Validity and Reliability of the VO_2 Master Pro

Introduction

VO_2 analyzers are worn by athletes to measure performance metrics such as VO_2 max and metabolic equivalents. These metrics are used by coaches to design individualized training programs. VO_2 measurements can be obtained either directly by measuring the heat a subject generates within a small enclosed chamber (direct calorimetry), or indirectly through analysis of inspired and expired gases (in-direct calorimetry). In-direct calorimetry is the preferred method for measuring athletic performance because it is simpler to implement and allows for maximal testing (VO_2 max) on a stationary bike or treadmill.

The advent of technology begets VO_2 analysis tools that go beyond the conventional lab test. Newer developments in technology have taken VO_2 analyzers off the lab bench and into the field. However, most portable units require large battery packs, usually housed in awkward backpacks or waistbands, that may impede the athlete during testing. A study by the University of IOWA found that increasing body weight with a backpack caused a detrimental effect on VO_2 [1]. At fixed treadmill speeds, subjects had an increase in VO_2 when loaded with a pack. The VO_2 Master Pro is a novel, patented VO_2 analyzer entirely self-contained to a small mask worn on the subject's face, eliminating the constraints of a backpack.

This study aimed to determine the validity and reliability of the VO_2 Master Pro when compared to a VacuMed metabolic simulator. The VacuMed simulator has been validated with the industry-standard Douglas bag method [2] and has been used to validate popular VO_2 analyzers such as the Cosmed K5 [3]. The simulator's design is based on concepts discussed by Huszczuk and Wasserman [4].

Twenty-four different set points of ventilation and metabolism were applied to two VM Pros, to examine accuracy and repeatability over a broad range. Bland-Altman plots, ordinary least products regression (OLP), mean percentage differences and typical percentage error were analyzed. A two-way random intraclass correlation (ICC) model was used to determine ICC coefficients to further determine reliability.

Method

Two VM Pros were used in three tests to determine intra and inter reliability. For each test, the device was connected to the flow conduit of a metabolic simulator (VacuMed Model 17056). Atmospheric pressure, temperature and humidity were recorded and used to determine the appropriate metabolic simulator mass flow rate of gas, as per manufacturer instructions [5]. Data was recorded at each test condition (table 1) after 30s of controlled input passed, to allow the metabolic simulator to reach stasis. Reported outputs were collected for a minimum of 10 breaths and averaged into a single recorded value.

Validity was examined using Bland-Altman plots, OLP regression, mean percentage differences and typical percent errors. Unit reliability was examined using intraclass correlation coefficients, minimum detectable change and typical error.

Table 1: *Controlled Inputs of VacuMed Metabolic Simulator*

Step	Tidal Volume (L)	Respiratory Frequency (Breaths Per Minute)	VO_2 STPD (mL)
1	1.5	22	1000
2	1.5	30	1300
3	1.5	40	1600
4	1.5	50	2000
5	2.0	25	1500
6	2.0	35	1750
7	2.0	45	2100
8	2.0	55	3000
9	2.5	22	2000
10	2.5	30	2300
11	2.5	36	2600
12	2.5	40	3000
13	3.0	20	2500
14	3.0	30	3000
15	3.0	35	3600
16	3.0	40	4000
17	3.5	20	3000
18	3.5	30	3300
19	3.5	36	3600
20	3.5	40	4000
21	4.0	20	3500
22	4.0	25	3625
23	4.0	30	3750
24	4.0	35	4000

Results

Table 2: *VO_2 Master Pro Intra – Inter Device Reliability Results*

	Ventilation	VO_2
ICC (Intra-Rater)	1.000 (0.995 - 1.000)	0.999 (0.996 - 1.000)
ICC (Inter-Rater)	1.000 (1.000 - 1.000)	0.999 (0.999 To 1.000)
Standard Deviation (%)	0.66	2.21
Typical Error Percent (%)	0.62	0.52
Minimum Detectable Change Intra-Rater (%)	1.72	2.34
Minimum Detectable Change Inter-Rater (%)	1.43	3.45

Intra and inter repeatability coefficients were greater than 0.999, demonstrating high reliability. Both ventilation and VO_2 had an excellent correlation between the metabolic simulator and the VO_2 Master Pro, with R^2 values of 0.9998 ($p < 0.01$) and 0.9972 ($p < 0.01$) respectively (figures 1 and 2). The confidence intervals of ventilation and VO_2 indicated no statistically significant bias, with their slopes passing through 1 and intercepts through 0. Mean percent differences were less than 1%.

