Adaptation of the VO2000 gas analiser's mask to mensuration of cardiorespiratory parameters in swimming*

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ABSTRACT

The aim of the present study was to develop a snorkel (SNK) with low cost for cardio respiratory parameters measurement in swimming. So, a mask of gas analyzer VO2000 (MASK) was adapted to a SNQ developed by man craftwork form with dead space of 250 ml. Eight subjects were submitted to two incremental tests (IT) on cycloergometer using the MASK and the SNK. The IT(s) occurred until voluntary exhaustion and it was composed per stages of 3 min and with initial load and grade increment of 35 W. In both situations, gaseous samples were collected in intervals of 10 s for determination of the amount of oxygen ($\dot{V}O_2$), of carbonic gas ($\dot{V}CO_2$) and of ventilatory volume (VE); heart rate (HR) measurement was done with monitor frequency heart (Polar). The comparison of the cardiorespiratory parameters ($\dot{V}O_2$, VE, $\dot{V}CO_2$) and HR measured with a SNK and a MASK was performed with the Student's *t* test of dependent samples, while the Pearson's correlation test and graphic analyzer of Bland and Altman were performed to verify the associations and agreement among parameters. In all cases the level of significance was $P < 0.05$. The appropriate equations of the correction of values originating from SNK was verified by systematic error (bias), aleatory (precision) and accuracy (ac). It was not found significant differences among the values of $\dot{V}O_2$, $\dot{V}CO_2$ and HR obtained with the MASK and SNK. The values of VE measured with SNK were found significantly higher than the obtained with the MASK. However, all parameters presented high agreement and correlation (0.88 to 0.97). Besides, low values of bias ($\dot{V}O_2$ = 0.11 L/min; VE = 4.11 L/min; $\dot{V}CO_2$ = 0.54 L/min; 8.87 bpm), precision ($\dot{V}O_2$ = 0,24 L/min; VE = 11.02 L/min; $\dot{V}CO_2$ = 0,18 L/min; 7.42 bpm) and accuracy ($\dot{V}O_2$ = 0,27 L/min; VE = 11.76 L/min; $\dot{V}CO_2$ = 0.56 L/min; 11.56 bpm) were verified. Thereby, we could conclude that the SNK developed in this study allow a validate measurement of cardiorespiratory parameters in swimming.

Keywords: Swimming. Snorkel. Oxygen uptake. Ventilatory volume. Heart rate.

INTRODUCTION

The measurement of cardiorespiratory parameters such as ventilatory volume, heart rate, carbon dioxide volume ($\dot{V}CO_2$) and especially oxygen uptake ($\dot{V}O_2$) has been topic of several investigations in Physiology of the Exercise, especially in swimming(1). Initially, the gases collected during the efforts were stored in a Douglas bag(2-4) for later analysis. Afterwards, the measurements of these parameters were made easier with the development of gas analyzers with electronic sensors(5-6) which enabled the acquisition of a great number of gas samples and also provide the results in a short period of time. Although the technological advance has made this kind of test performance easier, especially in swimming, it is extremely difficult to obtain a valid estimation for cardiorespiratory parameters(7). However, the importance of these data is crucial, since the technique applied during swimming can considerably modify the energy spent for the individual to move in the liquid environment(3,8). Dal monte *et al.*(7) reported that the power generated by the swimmer to win the drag may be affected by the use of maladjusted equipment, resulting hence in higher energy expenditure to perform swimming at a given velocity(8-9).

Toussaint *et al.*(10), developed a specific snorkel for swimming evaluation with the advantage to generate a low drag in relation to conventional snorkels. Dal Monte *et al.*(7) presented a snorkel similar to the one proposed by Toussaint *et al.*(10), but with lower dead space. These snorkels were designed however for Douglas bag. Keskinen *et al.*(6) validated in cycle ergometer a snorkel and a valve system for gas analysis breath to breath in swimming using the K4 gas analyzer.

