Author: R. Duffield, B. Dawson, H. Pinnington and P. Wong

Title: Accuracy and reliability of a Cosmed K4b2 portable gas analysis system.

Journal: Journal of Science and Medicine in SPort
ISSN: 1440-2440
Year: 2004
Volume: 7
Issue: 1
Pages: Nov-22

Abstract: The purpose of this study was to assess the validity and reliability of a Cosmed K4b2 portable telemetric gas analysis system. Twelve physically fit males performed a treadmill running session consisting of an easy 10 min run, a hard 3 min run and a 1 min sprint (with rest periods of 10 min separating each run), on four separate occasions. Sessions were identical with the exception of the apparatus used to measure O2. During two (test-retest) sessions a Cosmed K4b2 portable gas analysis system was used; in another, a laboratory metabolic cart, and in one session, both systems were used to measure O2 simultaneously. Comparison of Cosmed K4b2 and metabolic cart measurements in isolation revealed significantly (p<0.05) increased values of O2, CO2, FE CO2 (except FE CO2 at 10min) and lower values of FE O2 for each run duration by the Cosmed system. Linear regression equations to predict metabolic cart results from Cosmed values were, respectively; cart O2 = 0.926 ïƒ— Cosmed O2 -€“ 0.227 (r2 = 0.84) and cart CO2 = 1.057 ïƒ— Cosmed CO2 -€“ 0.606 (r2 = 0.92). Bland -€“Altman plots and comparison of the test-retest Cosmed measurements revealed that the K4b2 system showed good repeatability of measurement for measures of E, O2 and CO2, particularly for 10 and 3 min tests (ICC = 0.7 -€“ 0.9, p<0.05). In conclusion, the Cosmed K4b2 portable gas analysis system recorded consistently higher O2 and CO2 measurements in comparison to a metabolic cart, however, satisfactory test-retest reliability of the system was demonstrated.

Author Address: rduffield@csu.edu.au

URL: http://dx.doi.org/10.1016/S1440-2440(04)80039-2

Accuracy and reliability of a Cosmed K4b[2] portable gas analysis system.

R. Duffield, B. Dawson, H.C. Pinnington, P.Wong.

School of Human Movement and Exercise Science

University of Western Australia

35 Stirling Highway

Crawley, WA 6009

9/01/03

Corresponding Author: Rob Duffield c/- above address

Email: robd@cyllene.uwa.edu.au

Telephone: (618) 9380 2361

Fax: (618) 9380 1039

Abstract: (1st Importance heading)

The purpose of this study was to assess the validity and reliability of a Cosmed K4b^2 portable telemetric gas analysis system. Twelve physically fit males performed a treadmill running session consisting of an easy 10 min run, a hard 3 min run and a 1 min sprint (with rest periods of 10 min separating each run), on four separate occasions. Sessions were identical with the exception of the apparatus used to measure $\dot{V}O_2$. During two (test-retest) sessions a Cosmed K4b^2 portable gas analysis system was used; in another, a laboratory metabolic cart, and in one session, both systems were used to measure $\dot{V}O_2$ simultaneously. Comparison of Cosmed K4b^2 and metabolic cart measurements in isolation revealed significantly ($p<0.05$) increased values of $\dot{V}O_2$, $\dot{V}CO_2$, $F_E CO_2$ (except $F_E CO_2$ at 10min) and lower values of $F_E O_2$ for each run duration by the Cosmed system. Linear regression equations to predict metabolic cart results from Cosmed values were, respectively; cart $\dot{V}O_2 = 0.926 \cdot \text{Cosmed} \dot{V}O_2 - 0.227$ ($r^2 = 0.84$) and cart $\dot{V}CO_2 = 1.057 \cdot \text{Cosmed} \dot{V}CO_2 - 0.606$ ($r^2 = 0.92$). Bland –Altman plots and comparison of the test-retest Cosmed measurements revealed that the K4b^2 system showed good repeatability of measurement for measures of $\dot{V}_E$, $\dot{V}O_2$ and $\dot{V}CO_2$, particularly for 10 and 3 min tests (ICC = 0.7 – 0.9, $p<0.05$). In conclusion, the Cosmed K4b^2 portable gas analysis system recorded consistently higher $\dot{V}O_2$ and $\dot{V}CO_2$ measurements in comparison to a metabolic cart, however, satisfactory test-retest reliability of the system was demonstrated.

