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TITLE

VARIABILITY OF TIME TO EXHAUSTION DURING SUBMAXIMAL EXERCISE

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Variability of Time to Exhaustion During Submaximal Exercise

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***Key words**: coefficient of variation, blood lactate, sample size, power*
***Mots-clés**: coefficient de variation, lactate sanguin, taille de l'échantillon, puissance*

Abstract/Résumé

Exercise time to exhaustion (TE) is commonly used to evaluate the success or failure of such treatments as endurance training programs or nutritional supplements. The present study determined the variability of TE during submaximal exercise at 80% $\dot{V}O_2$max. Fifteen males performed cycle exercise to exhaustion on five occasions at the same time of day with a minimum of 72 hrs between sessions. There was no difference in TE (0.1 > p > 0.05) among the trials, with values ranging from 14.4 ± 1.1 min for Test 1 to 18.2 ± 2.4 min during the final test. Substantial variability in TE over the five trials was observed among subjects with coefficients of variation (CV) ranging from 2.8 to 31.4%. Subjects were divided into two groups using the median CV for TE. For the low CV group (n = 8), TE was significantly increased during Test 3 (14.9 ± 1.3 min) compared with Test 1 (12.8 ± 1.0 min) and Test 5 (12.5 ± 1.2 min). For the high CV group (n = 7), TE was increased during Test 5 (24.7 ± 3.7 min) compared with the other tests (18.5 ± 2.2 min). CV for $\dot{V}O_2$, $\dot{V}_E$, pH, P_{CO_2}, and rectal temperature were less than 5% and did not differ between groups. Post hoc power calculations revealed that if all subjects were considered as one group, sample size would have to increase to 40 to increase the power to 0.8. Due to the variability in TE that may be observed with males of average fitness, it is concluded that TE should not be the only dependent measure used to evaluate treatment effects during submaximal exercise.

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La durée d'un effort jusqu'à l'épuisement est généralement retenue comme mesure de réussite ou d'échec à un programme d'entraînement à l'endurance ou à l'incorporation d'un supplément nutritif. La présente étude détermine la variabilité de la durée d'effort au cours d'un exercice physique sous-maximal à 80% du $\dot{V}O_2$max. Au cours de cinq séances prévues à la même heure mais séparées d'au moins 72 h, 15 hommes accomplissent jusqu'à épuisement un exercice sur un ergocycle. D'une séance à l'autre, il n'y a aucune différence significative (0,1 > p > 0,05) entre les résultats dont les valeurs au premier test sont de 14,4 ± 1,1 min et au dernier, 18,2 ± 2,4 min. Une importante variabilité de la durée d'effort au cours des cinq séances est observée chez les sujets dont le coefficient de variation (CV) se situe entre 2,8 et 31,4%. La médiane du CV de la durée d'effort sert à diviser le groupe en deux sous-groupes. Chez le sous-groupe au faible CV (n = 8), la durée d'effort est significativement plus longue à la troisième séance (14,9 ± 1,3 min) qu'à la première (12,8 ± 1,0 min) et qu'à la cinquième (12,5 ± 1,2). Le sous-groupe au fort CV affiche une durée supérieure à la cinquième séance (24,7 ± 3,7 min) comparativement aux autres (18,5 ± 2,2 min). Les CV respectifs du $\dot{V}O_2$, du $\dot{V}_E$, du pH, et de la température rectale sont inférieurs à 5% et ne diffèrent pas entre les deux groupes. Une analyse post hoc de la puissance du test indique que, si les sujets étaient réunis dans un seul groupe, il faudrait augmenter la taille de l'échantillon à 40 pour obtenir une puissance de 0,8. À cause de la variabilité de la durée d'effort observée chez des hommes de condition physique moyenne, la valeur de la durée de l'effort ne devrait pas être la seule variable dépendante pour évaluer les effets d'un traitement au cours d'un exercice sous-maximal.

Introduction

When a research hypothesis is formed and an experimental design is developed, every attempt is made to eliminate or control the influence of extraneous factors that may mask the effect of a treatment. The purpose of these controls is to minimise total measurement error, and thus provide an environment that is as ideal as possible for identifying the treatment effect. Of equal importance, but often overlooked, is the selection of the sample size required for the experimental design. A well-controlled study may fail to reveal a significant treatment effect because of a small sample size. Alternatively, an experiment that involves a large number of subjects may fail to show a treatment effect because of the inherent variability or measurement error associated with the dependent measure.