Considering the lack of specific equipment for measurement of cardiorespiratory parameters in swimming, the present study had the aim to adapt the mask of the VO2000 gas analyzer to measure the VE, $\dot{V}O_2$ and $\dot{V}CO_2$ of swimmers.

METHODOLOGY

Eight active individuals, age range of 27 ± 4.1 years and body mass of 75 ± 5.8 Kg participated in the present study.

After having agreed and signed a written consent form approved by the Ethics in Research Committee of the Institute of Biosciences of the State University of the São Paulo Rio Claro Campus, the participants were submitted to two progressive tests in cycle ergometer separated by a minimum rest period of 24 hours. The efforts were performed using a VO2000 mask (MASK) and a swimming snorkel (SNK).

Prior to the tests, the participants remained seated in the cycle ergometer during 5 minutes (determination of the values concerned with the baseline) and later performed the incremental test which consisted of progressive efforts in cycle ergometer of mechanical breakage (Monark) with initial load of 35 w (warm-up) and increment of 35 w until voluntary exhaustion, which was assumed as the participant's inability to remain in the pre-set load for a period of 10 seconds. After exhaustion, the participants continued to exercise for approximately 5 minutes with load of approximately 35 w (back to calmness). The cardiorespiratory variables were measured at ten-second intervals with the use of a gas analyzer (VO2000). The equipment was automatically calibrated prior to each evaluation according to the manufacturer's specifications. Heart rate was checked at the end of each stage through a frequency meter (Polar, Kempela, Finland).

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Snorkel development

The snorkel consisted of one-inch commercial tubes and connections (PVC), connected to a rubber ending (1) joined to the 'elbow' (2) and the saliva container (3) which originally make the VO2000 mask (figure 1). The SNK was based so that the air tube was projected to the front of the participant's face and not to his side, as it is observed in conventional snorkels. This sketch was based on the snorkels elaborated by Toussaint *et al.*[10] and Dal Monte *et al.*[7] since they present reduced drag coefficients. The whole system weights 360 grams and has a dead space of 250 ml. The medium flow valve (4) was connected to the upper extremity of the snorkel (figure 1).

Figure 1 *– Representation of the Snorkel developed for measurement of cardiorespiratory parameters in swimming*

Statistical treatment

In order to analyze the data obtained during the incremental tests using the MASK or SNK, an algorithm was developed in Matlab 5.3® environment, specific to this purpose. The data concerning time(s) were interpolated allowing the determination of the ventilatory (VE), oxygen ($\dot{V}O_2$) and carbonic gas ($\dot{V}CO_2$) volumes for each stage. These data were assumed as the mean of the values obtained in the final minute of each stage.

The values of the cardiorespiratory parameters ($\dot{V}O_2$, VE, $\dot{V}CO_2$ and heart rate) obtained in the incremental test with the MASK and SNK were compared with the *t*-Student test for dependent samples and the possible associations of these parameters obtained with the MASK and SNK were used. The Pearson correlation test was also used. In all cases the significance level was preset for $P < 0.05$.

The points obtained of the relationship between the cardiorespiratory parameters measured with the MASK and the SNK were submitted to the linear regression procedure with the purpose to elaborate correction equations for the values derived from the SNK.

The coefficients of determination and residue (res) were analyzed in order to verify the validity of the correction equations. Moreover, the systematic (bias), random (precision) and accuracy (ac) errors were determined.

The res was assumed as the difference between the cardiorespiratory parameters values of the MASK theoretically estimated through regression equations from values derived from the SNK.

The ac was determined by the sum of the bias and precision. In this case the precision was assumed as being the standard deviation of the res while the bias corresponded to the linear coefficients (intercept-y) of each of the regressions ($ac^2 = precision^2 + bias^2$).

The agreement of the cardiorespiratory parameters values obtained with the MASK and SNK were quantified through the differences between the two observations using Bland and Altman graphic analysis[11]. An agreement limit (AL) of 95% was used by the following equation: AL = (1.96 x sd) ± Mdif; where sd = standard deviation and Mdif = mean of differences.