Keywords: Oxygen consumption, ventilation, metabolic cart, high intensity exercise, steady state exercise.

Introduction (1st importance heading)

The expansion of traditional laboratory based measurements into field settings has allowed for further investigation into the specific energetics of exercise conducted outside of controlled environments. A recording of oxygen uptake ($\dot{V}O_2$) is commonly taken for the indirect measurement of energy cost, which normally requires sophisticated laboratory equipment and surrounds [1]. Hence, difficulties often arise when attempting to record such measures in non-laboratory locations. However, the measurement of $\dot{V}O_2$ within specific sporting (field) settings is important for an improved understanding of the metabolic demands placed upon the body during various forms and intensities of exercise. A portable gas analysis system that is available is the breath by breath Cosmed $K4b^2$ system, which is the latest of a series (including the K2 and K4) of portable systems Cosmed (Rome, Italy) has produced.

Previous research reporting on the accuracy of the older Cosmed K2 unit indicated that $\dot{V}O_2$ was generally underestimated [2,3,4,5]. As the K2 model lacked a CO_2 analyser, the RER value was assumed to equal 1.00, hence the resulting inherent assumptions were believed to be the cause of the measurement errors. The more recent K4 and $K4b^2$ systems include a CO_2 Non-dispersive Infrared CO_2 analyser, allowing for measurements of F_E CO_2 and $\dot{V}CO_2$ and thus RER. Hausswirth et al. [6] reported acceptable levels of accuracy for $\dot{V}O_2$, $\dot{V}CO_2$ and R measurements made with the K4 unit when compared to a CPX Medical Graphics Metabolic cart for a range of cycle ergometer workloads between rest and maximal intensity. No significant differences ($p>0.05$) and strong correlations ($r = 0.95$) between the two measurement systems were noted for $\dot{V}_E$, $\dot{V}O_2$ or

$\dot{V}CO_2$.

To date, a growing number of published reports concerning the accuracy of the K4b^2 system are available, however no data on the reliability of the Cosmed K4b^2 system has been reported. Furthermore, many recent studies have reported use of this system for metabolic measurements [7,8,9]. Pinnington et al. [10] recently reported that significantly lower ($p<0.001$) $F_E O_2$ and $F_E CO_2$ values were measured by the K4b^2 Cosmed system compared to measures made by a metabolic cart from expired air collected in a Tissot tank during steady state treadmill running. Significantly higher ($p<0.05$) $\dot{V}_E$ values (3.5 - 4.0 l·min^{-1}) over a range of ventilations from 50 – 100 L·min^{-1} were also recorded by the Cosmed system compared to Morgan Ventilation monitor values. Strong Pearson correlation coefficients were reported ($r>0.92$) for the association between Cosmed values and metabolic cart/Morgan values for measures of $\dot{V}_E$, $\dot{V}O_2$, $F_E O_2$, and $F_E CO_2$ and $r = 0.87$ for $\dot{V}CO_2$. However, the difference between measurement systems was physiologically significant, with ANOVA and Bland – Altman plot analysis indicating a trend for lowered measures of $F_E O_2$ by the Cosmed K4b^2 system.

In contrast, McLaughlin et al. [11] reported acceptable findings when the Cosmed K4b^2 system was compared to criterion $\dot{V}O_2$ measures made using Douglas bags (DB) during cycle ergometry at intensities varying between rest and 250W. They reported no significant differences ($p>0.05$) in $\dot{V}O_2$ measures at rest or peak cycle intensity (250W) between the two systems. However, the Cosmed K4b^2 system did overestimate $\dot{V}O_2$ at a range of workloads between rest and maximum (50-200W) ($p<0.05$). Both $\dot{V}_E$ and $\dot{V}CO_2$

measures were reported to be significantly lower ($p<0.05$) than those obtained from the DB method at workloads of 200W and 250W. However, these authors stated that the differences measured were small (0.08 – 0.10 $l \cdot min^{-1}$) and that the Cosmed $K4b^2$ system was acceptable for the measurement of resting and exercise $\dot{V}O_2$. Similarly, Parr et al. [12] also compared the Cosmed $K4b^2$ system to the DB method for exercise intensities from rest to 250 W on a cycle ergometer. They reported that while $F_E\ O_2$ and $F_E\ CO_2$ values were significantly over and underestimated respectively, $\dot{V}O_2$, $\dot{V}CO_2$ and RER values up to 200 W were accurate, however at 250 W, $\dot{V}CO_2$ and RER were significantly underestimated.