An estimate of the expected variability of response for a dependent measure of interest can be used to select the sample size required to minimise the risk of a Type II (β) error (i.e., an incorrect decision to accept the null hypothesis) (Keppel, 1973). Results from pilot studies or previous investigations are ways of predicting subject variance prior to data collection. If sample size is selected without a priori information, then the power ($1 - \beta$) of the experimental design should at least be determined after the data analyses are completed to estimate the probability of the Type II error. This calculation is especially important for the investigator in deciding whether additional subject testing is required before the null hypothesis can be accepted or rejected.

Exercise time to exhaustion (TE) is a dependent measure that has been used to evaluate performance changes after endurance training programs (Hickson et al., 1988; Houmard et al., 1990) or the ingestion of nutritional or other ergogenic supplements (Bredle et al., 1988; Brewer et al., 1988; Murray et al., 1989). The variability of TE has been reported to be less than 5% for three incremental tests

to maximum on the treadmill for subjects of varied fitness levels (Kyle et al., 1989) and for highly trained and well-motivated cyclists performing four time trials over three distances (Hickey et al., 1992). Recently, Billat et al. (1994) documented that time to exhaustion was reliable and reproducible for the minimal running speed that elicited the $\dot{V}O_2$max of well-trained males. Little if any information is available that reports the variability in TE for moderately active subjects during submaximal exercise. The purpose of the present investigation, therefore, was to determine the variability of TE over five submaximal exercise tests. It was hypothesized that the coefficient of variation for TE, that is, (*SD*/mean) · 100, would be less than 10%.

Methods

SUBJECTS

Following the approval of the institute's ethics committee, written informed consent was obtained from 15 males (27.8 ± 4.4 yrs, 81.1 ± 9.9 kg, 1.77 ± 0.07 m, with a $\dot{V}O_2$max of 47.0 ± 4.9 mL · kg^{-1} · min^{-1}) who volunteered to participate in the study. Subjects were not told that the main purpose of the experiment was to examine the variability of their response during submaximal exercise until all the testing for all subjects had been completed.

INCREMENTAL EXERCISE TESTS

For determination of $\dot{V}O_2$max, subjects performed a 30 W · min^{-1} ramp-incremental exercise test beginning at 60 W on an electrically braked cycle ergometer (Ergomed 930, Siemens). $\dot{V}O_2$max was defined as the highest $\dot{V}O_2$ calculated over a 30-sec period. After a 60-min rest, subjects cycled continuously for 4 min at each of four power outputs. The $\dot{V}O_2$ measured during the last 60 sec at these power outputs was used to estimate the power outputs that demanded 50 and 80% $\dot{V}O_2$max for each subject. These power outputs were then used in the subsequent tests that evaluated the variability in the exercise time to exhaustion. $\dot{V}O_2$max was determined also with the same 30 W · min^{-1} ramp-incremental test after the five exercise tests had been completed (see below).

PROLONGED EXERCISE TESTS

Subjects exercised to exhaustion on five occasions at the power output equivalent of 80% $\dot{V}O_2$max. A 5-min warm-up at 50% $\dot{V}O_2$max preceded these tests to exhaustion. Verbal encouragement was provided toward the end of these sessions only to ensure that subjects ended a given trial on the completion of a minute. The subjects alone decided whether they could continue for another 60-sec period. No external time clues (i.e., clocks or radio) were provided, but the subjects were allowed to listen to recorded music. They were asked to maintain their normal diet throughout the study. No restrictions were imposed on their diet for the day prior to each exercise test. However, subjects were instructed not to consume any food or beverage for at least 4 hrs before each testing session. Two hours before each session they consumed 235 mL of a nutritional supplement

(Ensure Plus®, Ross Laboratories) containing 781, 474, and 225 kJ of carbohydrate, fat, and protein, respectively. Exercise tests were separated by a minimum of 72 hrs and were performed at the same time of day for a given subject. Laboratory temperatures varied from 20 to 23°C and subjects were cooled with a fan from behind during the tests. They also were asked to refrain from exercise, or at least to standardize their exercise routine, for the day prior to the tests.