RESULTS

The parameters obtained with the SNK presented high correlations with the ones obtained through the MASK (table 1). However, the VE values determined in the SNK were significantly higher than the ones obtained with the MASK. Except for the VE, the behavior of the remaining respiratory parameters, especially the $\dot{V}O_2$ measured with the SNK and MASK presented similar behavior (figure 2).

TABLE 1
Pearson correlation coefficient (r) among the ventilation (VE), heart rate (HR), oxygen ($\dot{V}O_2$) and CO_2 ($\dot{V}CO_2$) volume values determined with the use of the SNK and MASK during incremental effort in cycle ergometer

VE (L/min)	$\dot{V}O_2$ (L/min)	$\dot{V}CO_2$ (L/min)	HR (bpm)
0.88	0.95	0.86	0.99

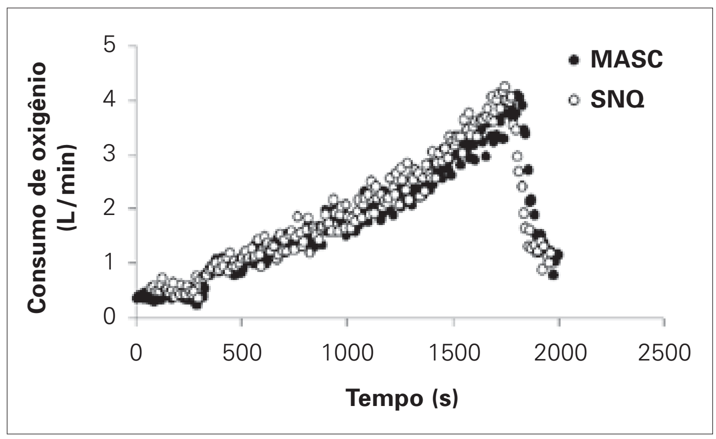

Figure 2 *– Oxygen uptake behavior during the two incremental tests in the same individual using the conventional VO2000 mask (MASK) and the Swimming Snorkel (SNK)*

The mean values ± standard deviation of the coefficients of linear and angular determinations of the individual regression equations of VE, $\dot{V}O_2$, $\dot{V}CO_2$ and HR are presented in table 2.

TABLE 2
Mean ± standard deviation values, of the determination coefficient (R^2) and parameters of the linear regression equation (inclination and intercept-y) of some cardiorespiratory variables (VE, $\dot{V}O_2$ and $\dot{V}CO_2$) in the two tests using the VO2000 mask and swimming snorkel

	Inclination	Intercept-y	R^2
VE (L/min)	1.12 (0.72 to 1.65)	1.10 (–5.10 to 6.99)	0.96 (0.92 to 0.99)
$\dot{V}O_2$ (L/min)	1.11 (0.93 to 1.36)	–0.06 (–0.25 to 0.13)	0.97 (0.95 to 0.99)
$\dot{V}CO_2$ (L/min)	1.06 (0.80 to 1.25)	0.00 (–0.16 to 0.25)	0.96 (0.90 to 0.99)

When the cardiorespiratory responses relationships are analyzed as a group, one may observe high correlation values (0.88 to 0.97) and determination coefficient (0.77 to 0.94). These results enabled the correction equations for all parameters (VE, $\dot{V}O_2$, $\dot{V}CO_2$ and HR) when measured with the SNK (figures 3abcd).

When the distribution of the difference of the values obtained with the MASK and SNK is analyzed, a random distribution around zero and majority of the cases within the high and low limits is observed. This data behavior shows high agreement between the values from the MASK and SNK (figures 4abcd).