Doyon et al. [13] reported no difference ($p<0.05$) in $\dot{V}O_2$ between the Cosmed $K4b^2$ system and a laboratory mixing box system (Applied Electrochemistry Inc. O_2 analyser, Beckman LB-2 CO_2 analyser and a Hewlett-Packard 4730A pneumotachograph) during a maximal incremental cycle ergometer exercise test. Subject's performed the incremental exercise test on three separate occasions with $\dot{V}O_2$ being recorded using either the laboratory mixing box system, the Cosmed $K4b^2$ system or the Cosmed $K4b^2$ system in an outdoor climate (2 ^{O}C) that replicated environmental conditions used in their research.

Finally, research by LaBreche and McKenzie [14] reported acceptable and comparable findings between the Cosmed $K4b^2$ system and a Physio-Dyne Technologies System for maximal incremental cycle ergometer tests. No significant differences ($p<0.05$) in VO_{2max} or VCO_{2max} were recorded between the two systems, however, V_E was reported to be significantly higher ($p<0.05$) in the $K4b^2$ system at maximal exercise.

Given some contradictory results reported in the literature an investigation of the system's accuracy and also reliability is crucial for any general application in physiological testing. Therefore, it was the aim of this study to test both the accuracy and reliability of the Cosmed K4b^2 system for primary measures of $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, $F_E O_2$ and $F_E CO_2$ when compared to a laboratory based Metabolic cart, following the precedent set in previous research [13,15]. Previous work from our laboratory [10] assessed the accuracy (but not the reliability) of the Cosmed K4b^2 system via a syringe method using expired air previously collected in a Tissot tank. The present study extended this work by using the Cosmed K4b^2 as it would normally be used with exercising subjects, at three different intensities of exercise.

The exercise modality, duration and intensity used in the testing protocol here were selected to simulate future planned field running exercise studies employing the Cosmed K4b^2. A 10 min run at a moderate speed allowed for the collection of sub maximal steady state exercise data, a 3 min run at a fast speed simulated the collection of accumulated oxygen deficit data and a 1 min sprint simulated the measurement of O_2 kinetics at supra-maximal intensities. While not spanning the physiological range of exercise ventilation values, this test protocol allowed for an assessment of the accuracy of the Cosmed K4b^2 when used at different exercise intensities, particularly prior to a steady state level being achieved.

Methods (1st Importance heading)

Sample (2nd Importance heading)

Twelve healthy, physically active male athletes, mean (±SD) height, body mass and age, 181.0 cm (±5.6), 76.3 kg (±7.6) and 23.3 years (±3.2) acted as subjects for this study. All gave their informed consent prior to participating in any testing and the procedures were approved by the Human Rights Committee of the University of Western Australia (UWA).

Experimental Design (2nd Importance heading)

All subjects undertook four testing sessions, with each session separated by at least a day and no more than a week, with time of day held constant across all testing sessions. Each session involved a series of treadmill (custom designed, School of Human Movement and Exercise Science, UWA) runs (at 1% grade), consisting of an easy 10 min run, a hard 3 min run and a 1 min sprint, with a rest period of 10 min between each run. Sessions were identical with the exception of the apparatus used to measure $\dot{V}O_2$. During two testing sessions the K4b² Cosmed portable gas analysis system was used, in another, a laboratory Metabolic cart (containing a Morgan Ventilometer and Ametek Applied Electrochemistry S-3A/I O_2 and CD 3A CO_2 analysers) and in one session both systems were used to measure $\dot{V}O_2$ simultaneously. Subjects were randomly allocated into four groups, between which the order of test sessions completed was changed, in order to ensure any practice effect was negated. Subjects were asked to refrain from heavy exercise for 24 h prior to testing and to refrain from food and caffeine consumption for the 2-3 h prior to testing.

Procedure (2nd Importance heading)

Depending on the testing session, either the K4b^2 Cosmed system and/or Metabolic cart were warmed up for 1 h prior to pre test calibration procedures being undertaken. On arrival subjects were weighed and then began a standardised 5 min warm up, consisting of treadmill running for 2 min at 8 km·h^{-1} and 3 min at 10 km·h^{-1}.