A 1.5-mL blood sample was taken at rest, following the warm-up at 50% $\dot{V}O_2$max, after 5 and 10 min of exercise at 80% $\dot{V}O_2$max, at 10-min intervals thereafter, and during the last 20 sec of exercise from a 21-gauge catheter (Butterfly®) inserted into a dorsal hand vein. The technique of heating the hand and forearm in a heating chamber to obtain arterialised-venous blood samples has been described previously (McLellan and Cheung, 1992). Each blood sample was collected in a heparinised plastic syringe and capped. A 25-μL aliquot was deproteinized immediately with 200 μL of 0.4 M perchloric acid and subsequently frozen at −20°C. The remainder of the blood sample was used for pH and P_{CO_2} analyses with a pH and blood gas analyser (Corning 168) which had been calibrated previously with precision buffers and gases of known composition. Core temperature was monitored throughout exercise from a rectal probe inserted approximately 15 cm beyond the anal sphincter. Changes in rectal temperature were used to correct pH and P_{CO_2} values measured at 37°C by the blood gas analyser. Blood lactate (La_b) concentrations were determined enzymatically using the methods described by Maughan (1982). All La_b analyses for a subject's five trials were assayed at the same time.

GAS EXCHANGE ANALYSES

For all testing sessions the subjects breathed through a low-resistance Hans-Rudolf respiratory valve. Expired gases were directed into a 5-L mixing box and through a turbine (Alpha Technologies VMM 110 series ventilation module) for determination of minute ventilation ($\dot{V}_E$). A sampling line directed dried gases from the mixing box to an O_2 (S-3A Applied Electrochemistry) and CO_2 (CD-3A Applied Electrochemistry) analyser. The gas analysers were calibrated before each test with a precision analysed gas cylinder with known O_2 and CO_2 composition while the turbine was calibrated with a 3-L syringe. After conversion of the analogue voltage outputs from the ventilation module and the gas analyzers into digital signals (Hewlett-Packard 59313 A/D converter), $\dot{V}_E$, carbon dioxide output ($\dot{V}CO_2$), and $\dot{V}O_2$ were calculated and printed on-line every 30 or 60 sec using appropriate software on a microcomputer (Hewlett-Packard 9825A). Heart rate was monitored by telemetry (Sport Tester, PE 3000) and recorded during the last 15 sec of each power increment of the incremental exercise tests and at 5-min intervals throughout the prolonged exercise tests.

DATA ANALYSES

A one-factor (trial) or a two-factor (trial × time) repeated measures ANOVA was used to compare responses among the five trials at 80% $\dot{V}O_2$max. Since the values of a given measure at the different levels of the repeated factor are not independent but are highly correlated, the Greenhouse-Geisser correction was

applied to these ANOVA to reduce the risk of a Type I error. Individual coefficients of variation were calculated for all dependent measures. To further examine those factors that could be involved in the extent of the variability in TE, the median coefficient of variation for TE was used to divide subjects into high variation ($n = 7$) or low variation ($n = 8$) groups. This separation of subjects was not planned beforehand. Therefore the subsequent group comparisons are not based on a true random sampling distribution. However, the magnitude of the variability in TE was the only bias involved in the separation of subjects. Comparisons between groups involved two-factor (group × trial) repeated measures ANOVA, again using the Greenhouse-Geisser correction for the repeated factor (trial), or independent t tests when a repeated factor was not involved. When a significant corrected F ratio was obtained, a Newman-Keuls post hoc comparison was made to clarify the differences among treatment means. For these statistical analyses, the 0.05 level of significance was used.

A post hoc determination of the power ($1 - \beta$) of the experimental design was calculated as follows (Keppel, 1973):

$$\hat{\phi}^2_{\text{trials}} = (\text{trials} - 1)\,\frac{(\text{MS}_{\text{trials}} - \text{MS}_{\text{S/trials}})/\text{trials}}{\text{MS}_{\text{S/trials}}},$$

where $\text{MS}_{\text{trials}}$ is the mean square variance for the treatment effect of the trials, $\text{MS}_{\text{S/trials}}$ is the subject within-trials mean square variance, and the parameter ϕ at the 0.05 level of significance is used to determine $1 - \beta$ from power function curves with the appropriate number of degrees of freedom for the numerator, $\text{MS}_{\text{trials}}$ (i.e., trials − 1), and the denominator, $\text{MS}_{\text{S/trials}}$ (trials − 1)(subjects − 1). The caret over ϕ indicates that this is a population estimate based on sample values. Following this calculation, the post hoc determination of the sample size required to increase the power to 0.8 was made as follows (Keppel, 1973):