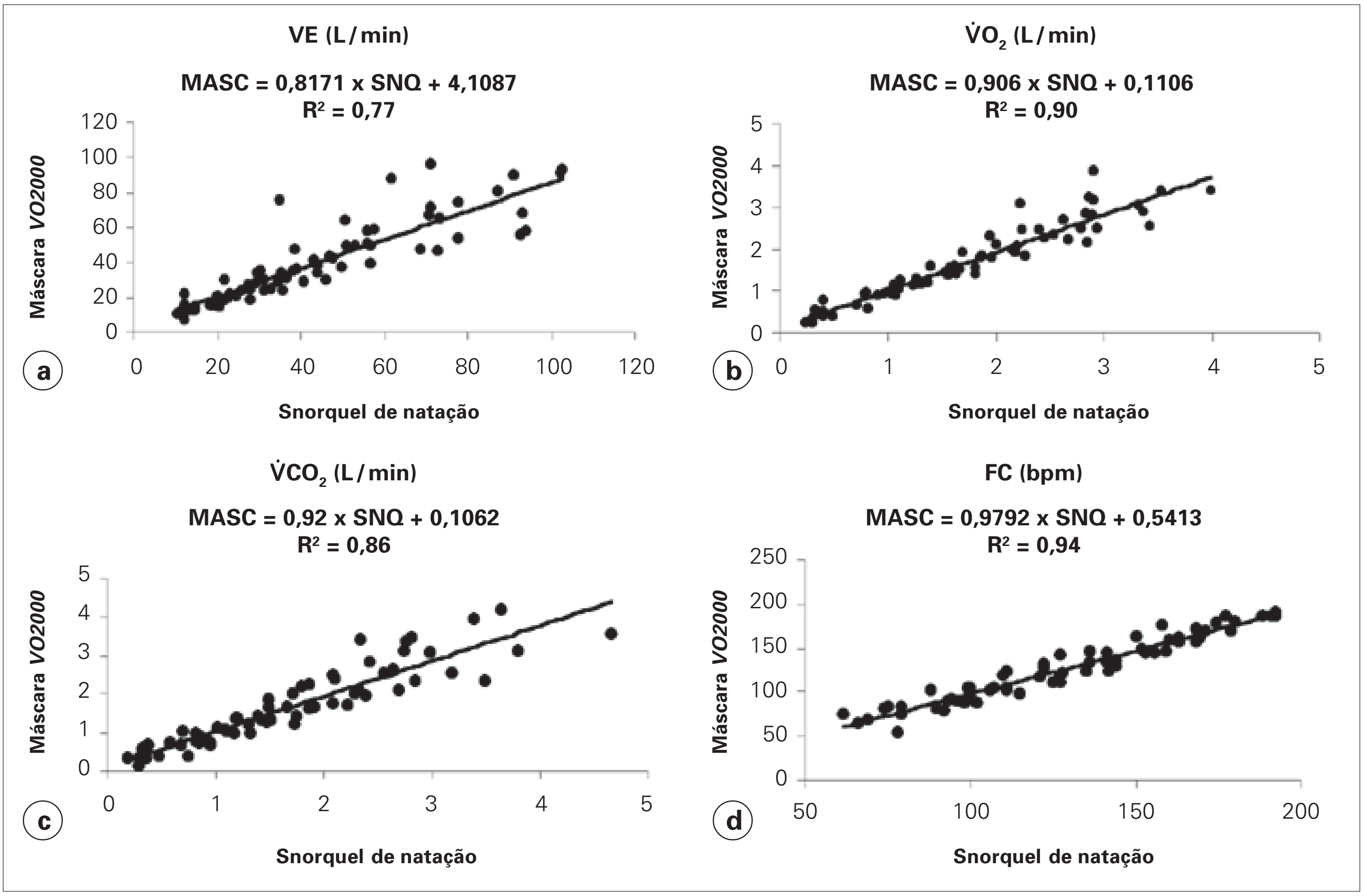

Figure 3 *– Correction equation of the VE **(a)**, $\dot{V}O_2$ **(b)**, $\dot{V}CO_2$ **(c)** and HR **(d)** determined from the linear regression between the values obtained with the VO2000 Mask and the swimming Snorkel*

