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Repeatability of measurements of oxygen consumption, heart rate and Borg's scale in men during ergometer cycling

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Summary

The coefficient of repeatability (COR), expressed as 2 SD of differences, was calculated between two measurements of oxygen consumption ($\dot{V}O_2$), heart rate (HR) and rating of perceived exertion (RPE) during ergometer cycling by men. The two sets of measurements were performed 5 to 6 weeks apart. Nineteen healthy men performed an incremental maximal exercise test on an ergometer cycle. The load started at 50 W and increased by 5 W 20 s^{-1} until exhaustion was reached. At 40% of the individual maximum load of the pretest, the load was kept constant for 4 min in order to reach steady state. Gas measurements were recorded continuously by computerized instrumentation. The HR was monitored with electrocardiography (ECG) and the perceived exertion was evaluated using Borg's scale. The COR of $\dot{V}O_2$ at sub-maximal load was 14% and at maximum load 11%. The values in absolute figures were 209 and 332 ml min^{-1}. The corresponding COR of the HR was 16% at sub-maximum load and 6% at maximum load, and an evaluation of the perceived exertion yielded CORs in absolute values of 4·8 and 1·3, respectively. The COR for $\dot{V}O_2$, HR and ratings of perceived exertion when cycling on an ergometer cycle thus indicate a better agreement between the measurements at maximum load. The COR of the heart at sub-maximal loads must be kept in mind when using HR for estimation of $\dot{V}O_{2\,max}$. The reported findings should be considered when using tests on an ergometer cycle for evaluating exercise capacity.

Introduction

In health as well as in disease it is important to have a reliable measure of an individual's exercise capacity in order to be able to plan and evaluate an exercise programme. Several methods are available for evaluating physical capacity, such as Cooper's test (Grant *et al.*, 1995), shuttle walk test (Payne & Skehan, 1996), step test (Keren *et al.*, 1980), physical performance on a treadmill or ergometer cycling (Wisén & Wohlfart, 1999). All forms of physical activity increase the metabolic rate involving the oxygen transport systems. It is therefore of particular interest to have an accurate measure of the oxygen consumption. This can be obtained with continuous measurements of oxygen consumption by computerised instrumentation.

The measurement of heart rate (HR) is widely applied to estimate the oxygen consumption ($\dot{V}O_2$) and to evaluate physical capacity (Åstrand & Rhyming, 1954). Heart rate can also be used for exercise prescription and to assess the outcome of interventions such as exercise programmes. By using Borg's scale 6–20 (Borg, 1982) a subjective rating of perceived exertion (RPE) can be obtained. The RPE *ad modum* Borg is often used for regulation of the intensity as well as evaluation of an exercise programme.

Many factors can influence the results of a physical test. Environmental factors such as temperature can effect the magnitude of the response of all basic physiological systems (Sawaka *et al.*, 1985). Likewise, the time of the day (Hill, 1996) and the time and quantity of the most recent meal (Yi *et al.*, 1990) can influence measurements of physical capacity. Smoking also affects the measurements (Ingemann-Hansen & Halkjaer-Kristensen, 1977; Rotstein & Sagiv, 1986).

The day-to-day variation in oxygen consumption (VO_2) during ergometer cycling by male adolescents was previously found to be 390 ml min^{-1} at maximum load and 199 ml min^{-1} at sub-maximal load (Wergel-Kolmert *et al.*, 2001). Usually, there are some weeks of exercise training between two physical tests. It is thus of special interest to study the repeatability of the measurements of a physical test taking this realistic time into consideration.

The aim of this study was to determine the repeatability of oxygen consumption measurements using respiratory gas analysis, HR, measured by electrocardiography (ECG), and ratings of perceived exertion (RPE) using Borg's scale, in men performing maximal incremental exercise on an ergometer cycle. The results are of importance in evaluating physical

capacity before and after physical exercise of individuals and groups.

Methods

Subjects

Seventy-one males volunteered to participate in a medical study initiated by Pharmacia & Upjohn. Only non-smoking healthy men were allowed to participate in the study. After being given oral and written information, informed consent was obtained. The study was approved by the Ethics Committee of Lund University Hospital. The males went through a clinical examination by a physician, including medical history, physical examination, laboratory evaluations of blood and urine and electrocardiography.

