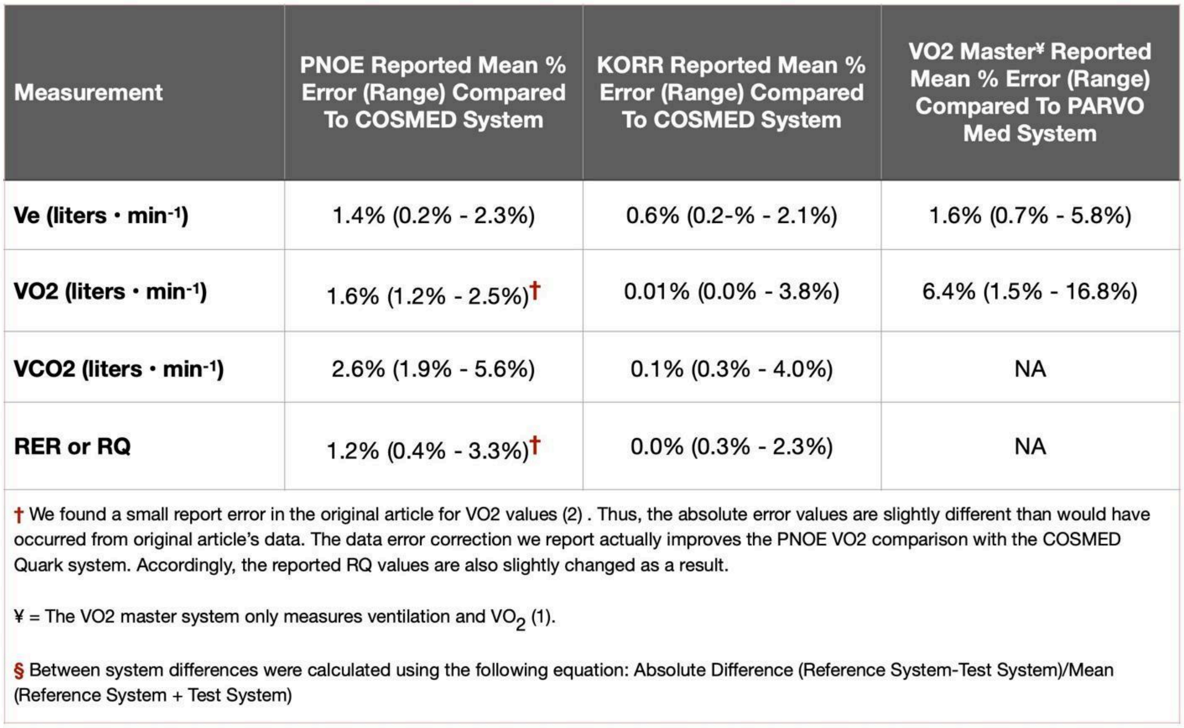
VI. DISCUSSION

This study's purpose was to compare the reliability and validity of the KORR metabolic system compared to a previously validated metabolic system, the COSMED Quark medical research system. The Quark metabolic cart was previously compared to the Douglas Bag Gold Standard method (Nieman et al., 2013). Where Nieman et al. (Nieman et al., 2013) determined that the Quark metabolic system measured values for ventilation and VO2 were in excellent agreement with the Douglas Bag method at submaximal and maximal effort exercise (Ventilation: r-square = 0.94, mean differences ± 11.1 mls • min-1; Oxygen Uptake: r-square = 0.97, mean differences ± 2.3 mls • kg-1 • min-1). In addition, the mean absolute oxygen uptake difference for all measurements (submaximal and maximal efforts) was 0.8% (COSMED: 2.754 ± 1.193; Douglas Bag Method: 2.731 ± 1.195 mls • min-1).

In the current study, there was excellent agreement between the COSMED and KORR metabolic testing systems during both steady-state submaximal and maximal exercise efforts. Interestingly, while the COSMED system is a breath-by-breath system and KORR uses a mini-mixing chamber (not breath-by-breath) design, our results were similar to a previous study comparing the PNOE breath-by-breath system with the same COSMED system used in the current study (Tsekouras et al., 2019). Tsekouras et al. (2019)

reported for VO2 (ml • min-1), the mean percent difference across all stages combined was 1.5% (COSMED: 2.217 ± 0.605; PNOE: 2.183 ± 0.604 liters • min-1). In the current study, looking at the VO2 (liters • min-1) comparison between systems, the difference was 0.0% (COSMED: 2.750 ± 0.409; KORR: 2.750 ± 0.477 liter • min-1). For VCO2 (mls • min-1), the reported PNOE to the COSMED system percent mean difference was 2.6% (COSMED: 2.209 ± 0.738; PNOE: 2.152 ± 0.741 liters • min-1). The KORR percent mean difference in VCO2 was 0.1% (COSMED: 2.736 ± 0.583; KORR: 2.740 ± 0.645 liters • min-1). For ventilation, the PNOE versus COSMED was 1.4% (COSMED: 55.6 ± 17.5; PNOE: 54.8 ± 17.0 liters • min-1) while the KORR system was 0.6% (COSMED: 87.5 ± 25.9; KORR: 87.0 ± 26.2 liters • min-1). Finally, PNOE measured RER percent difference compared to COSMED was 1.2% (COSMED: 0.98 ± 0.07; PNOE: 0.97 ± 0.08) while the KORR system was 0.0% (COSMED: 0.99 ± 0.07; KORR: 0.99 ± 0.07). Table 4 summarizes the absolute mean % error values and the range across all stages measured in the PNOE and the current study. Additionally, using data supplied by Montoye et al. (Montoye et al., 2020), a similar comparison in Table 4 included their study, which compared the PARVO versus the VO2 Master portable metabolic system