Cosmed sessions (3rd Importance heading)

A description of the structure of the Cosmed K4b^2 has previously been reported [10]. Following the warm up, calibration of both the Cosmed turbine and gas analysers occurred (in line with manufacturer's instructions). This involved 10 pumps of a 3 L syringe into the Cosmed turbine for ventilation volume and a one point gas analyser calibration check with (alpha verified) beta standard calibration gas (BOC gases, Chatswood, Australia). The base harness was then arranged and the Cosmed K4b^2 system attached to the subject's torso. Following the warm up, subjects were allowed 10 min to stretch before they commenced the 10 min run at 10 km·h^{-1}. At the completion of the run, the treadmill was stopped, the subjects were seated and the sample line was removed from the connection to the face mask/turbine and connected to the calibration gas cylinder described previously.

Cosmed measurement was then ceased and a 10 min recovery period begun. Directly following the cessation of Cosmed measurement, a post-test turbine and gas analyser calibration check were undertaken. These were identical to the pre test calibration procedures. Once these post- test verifications were complete, pre-test turbine and gas analyser calibration for the next treadmill run were conducted (as previously outlined). Both a pre-test calibration and a post-test verification for ventilation volume and fractional gas concentrations were conducted for each test to assess the accuracy and consistency of the measurements made. Once calibration procedures were concluded, subjects were prepared for the commencement of the 3 min run at 16 $km \cdot h^{-1}$, after which the same calibration/verification procedures were followed. During the 10 min recovery period following the 3 min run and at the end of the 1 min run (at 20 $km \cdot h^{-1}$), these procedures were again employed.

Metabolic cart session (3rd Importance heading)

The test format and pre and post exercise calibration/verification procedures used during the metabolic cart session were identical to those described above in the Cosmed testing sessions. Subjects breathed through a Hans-Rudolph two-way breathing valve with measurements made of inspired volume by a Morgan Ventilometer turbine (Model 096, Kent, UK). Software functions on an external computer attached to the Ventilometer converted $\dot{V}_I$ to $\dot{V}_{E\,(STPD)}$ for comparison to Cosmed ventilation values. Expired gas samples were analysed for O_2 and CO_2 concentrations using Ametek gas analysers (S-3A/I O_2 and CD 3A CO_2 respectively: Pittsburgh, USA). Average gas concentrations and turbine volume data were reported every 15 s.

Simultaneous Cosmed and Metabolic cart session (3rd Importance heading)

Identical calibration and verification procedures to those previously outlined were again employed pre and post-test in this simultaneous measurement session. To facilitate simultaneous measurements of $\dot{V}O_2$, prior to the start of the 10 min test the windshield was removed from the K4b^2 Cosmed turbine so a moulded PVC piping connection could be attached to allow an airtight seal between the turbine of the K4b^2 and the inlet/outlet port of the two-way Hans-Rudolph valve. Thus, when subjects inhaled, air was drawn through Collins tubing connected to the Morgan Ventilometer situated on the Metabolic cart (allowing the measurement of $\dot{V}_I$), then through the Hans-Rudolph valve. During expiration, air passed first through the Cosmed turbine (with a small sample drawn into the Cosmed K4b^2 analysers), then into the Hans-Rudolph valve and through the expiratory port into the Metabolic cart for measurement of $F_E\ O_2$ and $F_E\ CO_2$. This set up allowed both the K4b^2 Cosmed and the Metabolic cart to simultaneously measure respiratory parameters during the same bout of exercise. These data were temporally aligned to ensure the same ventilatory and gas concentration data were being compared.

Statistical Analysis (2nd Importance heading)

All data collected was collated in Excel files before analysis was conducted using the statistical package SPSS 8.0. Prior to analysis, Cosmed $\dot{V}_{E\ BTPS}$ measures were converted into $\dot{V}_{E\ STPD}$ values according to standard gas law correction procedures. The reliability of $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, $F_E\ O_2$ and $F_E\ CO_2$ measures made by the Cosmed K4b^2 system were assessed via the calculation of intra-class correlations (ICC) and Bland - Altman plot analysis [(16)] between the final minute means of the two Cosmed tests for each of the three run times. The Technical Error of Measurement (TEM) of the K4b^2 system was also calculated for these variables. Cosmed K4b^2 validity was assessed by comparing the measures made of $\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, $F_E\ O_2$ and $F_E\ CO_2$ by the two different systems (average of Cosmed and Cosmed repeat tests v metabolic cart test) with a paired samples t-test. A one way ANOVA (with a Scheffe' post hoc test) was also performed to compare the data from all tests (Cosmed, Cosmed repeat, metabolic cart, and both Cosmed and cart in synchronisation). Significance was set a priori as $p<0.05$.