Pre-test

In order to determine the physical capacity of the participants and for medical safety reasons, they were required to perform a conventional clinical symptom-limited ramp ergometer cycle pre-test with ECG recordings. The pre-test started with cycling at 60 rpm at a workload of 50 W and increased by 5 W 20 s^{-1} until exhaustion. The men were accepted for participation in the study if the tests were performed without problems, and if they reached 80–130% of the age-predicted maximum workload according to Nordenfelt *et al.* (1985). Forty-two men reached this level. These men were randomly divided into an experimental group (with drug treatment) and a control group (receiving placebo). The control group consisted of 19 men and only these individuals were included in this study.

Equipment

All measurements (tests 1 and 2) were carried out by the same investigators and were performed at the Department of Clinical Physiology at the University Hospital in Lund, Sweden. A Siemens-Elema/Rodby 380B ergometer cycle was used. Respiratory gas analysis and volume measurements were performed with a face-mask connected by a tripleV (flow/gas sensor) and a Twin Tube to an Oxycon apparatus (Jaeger Oxycon Champion, Breda, the Netherlands). The equipment was calibrated just before the tests to compensate for ambient conditions such as air pressure, temperature and humidity.

A series of tests of the day-to-day variation in volume calibration were performed. A 2-l syringe and metronome were used to obtain 20, 40, and 60 l min^{-1} in minute ventilation. The tests were performed on five different days and on each day the standard volume calibration was made. There was no deviation from linearity between minute volume and a metronome frequency and the day-to-day variation in minute volume was 810 ml min^{-1} (2 SD).

The HR was assessed with a five-lead electrocardiogragh (ECG Megachart, Siemens-Elema, Sweden). The amplified ECG signal was fed into the Oxycon apparatus and used to calculate the HR. The exertion was assessed according to the method of Borg (1982), using the RPE scale, 6–20.

Test measurements

Each subject underwent two graded exercise tests with continuous measurement of the expired gases. The measurements were performed at about the same time of day for each individual, 5 to 6 weeks apart. All participants were instructed not to take part in any sporting activities 48 h before the test, not to eat 3 h before the test and not to drink coffee 2 h before the test. They were also asked not to change their sporting activities between the test sessions. It was ascertained whether the test person had followed the instructions concerning physical activity, food and beverages before coming to the hospital. Each male's weight was determined to the nearest kilogram on a standard physician's beam scale, with the male dressed in light underwear and wearing no shoes. His height was measured on a standard wall-mounted height board and his body mass index (BMI) was calculated. The characteristics of the studied group are presented in Table 1. After recording weight and height, the cycle was individually adjusted. Age, weight, height and sex were fed into the computer manually. The face-mask was fitted so as to avoid leakage, and the electrodes for measuring HR were carefully placed to obtain a good signal. Wearing shorts and sports shoes, the men started cycling at a load of 50 W after 2 min of rest on the cycle. The load increased by 5 W 20 s^{-1} until 40% of the individual maximum workload obtained from the pretest was reached. At this level the load was kept constant for 4 min in order to reach steady state. Thereafter, cycling continued until exhaustion. Three minutes of rest on the cycle followed. Gas measurements were made continuously by the Oxycon apparatus and the values were recorded every 10 s. Borg's 6–20 scale was used every 2 min to rate the perceived exertion and the values were recorded on the ECG Megachart sheet. The subjects were asked to evaluate the general rate of perceived exertion (respiratory/overall). The RPE values at the sub-maximal load and also at the end of exercise were analysed. ECG was monitored continuously, and HR was recorded every 10 s. The measurements performed on the two occasions followed the same procedure.

Table 1 Characteristics of the men (n = 19).

Variable	Mean (SD)	Range
Age (years)	27 (7·0)	20–48
Height (cm)	180 (5·7)	167–189
Weight (kg)	76 (7·3)	66–92
BMI*	23 (2·2)	20–27

*Body mass index (weight/height^2).

Analysis of data and statistics

The data files from the Oxycon apparatus were transferred to Matlab® (Mathworks, Incorp., Natick, MA, USA) and analysed. The signals were slightly low-pass filtered. Heart rate and $\dot{V}O_2$ at rest were taken as the mean of the filtered values during the last minute before the start of cycling. The filtered values at the fixed sub-maximal load were taken just before the load started to increase again. Maximum HR and maximum $\dot{V}O_2$ were the maximum of the filtered values at the end of exercise.

To analyse the repeatability of the measurements performed on the two test occasions, the differences between the measurements were plotted against the mean according to the method of Bland & Altman (1986). The mean of the differences between the measurements was calculated, and the hypothesis of zero bias was tested using Student's t-test. A significance level of $P = 0{\cdot}05$ was chosen. The coefficient of repeatability (COR) was calculated as 2 SD of the difference between the two measurements according to the British Standards Institution (1979). COR was presented as absolute values and expressed as a percentage (2 SD/mean). Spearman's rank correlation coefficient (r_s) was used to study the correlation between changes of HR and changes of $\dot{V}O_2$.