Table 3: Validation Results

	R^2	Slope (95% CI)	Intercept (95 % CI)	Mean % diff (Min - Max)	Typical Percent Error
Ventilation	0.9998	0.9977 (0.9916 To 1.0039)	-0.2981 (-0.8668 To 0.2707)	-0.62 (-2.85 To 0.25)	0.466
VO_2	0.9972	0.9951 (0.9719 To 1.0183)	15.461 (-51.729 To 82.704)	0.22 (-5.05 To 3.91)	1.56

Bland-Altman plots demonstrated excellent agreeability and low deviation across the entire range, with a mean error of 0.5L/min [-1.31,0.332] for ventilation (figure 3) and 2mL/min [-94.0,98.15] for VO_2 (figure 4), given a 95% confidence interval.

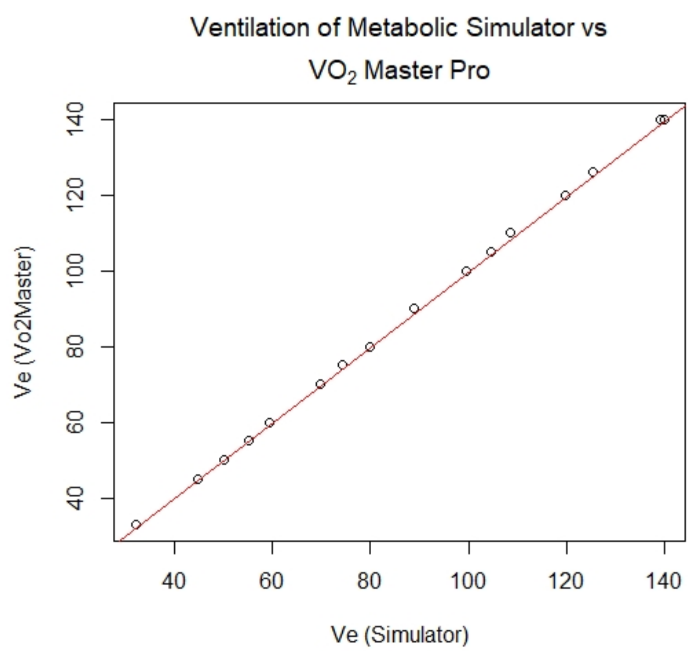

Figure 1: Ventilation Reported by Simulator Vs VO2 Master Pro (R^2 = 0.9998, $p < 0.01$).

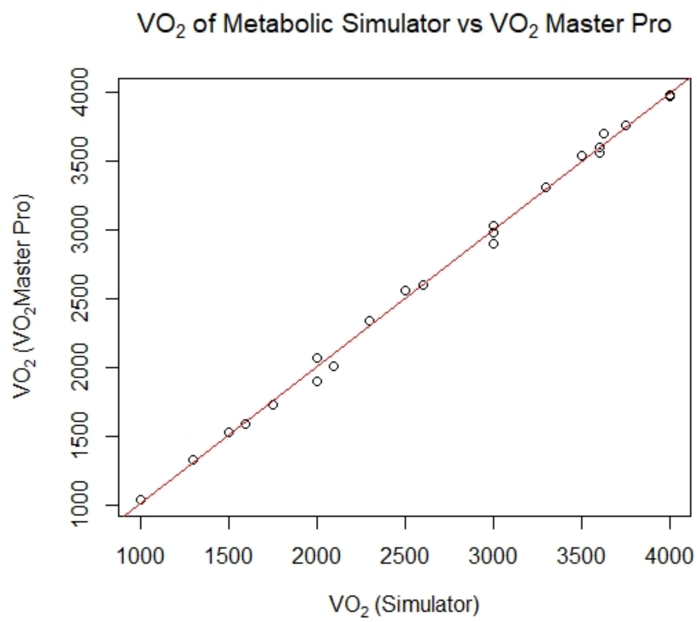

Figure 2: VO2 Reported By Simulator versus VO_2 Master Pro ($R^2 = 0.9972$, $p < 0.01$).