Table 4 - Absolute % Difference§ and Range Between Systems Compared Across All



Measurement	PNOE Reported Mean % Error (Range) Compared To COSMED System	KORR Reported Mean % Error (Range) Compared To COSMED System	VO2 Master¥ Reported Mean % Error (Range) Compared To PARVO Med System
Ve (liters • min^{-1})	1.4% (0.2% - 2.3%)	0.6% (0.2-% - 2.1%)	1.6% (0.7% - 5.8%)
VO2 (liters • min^{-1})	1.6% (1.2% - 2.5%)†	0.01% (0.0% - 3.8%)	6.4% (1.5% - 16.8%)
VCO2 (liters • min^{-1})	2.6% (1.9% - 5.6%)	0.1% (0.3% - 4.0%)	NA
RER or RQ	1.2% (0.4% - 3.3%)†	0.0% (0.3% - 2.3%)	NA

† We found a small report error in the original article for VO2 values (2) . Thus, the absolute error values are slightly different than would have occurred from original article's data. The data error correction we report actually improves the PNOE VO2 comparison with the COSMED Quark system. Accordingly, the reported RQ values are also slightly changed as a result.

¥ = The VO2 master system only measures ventilation and VO$_2$ (1).

§ Between system differences were calculated using the following equation: Absolute Difference (Reference System-Test System)/Mean (Reference System + Test System)

In the current study, there were no significant differences observed in determining VO2 max between the systems for all subjects combined and when comparing the test-retest group (Figures 2 & 3). Additionally, Table 3 highlights that both the COSMED and KORR systems had excellent test-retest agreement within and between the systems. For example, if one looks closely at the VO2 (liters • min-1) results, one can see that for each stage, both systems pick up each stage's subtle day-1 to day-2 differences. To illustrate, at 60%, both systems showed oxygen uptake was slightly higher on day 1 versus day 2. For 75% of the max, day 1 and day 2 are virtually the same in both systems. And for the final submaximal effort state at 90% of max, the day 1 data was slightly lower than day 2 in both systems.

These findings are important because systems must be able to correctly detect small, moderate, and large changes accurately. For example, in the HERITAGE Family Study (Bouchard et al., 1999), the authors found that after 20-weeks of standardized supervised aerobic training, the mean oxygen uptake increase was approximately 400 mls for 481 subjects tested pre-to-post.

However, the study also showed that there was extensive adaptation heterogeneity across individuals, with some losing or having only very small changes in VO2 max over time, and others gaining in excess of 1-liter • minute-1 in VO2 max. Thus, given the individual heterogeneity and the relatively small mean changes in fitness likely even over long-duration interventions, it is necessary for metabolic systems to be able to detect relatively small differences over time.

The primary purposes of many newer metabolic systems are to monitor a person's fitness and wellness programming outcomes over time by using a simplified and less expensive testing process. Therefore, it is critical that such systems can detect similar subtle changes consistently and accurately that occurred in the current study. For example, a recent study published by Montoye at al. (2020), comparing the VO2 Master portable metabolic system versus the Parvomedics 2400 (criterion) system, showed that the VO2 Master device had a mean VO2 percent error for submaximal and maximal exercise ranging from 0.8 to 5.8%. However, regression analysis of the VO2 max data in liters • minute-1 between both systems showed there was minimal agreement between the systems (r-squared = 0.17, SEE = 0.302, p = NS). In contrast, the same analysis comparing the KORR to COSMED systems showed excellent agreement (r-squared = 0.94, SEE = 1.41, p = 0.0001) and between the PNOE and COSMED system (Intraclass Correlation Coefficient = 0.98, Confidence Interval = 0.96 - 0.99, p = 0.0001). To further emphasize the importance needed for accurately being able to collect reliable and valid metabolic data, if one considers the 302 ml SEE in the VO2 Master study in context to the training changes observed in the Heritage Family Study, approximately 175 of 481 total subjects were tested in this study (36% of the study population), improved ≤ 300 mls. Thus, the VO2 Master system may not be able to consistently detect such small changes in VO2 max, while both the PNOE and KORR systems appear accurate enough to determine these changes.

In conclusion, this study's results show that the KORR metabolic system data were both reliable and valid compared to the COSMED Quark system when strict research testing guidelines and protocols were used. At the same time, the authors believe that manufacturers of these newer devices should provide clear and detailed testing guidelines and training programs for testing personnel. No matter how accurate a metabolic system is, without proper protocol design and general testing procedures, achieving accurate client data may be compromised (Broeder, 2014).

VII. ACKNOWLEDGEMENTS

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VIII. DATA AVAILABILITY

This study's data will be provided by the corresponding author as needed.

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