Results

In Table 2 mean ± 1 SD of the measurements of $\dot{V}O_2$, and HR at rest, when cycling at sub-maximal and maximal loads, on the two test occasions, can be seen. The mean values of the maximal loads and perceived exertion on the two occasions are also given. The mean maximum load and mean maximum $\dot{V}O_2$ were slightly higher in test 2, but there were no significant differences between the mean values in any of the measurements.

For a closer study of the variation of the maximum loads on the two test occasions, the results were analysed *ad modum* Bland & Altman (1986). The upper and lower limits for repeatability, defined as ±2 SD were calculated to ±23 W. Expressed in percentage of the mean maximum load COR was 9% (Table 2).

Table 2 Mean values (SD) from each of the two tests and coefficient of repeatability (COR, 2 SD of the differences between the two measurements). COR is also given as percentage of the mean of the two measurements. Values from the two tests (1 and 2) are from rest, at sub-maximal load and maximum load.

	$\dot{V}O_2$ (ml min^{-1})	HR (bpm)	RPE	Load (W)
Rest 1	333 (77)	85 (10)	–	–
Rest 2	365 (69)	85 (13)	–	–
Submax 1	1446 (175)	125 (15)	11·3 (2·1)	99 (12)
Submax 2	1445 (149)	124 (15)	10·9 (1·7)	99 (12)
Max 1	2910 (427)	185 (15)	19·1 (0·5)	249 (37)
Max 2	2963 (410)	186 (15)	19·3 (0·7)	254 (36)
COR, rest	191 (55%)	18 (21%)	–	–
COR, submax	209 (14%)	20 (16%)	4·8 (43%)	–
COR, max	332 (11%)	10 (6%)	1·3 (7%)	23 (9)

A corresponding analysis was performed on the variation in HR. At rest, the COR was 18 bpm or, expressed as a percentage of the mean of the two measurements, 21%. At sub-maximal load the COR of the HR was 20 bpm or 16% and at maximum load 10 bpm or 6·1% (Fig. 1).

In Fig. 2 the results of a corresponding analysis for $\dot{V}O_2$ can be seen. At rest the COR of $\dot{V}O_2$ was 191 ml min^{-1} (55%), at sub-maximal load 209 ml min^{-1} (14%) and at maximum load the COR was 332 ml min^{-1} (11%).

No correlation was found between the test–retest variation in HR and $\dot{V}O_2$ at sub-maximal load ($r_s = 0{\cdot}20$) or maximum load ($r_s = 0{\cdot}26$). The mean respiratory exchange ratio (RER) was 0·97 at the sub-maximal load.

The variations in $\dot{V}O_2$ between the tests correlated with the variations in minute ventilation ($r = 0{\cdot}80$). The technical day-to-day variation of minute volume was 0·810 l min^{-1} (tested as described above, at 20, 40 and 60 l min^{-1}, $n = 5$ test sessions). The relation between technical and biological day-to-day variation will be discussed.

The day-to-day variation in $\dot{V}O_2$ was not dependent on fir-filtration used in this study. We also tested the day-to-day

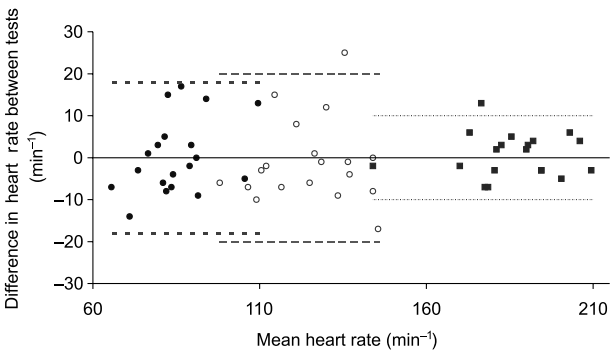

Figure 1 The difference in heart rate (test 2 − test 1) plotted against the mean of the measurements ($n = 19$) at rest (filled circles), when cycling at sub-maximal load (open circles) and at maximum load (filled squares). The upper and lower lines show ±2 SD.