In order to refine the accuracy of the Cosmed $K4b^2$ measurements, post-hoc linear regression equations were derived to predict metabolic cart $\dot{V}O_2$ and $\dot{V}CO_2$ values based on values measured with the Cosmed $K4b^2$. Data from the 10, 3 and 1 min runs were pooled to produce an overall regression equation for $\dot{V}O_2$ and $\dot{V}CO_2$ respectively. These respective regression equations were compared to individual equations calculated for the three test durations for both $\dot{V}O_2$ and $\dot{V}CO_2$ respectively, however as only very minor differences ($p>0.05$) were recorded, the pooled regression equations were used.

Results (1st Importance heading)

For Cosmed measures, final minute breath by breath values, for each variable, were averaged for each exercise duration. For metabolic cart measures, final minute values for V_E, VO_2 and VCO_2 were obtained by adding together 4 x 15 s values, while F_E O_2 and F_E CO_2 values were averaged.

Reliability (2nd Importance heading)

No significant differences ($p>0.05$) were noted between the test-retest Cosmed trials for any variable ($\dot{V}_E$, $\dot{V}O_2$, $\dot{V}CO_2$, F_E O_2 and F_E CO_2) for the 10, 3 or 1 min runs. The results of the ICC and TEM analysis at each time point for these variables are shown in Table 1.

Bland – Altman plots indicated satisfactory limits of agreement between the Cosmed K4b^2 and Metabolic cart for measures of $\dot{V}_E$, $\dot{V}O_2$ and $\dot{V}CO_2$ (presented in Figures 1, 2 and 3). As Bland and Altman [16] state, in order to have satisfactory repeatability, 95% of the difference between two measures must fall within two standard deviations. Here, all but one data point fell within the 95% confidence levels. Values for the limits of agreement and bias for $\dot{V}_E$ were $\pm$16.3 and $\pm$1.27 $l \cdot min^{-1}$, for $\dot{V}O_2$ $\pm$ 0.82 and $\pm$0.08 $l \cdot min^{-1}$ and for $\dot{V}CO_2$ $\pm$ 0.67 and $\pm$0.06 $l \cdot min^{-1}$ respectively.

Validity (2nd Importance heading)

These results are shown in Table 2. As no significant differences were found between the Cosmed test-retest trials, the data from the two tests were pooled together to give a mean Cosmed measure. This mean data was then used in all further analyses. No significant differences ($p>0.05$) were noted between the Cosmed K4b^2 and the metabolic cart measurement of $\dot{V}_E$ at any time point. However, Cosmed K4b^2 values for $\dot{V}O_2$, $\dot{V}CO_2$ and $F_E\,CO_2$ for each run (except the 10min $FeCO_2$) were significantly higher ($p<0.05$) than Metabolic cart values. Significant decreases ($p<0.05$) were also recorded in Cosmed $F_E\,O_2$ for each run (10, 3 and 1 min) compared to the cart.

When the two systems were run in synchronisation, significantly increased ($p<0.05$) $\dot{V}O_2$, $\dot{V}CO_2$ and $F_E\,CO_2$ values and decreased $F_E\,O_2$ values were obtained for the Cosmed in comparison to the cart values, however, $\dot{V}_E$ values showed no significant difference for any run. Significant differences ($p<0.05$) were also recorded between isolated Cosmed test measurements and Cosmed measurements taken during synchronisation with the cart for $\dot{V}O_2$ (10 and 3 min), $\dot{V}CO_2$ (10 and 3 min), $F_E\,O_2$ (10 and 3 min) and $F_E\,CO_2$ (10, 3 and 1 min trials). For all three test durations, Cosmed in synchronisation with cart values for $\dot{V}O_2$ and $\dot{V}CO_2$, were higher than those obtained in isolation from Cosmed test measures (Table 2), with significantly greater ($p<0.05$) values recorded for 10 and 3 min tests. The results of linear regression equation formulation to predict metabolic cart results from Cosmed values were:

$$\text{Metabolic cart } \dot{V}O_2 = 0.926 \cdot \text{Cosmed} - 0.227 \quad (r^2 = 0.84).$$

$$\text{Metabolic cart } \dot{V}CO_2 = 1.057 \cdot \text{Cosmed} - 0.606 \quad (r^2 = 0.92).$$