$$\Sigma\hat{\alpha}_i^2 = \frac{(\text{trials} - 1)}{\text{s}}(\text{MS}_{\text{trials}} - \text{MS}_{\text{S/trials}})$$

and

$$\hat{\phi}^2_{\text{trials}} = \frac{\text{s}'\Sigma\hat{\alpha}_i^2/\text{trials}}{\text{MS}_{\text{S/trials}}},$$

where $\Sigma\hat{\alpha}_i^2$ is an estimate of the sum of the squared deviation scores using the number of subjects, s, involved in the experiment, and s' is the number of subjects required for the desired level of $1 - \beta$.

Results

Figure 1 shows there was no difference among the five trials for TE ($p < 0.1$), although mean values increased from 14.4 min for Trial 1 to 18.2 min for Trial 5. Individual coefficients of variation for TE ranged from 2.8 to 31.4%. Figure 2 presents individual data for TE during the five trials, with subjects divided into high (H) and low (L) variability groups. Coefficients of variation for TE were significantly different between Groups H (23.5 ± 2.1%) and L (12.0 ±

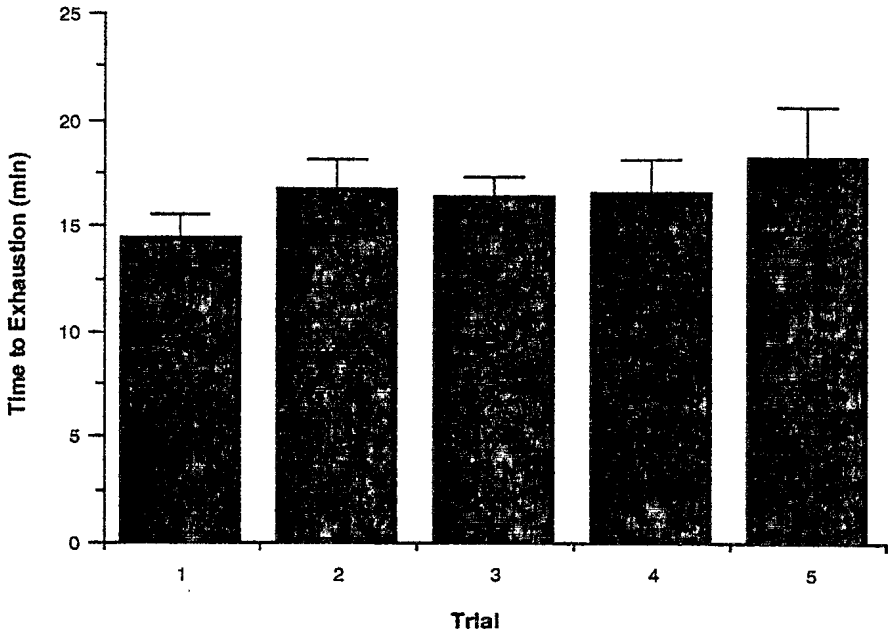

Figure 1. Mean (±*SEM*) times to exhaustion for the five trials considering all 15 subjects as one group.

2.0%). Mean data for TE are shown in Figure 3 for the two groups. For Group H, TE increased significantly during Trial 5 compared with the other trials. In contrast, for Group L, TE was significantly increased for Trial 3 compared with Trials 1 and 5. There was a significant difference between groups for TE during Trials 2, 4, and 5.

Table 1 presents gas exchange, T_{re}, and blood measurements following 5 min of exercise at 80% $\dot{V}O_2$max test for Groups L and H during the five trials. There was no difference between groups or among the trials for any of the dependent measures shown in Table 1. All values either increased ($\dot{V}O_2$, $\dot{V}_E$, T_{re}, and La_b) or decreased (R, P_{CO_2}, and pH) significantly by the end of each test, but the magnitude of this change did not differ between groups. Over the duration of all trials, Group H exercised at a significantly lower %$\dot{V}O_2$max compared with Group L (80.5 vs. 85.5%, respectively), but individual differences in this average exercise intensity were not related to the variation in TE ($r = -0.22$, $p > 0.05$).