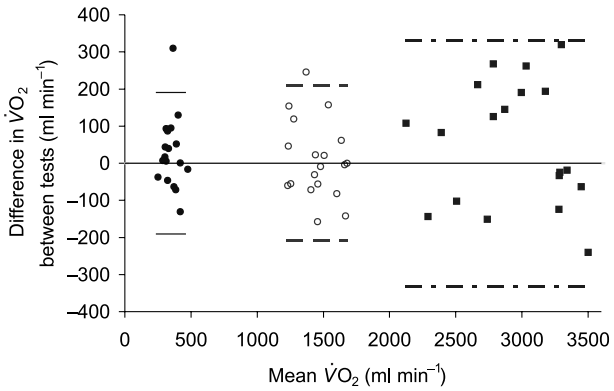

Figure 2 The difference in $\dot{V}O_2$ (test 2 − test 1) plotted against the mean of the measurements ($n = 19$) at rest (filled circles), when cycling at sub-maximal load (open circles) and at maximum load (filled squares). The upper and lower lines show ±2 SD.

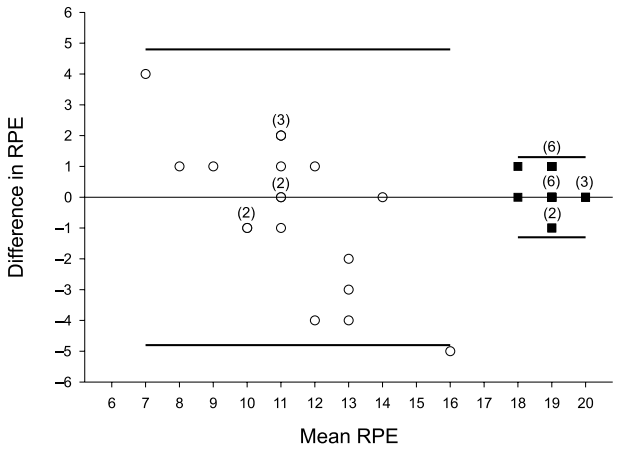

Figure 3 The difference in rating of perceived exertion (RPE) (test 2 − test 1) plotted against the mean of the measurements ($n = 19$), when cycling at sub-maximal load (open circles) and at maximum load (filled squares). The upper and lower lines show ±2 SD.

variation in $\dot{V}O_2$ at the sub-maximal load using another type of filtration. A floating average of six consecutive values (a period of 1 min) was calculated. With this filtering technique the day-to-day variation in $\dot{V}O_2$ was 220 ml min^{-1} (COR), i.e. similar to the values based on the fir-filtration.

The COR when using Borg's scale for ratings of perceived exertion (RPE) was 4·8 (2 SD) at sub-maximal loads and 1·3 (2 SD) at maximal loads (Fig. 3). All male subjects tested cycled close to their maximum on the two test occasions. This was shown by the ratings of 19·2 (mean) on the scale. There was a tendency for men who rated their perceived exertion as high in the first test to rate their perceived exertion lower in the second, and vice versa. This can be seen in Fig. 3.

Discussion

Oxygen consumption

In this study, the COR in oxygen consumption in men when performing an ergometer cycling test tended to be lower at maximum load (11%) than at sub-maximal loads (14%) and at rest (55%). The tendency was the same for HR, with CORs of 6, 16 and 21%.

The COR at maximum load agrees well with results from earlier studies. A newly published study found a COR of maximum $\dot{V}O_2$ of 16%, based on measurements on 19 healthy volunteers who underwent two sessions of maximal testing on an ergometer cycle, with an interval of about a week (Baba *et al.*, 1999). Bingisser *et al.* reported coefficients of repeatability of 8 and 13% for maximum $\dot{V}O_2$ in well-trained and untrained healthy subjects, respectively. Repeatability coefficients were found not to differ between males and females (Bingisser *et al.*, 1997). In this study, with measurements 5–6 weeks apart, the COR (2 SD) for $\dot{V}O_2$ in absolute terms was 332 ml min^{-1}.

The aerobic capacity include functional capacity of the cardiorespiratory system of a person's ability to perform strenuous work (Åstrand & Rodahl, 1977). Maximal exercise testing is often considered the best method for assessing maximum aerobic capacity. However, physical conditions such as pain, fatigue or musculoskeletal impairment, may make maximal testing impossible. In such a case sub-maximal exercise testing could be an alternative. In this study, the COR (2 SD) in oxygen consumption ($\dot{V}O_2$) at sub-maximal load was 209 ml min^{-1}. This is very similar to the value reported in an earlier study where the day-to-day variation (2 SD) in oxygen consumption at sub-maximal load on an ergometer cycle was found to be 199 ml min^{-1} in male adolescents (Wergel-Kolmert *et al.*, 2001).