INSERT TABLE 1

INSERT TABLE 2

Discussion (1st Importance heading)

A growing body of literature exists which both uses the Cosmed K4b^2 for measurement of $\dot{V}O_2$ and reports the accuracy, however, little data is available verifying the reliability of this system. The data collected here with the K4b^2 Cosmed system for the test-retest trials indicated the unit had satisfactory reliability, particularly for the 10 and 3 min tests. No significant differences were observed for any variable between either test involving the Cosmed unit as the sole measurement device. Bland – Altman plots indicated acceptable limits of agreement between Cosmed K4b^2 measures on different days, with all but one datum point falling between two standard deviations from the mean value. In combination, strong ICC values were also obtained on all variables for the 3 and 10 min tests, with moderate ICC values for the 1 min test, indicating that the Cosmed K4b^2 unit (on different days) generally had low levels of systematic or error variance. The TEM data calculated for the Cosmed unit was also mostly acceptably low (<5% generally), again indicating a strong reliability of measurement for all variables. However, measures taken during the 1 min run did display increased TEM values (10-12%), which may be due to a greater degree of within-subject variability in the O_2 kinetics for this exercise duration [17], given the relatively short length of exercise time and near maximal intensity of this run.

In assessing the accuracy of the Cosmed K4b^2 system, the initial intention was to compare simultaneous measurements made by the Cosmed and Metabolic cart systems as they operated in synchrony. However, this became impractical after data collection, as for unknown reasons (possibly due to changes in the flow characteristics or change in dead space, although this was only increased by 94.5 mL), the simultaneous Cosmed K4b^2 test values showed marked levels of inaccuracy, being significantly higher than isolated Cosmed test values for most of the measured variables. Cosmed in synchronisation $\dot{V}O_2$ and $\dot{V}CO_2$ data were consistently higher (≈ 0.5 l·min^{-1}) than Cosmed in isolation test data for all three runs. This was principally due to a lower and higher $F_E O_2$ and $F_E CO_2$ respectively, as $\dot{V}_E$ values were not different. Also, Cosmed values showed significant differences to Metabolic cart values while in synchronisation, but Metabolic cart in isolation and cart in synchronisation values showed virtually no difference (only $F_E CO_2$ at 10 min). Hence, the Cosmed and Metabolic cart in synchronisation data were omitted and the Cosmed and Metabolic cart in isolation tests compared in further analysis. McLaughlin et al. [11] also reported an excessive discrepancy between Cosmed and

Metabolic cart values of $\dot{V}O_2$ when measurements were taken by both systems (DB and Cosmed K4b^2) in synchronisation, suggesting an interference of the DB apparatus on the Cosmed K4b^2. Differences in $\dot{V}O_2$ and $\dot{V}CO_2$ values reported between measurement methods in the present study were seen to result from the Cosmed measurement of fractional gas concentrations (respectively lower $F_E O_2$ and higher $F_E CO_2$ values), as no significant difference between synchronised or isolated Cosmed tests was noted for the measure of $\dot{V}_E$.