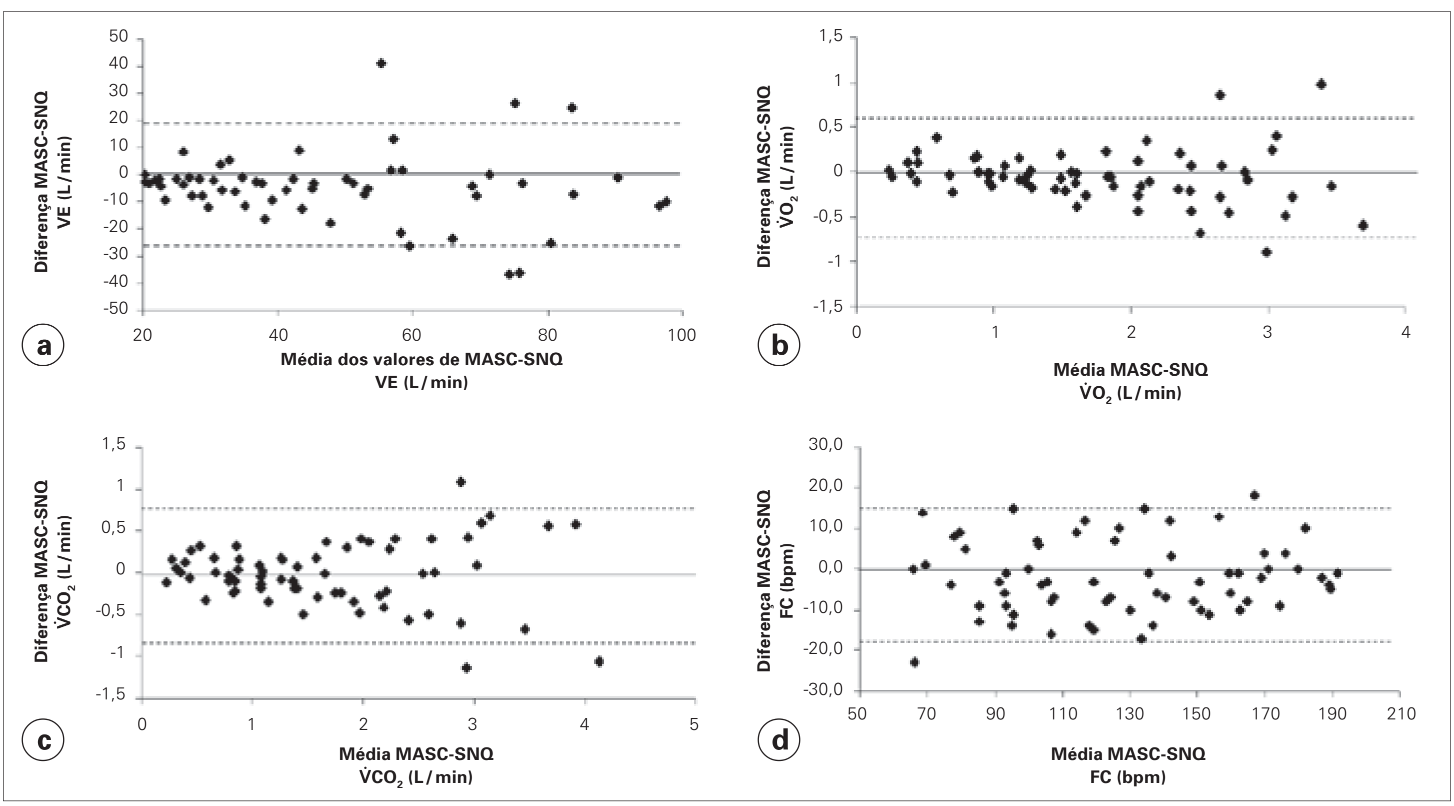

Figure 4 *– Values of the mean difference of VE **(a)**, $\dot{V}O_2$ **(b)**, $\dot{V}CO_2$ **(c)** and HR **(d)** determined with the use of the VO2000 Mask and Swimming Snorkel*

The values of VE, $\dot{V}O_2$ and $\dot{V}CO_2$ for the systematic, random and accuracy errors were similar to the rest values. Moreover, the HR errors were lower than the ones verified at rest.