Heart rate

During the test the men were encouraged to continue cycling until exhaustion. The mean maximum HRs recorded were 185 (test 1) and 186 (test 2) and COR was 10 bpm or 6%. The corresponding values were 20 bpm (16%) at sub-maximal load and 18 bpm (21%) at rest. Thus, there was a tendency towards a lower COR as the load increased. Anxiety before and at the beginning of the test probably influenced the HR.

The HR at sub-maximal exercise can be used for prediction of maximum oxygen consumption using a two-point-technique, see Wisén & Wohlfart (1999). When using the two-point-technique HR at two or more exercise levels are used and extrapolated to a maximum HR to obtain a maximum exercise level. The HR at sub-maximal load can also be used for prediction of maximum oxygen consumption using a nomogram. A predicted maximum $\dot{V}O_2$ is obtained by using the linear relationship between HR and $\dot{V}O_2$, and extrapolating to the age-predicted HR max (Åstrand & Ryhming, 1954). This nomogram is widely applied. When using the nomogram for the evaluation of the maximum aerobic capacity in this study, the value obtained was found to be higher (mean 0·8 l min^{-1}) than the directly measured maximum $\dot{V}O_2$. It is thus important to bear the COR of the HR at sub-maximal load in mind when using the value for the prediction of the maximum oxygen consumption. A better prediction of $\dot{V}O_{2\,max}$ can be obtained when the exercise intensity is higher than was the case in this study (mean HR at sub-maximal load was 125 bpm, Table 2).

Ratings of perceived exertion

The RPE is an accepted method of assessing exercise intensity for the prescription of exercise programmes (Wilmore & Costill, 1999). In an earlier study (Eston & Williams, 1988), the reliability of the RPE was assessed for the prescription of exercise intensity during cycling. It was suggested that the RPE provides a useful frame of reference for regulation of high levels of exercise intensity in healthy men and women. Some practice with the scale has been found to improve its application at lower exercise levels. Stamford (1976) has demonstrated a strong relationship between the RPE and HR. The author also concluded that category ratings of perceived exertion according to Borg's scale

offer a sensitive and reliable measure of the stress encountered during work. A strong tendency towards greater reliability as the work became more intense, as well as with more experience with the scale, was also shown. The repeatability was also found to be better during strenuous physical work in the present study with a COR, in absolute values, of 5 at sub-maximal load and 1 at maximum load on Borg's scale. However, the sub-maximal level (40%) used in this study could be too low. The perceptual cues coming both from respiratory strain (usually predominant in the first phase of physical exercise) and muscular fatigue in the legs (usually arising in a successive phase) are probably mixed at this level. This could interfere with the evaluation process and result in an inaccurate judgement.

Test group

In order to conduct risk assessment and to ensure the health of the men taking part in the study, they were required to pass a thorough medical examination. The men also performed a pretest within certain limitations of physical capacity, 80 to 130% of Nordenfelt's reference values (Nordenfelt *et al.*, 1985). Thus, the men taking part in the study had been physically examined, were fit and accustomed to the equipment and test procedure. Before each test occasion on the ergometer cycle, it was ascertained whether the instructions concerning meals and physical exercise had been followed.

Technical and biological day-to-day variations

Before the tests the equipment was checked and the Oxycon apparatus carefully calibrated. The gas measurements, recorded every 10 s, may be disturbed by changes in ventilation in unsteady states, such as temporary hypo- or hyper-ventilation. The variation in the measurements should depend on the true biological variation, but may also depend on technical factors. The scattered gas values were smoothed using a low-pass filter in order to obtain a more stable signal.

The day-to-day variation of the volume/flow calibration (see Methods) was $0{\cdot}810\ \mathrm{l\ min^{-1}}$. Assuming that $25\ \mathrm{l\ min^{-1}}$ in minute ventilation corresponds to $\dot{V}O_2 = 1\ \mathrm{l\ min^{-1}}$, a variation of $0{\cdot}8\ \mathrm{l\ min^{-1}}$ in minute ventilation would correspond to a variation of $<40\ \mathrm{ml\ min^{-1}}$ in $\dot{V}O_2$. This value should be compared to the recorded variation in $\dot{V}O_2$ of about $200\ \mathrm{ml\ min^{-1}}$ at the sub-maximal load. The following expression describes the relationship:

$$40^2 + X^2 = 200^2 \qquad (1)$$

where X is the combined effect of the biological variation and the error in measurement of O_2-concentration. The latter is probably smaller than the error in volume/flow calibration. Solving (1) gives $X = 4\ \mathrm{ml\ min^{-1}}$. The day-to-day variation of $\dot{V}O_2$ reported is thus dominated by the biological variation.

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