While our analysis indicated that the Cosmed K4b^2 system showed satisfactory reliability, especially for 10 and 3 min tests, this was not the case for the validity or accuracy of this Cosmed unit. The results indicated that the Cosmed K4b^2 turbine is an accurate tool for the measurement of ventilation, but Cosmed measures of $\dot{V}O_2$, $\dot{V}CO_2$, $F_E O_2$ and $F_E CO_2$ all differed significantly to measures obtained from the Metabolic cart. Both $\dot{V}O_2$ and $\dot{V}CO_2$ measures taken with the Cosmed K4b^2 system showed higher values when compared to data collected using the Metabolic cart for all three runs. Accordingly, Cosmed K4b^2 measures of $F_E O_2$ and $F_E CO_2$ were always lower and higher respectively than values obtained from the Metabolic cart and would potentially be the cause of the previously described overestimation of $\dot{V}O_2$ and $\dot{V}CO_2$ by the Cosmed K4b^2 unit reported by Pinnington et al. [(10)]. While Parr et al. [(12)] reported no differences in either $\dot{V}O_2$ or $\dot{V}CO_2$ values between measurement devices, they reported an under and over-measurement of $F_E CO_2$ and $F_E O_2$ respectively, which is in opposition to the results of Pinnington et al [(10)]. McLaughlin et al. [(11)] reported underestimation of $F_E O_2$ and $F_E CO_2$ data when compared to reference gases passed through the Cosmed K4b^2 unit to test for analyser drift. Pinnington et al. [10] also showed similar $F_E O_2$ measurement errors, and hence, similar overestimation of $\dot{V}O_2$, as was observed in the current study. Both $\dot{V}O_2$ and $\dot{V}CO_2$ measures reported by us previously showed similar inaccuracies to those reported in the current study, being higher by approximately 0.4 - 0.6 $l \cdot min^{-1}$ when measured by the Cosmed $K4b^2$ system. This somewhat differs from the results of McLaughlin et al. [11] who found that while $\dot{V}O_2$ was increased when measured by the Cosmed $K4b^2$ (except at rest and max workload), both $\dot{V}_E$ and $\dot{V}CO_2$ were lower than comparative measures made via DB at higher exercise intensities.

Causes of the observed differences in $\dot{V}O_2$ and $\dot{V}CO_2$ values between the metabolic cart and Cosmed $K4b^2$ systems in the present study remain speculative. As no significant differences were recorded for the measurement of ventilation between the two systems for any of the runs, the likely reason for the overestimation of $\dot{V}O_2$ and $\dot{V}CO_2$ by the Cosmed $K4b^2$ appears to be measurement error in the expired fractional gas concentrations. Errors of this sort may result if water vapour passing through the sample line (Nafion®) tubing is not completely equilibrated with the surrounding environmental vapour pressure, thereby potentially allowing the passage of excessive water vapour to the gas analysers. However, there is no direct evidence of this occurring; testing of this possibility awaits further study.

The Cosmed in synchronisation with Metabolic cart measures of $\dot{V}O_2$ and $\dot{V}CO_2$ were also higher than Cosmed in isolation values, for unknown reasons. Again, while purely speculative, it is possible the Cosmed turbine – Hans Rudolph valve apparatus arrangement may have limited the continuous movement of expired air. In the event of an obstruction of the flow of expired air through the turbine arrangement, subjects might then inhale the remnants of previously expired gases. Therefore, continual re-breathing from previously expired air may result in lowered and increased measures of $F_E O_2$ and $F_E CO_2$ respectively by the Cosmed K4b^2 (when measuring in synchrony with the Metabolic cart). While McLaughlin et al. [(11)] reported an interference of one system on the other when measured in synchrony, they did not report actual results. In the present study $\dot{V}_E$ values were not significantly different (p>0.05) between the Cosmed K4b^2 (either in synchrony or in isolation) and the metabolic cart values. While Cosmed K4b^2 measures in $\dot{V}_E$ were higher during synchrony, these differences were not significant, thus the difference in $\dot{V}_E$ was not regarded as a main factor in the greater $\dot{V}O_2$ and $\dot{V}CO_2$ values recorded by the Cosmed K4b^2 when used in synchrony with the Metabolic cart.

Based on the consistent differences detected here between the Cosmed K4b^2 and Metabolic cart measures of $\dot{V}O_2$ and $\dot{V}CO_2$, post hoc linear regression equations were calculated in order to predict Metabolic cart values from the Cosmed K4b^2 values. Previous work [(10)] also proposed linear regression equations to predict Metabolic cart values based on Cosmed K4b^2 measures of $F_E O_2$ ($r^2 = 0.94$), $F_E CO_2$ ($r^2 = 0.86$) and ventilation ($r^2 = 0.96$). Correction of the Cosmed data (as displayed in Table 2) by the regression equations of both the present and previous study from our laboratory produced very similar results, indicating either set of regression equation could be applied to correct Cosmed K4b^2 data. These values are shown in Table 3.

INSERT TABLE 3 HERE.