With the exception of La_b, coefficients of variation for the dependent measures shown in Table 1 for both groups were less than 5% averaged over all trials. The variation in these measures did not differ between groups and was not related to the variation in TE. However, there was a significant difference between groups for the coefficient of variation for La_b, which averaged 8.2 ± 0.9% and 11.1 ± 0.9% for Groups L and H, respectively. The individual variability in La_b during the exercise tests showed a weak but significant correlation (r = 0.58) with the variation in TE.

There was no difference between groups in $\dot{V}O_2$max (3.57 ± 0.28 L · min^{-1} for L and 3.93 ± 0.17 L · min^{-1} for H). Also, there was no change in $\dot{V}O_2$max as a result of the five performance tests. Individual differences in $\dot{V}O_2$max were not related to the variation in TE ($r = 0.22$, $p > 0.05$).

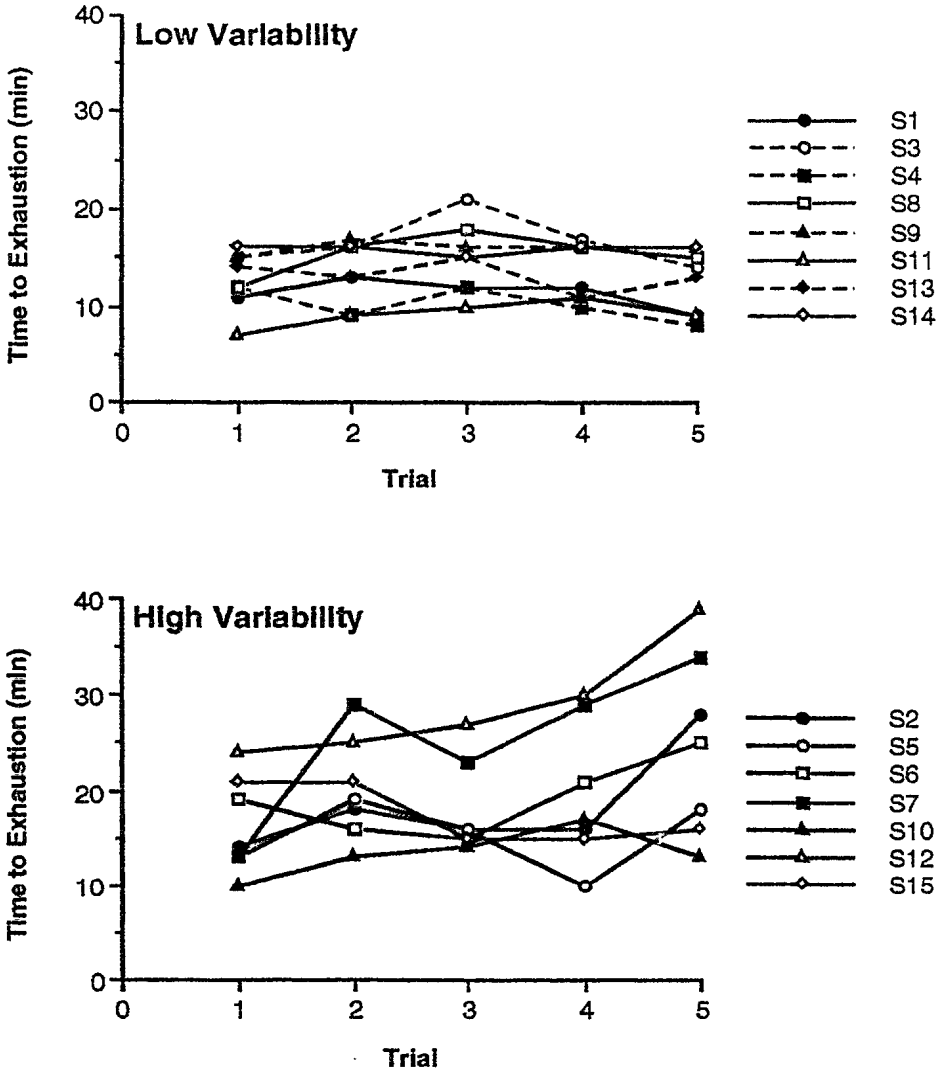

Figure 2. Individual times to exhaustion for the five trials with subjects divided into groups of high (n = 7) and low (n = 8) subject variability.