Specifically analyzing the accuracy values, which is composed by the sum of the systematic and random errors, it was observed that they approximately corresponded to 12, 8, 15 and 6% to the maximal values of VE, $\dot{V}O_2$, $\dot{V}CO_2$ and HR respectively, obtained during the incremental tests (table 3).

TABLE 3
Values of the systematic (Bias), random (Precision) and accuracy errors of ventilation (VE), oxygen uptake ($\dot{V}O_2$), CO_2 production ($\dot{V}CO_2$) and heart rate (HR) obtained with the VO2000 mask and swimming snorkel

	Bias	**Precision**	**Accuracy**
VE (L/min)	4.11	11.02	11.76
$\dot{V}O_2$ (L/min)	0.11	0.24	0.27
$\dot{V}CO_2$ (L/min)	0.54	0.18	0.56
HR (bpm)	8.87	7.42	11.56

DISCUSSION

The main findings of the present study were the high correlations and agreements among the $\dot{V}O_2$, $\dot{V}CO_2$, VE and HR values measured with the MASK and SNK during incremental test in cycle ergometer.

Once one believes in the importance of the measurement of cardiorespiratory variables, especially the oxygen consumption in swimming[3,8,12]; the validity of the results may be compromised during swimming due to an additional drag, depending on the respiratory valve used[10] and the lack of a specific swimming snorkel for the VO2000 gas analyzer. The present study manually adapted the MASK of the VO2000 to a swimming SNK, using some measurement and analysis procedures similar to the ones used by Keskinen *et al.*[6]. Although the drag coefficient had not been measured, the air tube of the SNK developed in the present investigation was designed in front of the swimmer's face and not on his side, as it is observed in conventional snorkels. Such design was based on the snorkels elaborated by Toussaint *et al.*[10] and Dal Monte *et al.*[7] since they present reduced drag values.

The results of all parameters measured were highly correlated (0.88 to 0.99) and except for the VE, they did not present significant differences. Investigations have reported that the VE measured in swimming is usually lower than the ones seen in running[2,4].

In the present study, the VE values determined with the SNK were higher than the ones determined with the MASK, although both tests have been performed in a cycle ergometer. Keskinen *et al.*[6] when validated a specific snorkel to swimming for the K4 gas analyzer (Cosmed, Italy) also verified that the VE values derived from the SNK were significantly higher than the ones obtained with the MASK. These differences were attributed by the researchers to several factors such as the difference in the respiratory mechanisms due to the use of the SNK, increase in the dead space, and distance of the ending until the turbine as well as differences in resistance in the air flow.

Gyton and Hall[13] reported that the air keep in the dead space (anatomic and physiological) is expired before the alveolar air. Therefore, the additional dead space (250 ml) may have been the responsible for the differences in the VE values since they have made the gas exchanges difficult, which resulted in increases of PCO_2 in the blood and consequently stimulated the increases of VE. Toklu *et al.*[14], observed significant increases in VE, $\dot{V}O_2$, $\dot{V}CO_2$, heart rate and tidal volume with an addition of a snorkel with 165 ml of dead space and proposed a new SNK with a low resistance and with a 'two-way' valve (Two-Way). These researchers believe that with this SNK the expired air (containing high values of CO_2) is not re-inspired and therefore would not influence in the cardiorespiratory parameters values.

The SNK developed in the present study was manually designed and is simpler than the SNK presented by Toklu *et al.*[14]. However, the correction equations of the respiratory variables (VE, $\dot{V}O_2$, $\dot{V}CO_2$ and HR) obtained from the relationship between the MASK and SNK presented reduced values of systematic, random and accuracy errors. Besides the high correlations observed among these results, the Bland and Altman graphic analysis[11] demonstrated high agreement. In addition to these responses, the participants did not report additional discomfort while using the SNK in relation to the MASK.

Although further research is needed in order to quantify the PCO_2 and PO_2 as well as the existence of additional drag with the use of SNK, one may conclude that the SNK manually developed in the present investigation is an accessory that may be used joined with the VO2000 gas analyzer for measurement of cardiorespiratory parameters valid in swimming.

All the authors declared there is not any potential conflict of interests regarding this article.

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