In conclusion, the results of this study indicated that the Cosmed K4b^2 system demonstrated satisfactory reliability (particularly for steady state and sustained maximal exercise intensities), showing good repeatability of measurement over varying run durations (up to 10 min) and exercise intensities. The comparison of Cosmed K4b^2 and metabolic cart values revealed a significant overestimation of both $\dot{V}O_2$ and $\dot{V}CO_2$ by the Cosmed K4b^2 system. While $\dot{V}_E$ measurements showed no difference, $F_E O_2$ and $F_E CO_2$ values for the Cosmed K4b^2 were lower and higher respectively than recorded by the metabolic cart. While these current conclusions formed may be specific to the particular unit assessed in the present research, regression equations, such as reported here, may be useful in order to improve the accuracy of Cosmed K4b^2 measures.

References (1st Importance heading)

1 Macfarlane, D.J. Automated metabolic gas analysis systems: a review. *Sp Med.* 2001; 31(12): 841 – 861.

2 Lucia, A., Fleck, S.J., Gotshall, R.W. et al. Validity and reliability of the Cosmed K2 instrument. *Int J Sp Med*. 1993; 14(7): 380 - 386.

3 Peel, C. and Utsey, C. Oxygen consumption using the K2 telemetry system and a metabolic cart. *Med Sci Sp Ex*. 1993; 25(3): 396 - 400.

4 Crandall, C.G., Taylor, S.L. and Raven, P.B. Evaluation of the Cosmed K2 portable telemetric oxygen uptake analyser. *Med Sci Sp Ex*. 1994; 26(1): 108 - 111.

5 Sheel, A.W., Lama, I., Potvin, P. et al. Comparison of Aero-bars versus traditional cycling postures on physiological parameters during sub maximal cycling. *Can J Appl Phys*. 1996: 21(1): 16-22

6 Hausswirth, C., Bigard, A.X. and Le Chevalier, J.M. The Cosmed K4 telemetry system as an accurate device for oxygen uptake measurements during exercise. *Int J Sp Med*. 1996; 18: 449 - 453.

7 Billat, V.L., Slawinski, J., Bocquet, V. et al. Intermittent runs at the velocity associated with maximal oxygen uptake enables subjects to remain at maximal oxygen uptake for a longer time than intense but sub-maximal runs. *Eu J App Phys*. 2000; 81(3): 188 - 196.

8 Swartz, A.M, Strath, S.J., Bassett Jr. et al. Estimation of energy expenditure using CSA accelerometers at hip and wrist sites. *Med Scin Sp Ex*. 2000; 32 (9 Suppl): S450-456.

9 Bishop, D., Spencer, M., Duffield, R. et al. The validity of a repeated sprint ability test. *J Sci Med Sports*. 2001; 4(1):19-29.

10 Pinnington, H.C., Wong, P., Tay, J. et al. The level of accuracy and agreement in measures of $F_E O_2$, $F_E CO_2$, and $\dot{V}_E$ between a Cosmed K4b[2] portable respiratory gas analysis system and a metabolic cart. *J Sci Med Sport*. 2001; 4(3): 324 - 335.

11 McLaughlin, J.E., King, G.A., Howley, E.T. et al. Validation of the Cosmed K4b[2] portable metabolic system. *Int J Sp Med*. 2001; 22: 280 - 284.

12 Parr, B.B., Strath, S.J., Bassett, D.R. et al. Validation of the Cosmed K4b[2] portable metabolic measurement system. *Med Sci Sp Ex*. 2001; 33(5 Supp): S300.

13 Doyon, K.H., Perrey, S., Abe, D. et al. Field testing of VO_2 peak in cross country skiers with a portable breath by breath system. *Can J App Phys*. 2001; 26(1): 1 – 11.

14 LaBreche, J.M. and McKenzie, D.C. Evaluation of the Cosmed K4b[2] portable metabolic system during maximal exercise. *Can J App Phy*. 2001; 26(5): 492 - 493.

15 Melanson, E.L., Freedson, P.S., Hendelman, D. et al. Reliability of a portable metabolic measurement system. *Cann J App Phy*. 1996; 21(2): 109 – 119.

16 Bland, J.M. and Altman, D.G. Statistical methods for assessing the agreement between two methods of clinical measurement. *The Lancet Feb*. 1986; 8: 307 – 310.

17 Hughson, R.L. and Inman, M.D. Oxygen uptake kinetics from ramp work tests: variability of single test values. *JAP*. 1986; 61(1): 373 – 376.