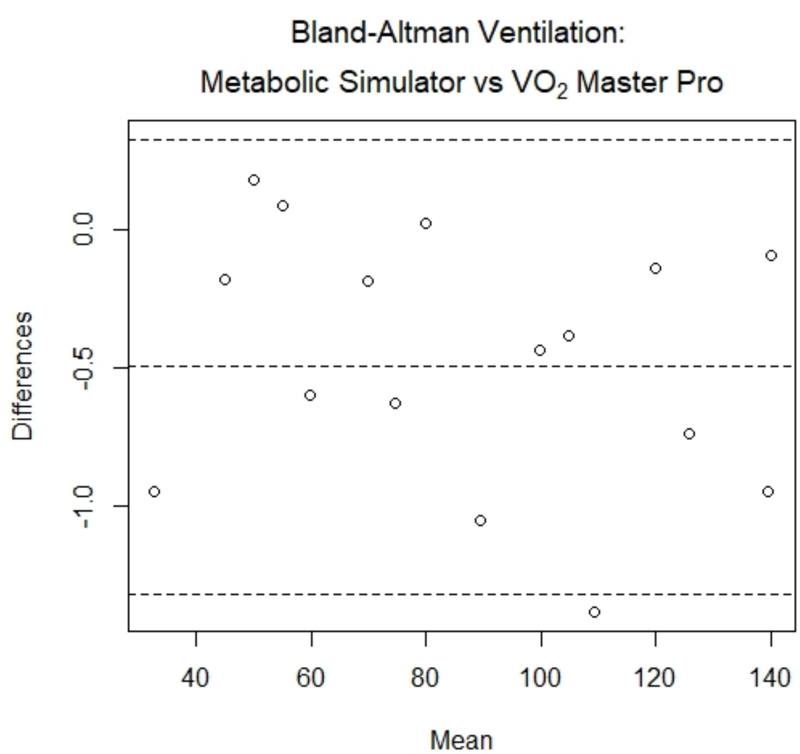

Figure 3: Bland-Altman Plot of Ventilation with mean of 0.5L/min [-1.31, 0.332].

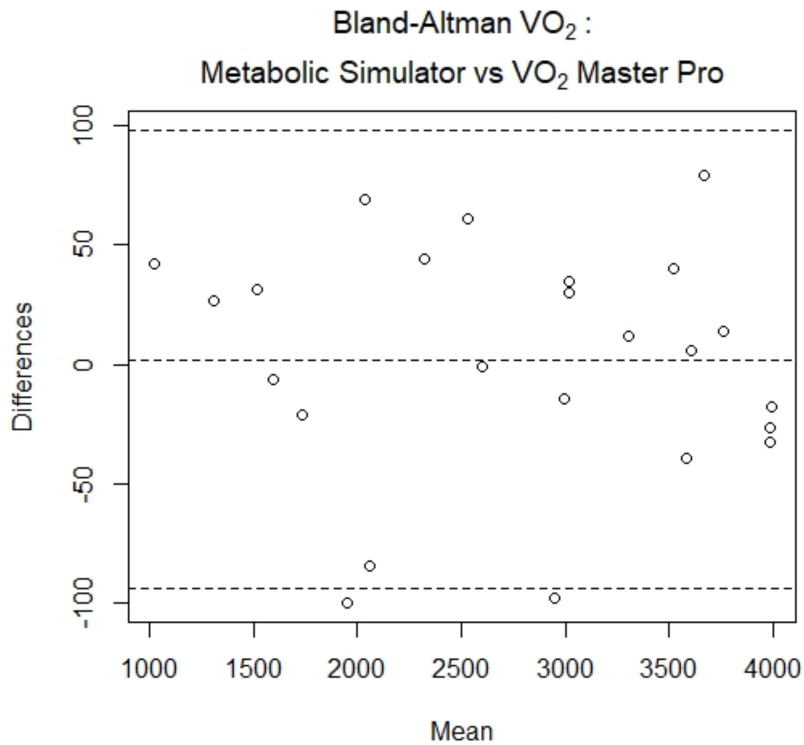

Figure 4: Bland–Altman Plot of VO_2 with a mean of 2mL/min [-94.0,98.15].

Discussion

This research is subject to several limitations. The VacuMed metabolic simulator is only capable of producing VO_2 inputs of up to four liters per minute. This study tested VO_2 inputs from one liter up to the maximum. The Vacumed 17056 has a series of fixed tidal volume selections from one to four liters, in half-liter increments. As such, this study was unable to test any tidal volume measurements between the half-liter steps, above four liters, or below one liter. In future studies, validation at greater tidal volumes, ventilations and metabolic rates should be evaluated. In addition, validation at resting metabolic rates and ventilations should be examined.

Conclusion

The VO_2 Master Pro demonstrated excellent agreement with the simulator throughout the entire tested metabolic range. The mean differences of 2mL/min for VO_2 and 0.5l/min for ventilation demonstrated no proportional or fixed bias, with confidence intervals crossing through zero and one respectively. Typical percent error was less than 2% for all metrics, easily achieving the 3% recommendation by the Australian sports institute [6]. Intra and inter reliability of the VO_2 Master Pro were excellent with ICC coefficients greater than 0.99, and minimum detectable changes less than 3.5% for VO_2 and 1.5% for ventilation. These results are comparable to popular VO_2 analyzers such as the Cosmed K5 [3].

References

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