There was a significant reduction in the coefficient of variation for TE for both groups when the first and last trials were eliminated. Values decreased to 9.2 ± 1.8% for L and to 16.1 ± 3.0% for H.

Table 2 reports the post hoc determination of the power of the experimental design. The risk of a Type II error (β) was 0.6 with all subjects considered as one group. The chance of this error decreased when subjects were separated into Groups H and L. For H, the increase in power (and decrease in Type II error) could be attributed largely to the greater proportion of variance ascribed to the "trial" factor. For L, however, the change in power reflected a greater proportional change in the variance assigned to the interaction of subject responses over the different trials. Table 3 shows the post hoc calculation of the sample size required to attain a power of 0.8. If subjects remained as one group, sample size would have to increase from 15 in the present study to 40 to reach a power of 0.8. With subjects classified into groups of high and low variability, total subject numbers would have to increase to only 22.

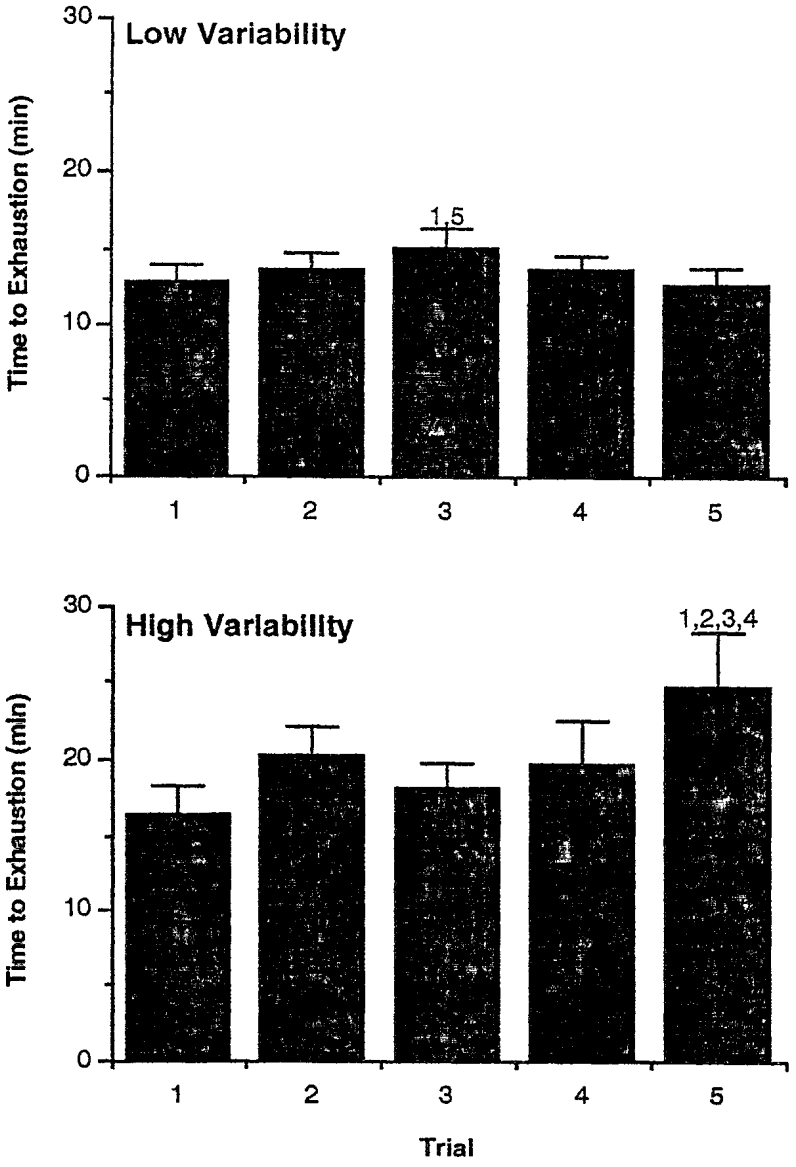

Figure 3. Mean (±*SEM*) times to exhaustion for the five trials with subjects divided into groups of high (n = 7) and low (n = 8) subject variability. Numbers above a trial refer to the trial number that is significantly different.

Discussion

This study has revealed that there is a substantial range of individual variability in the dependent measure TE during submaximal exercise at 80% $\dot{V}O_2$max. The mean coefficient of variation of 17.3% for TE is greater than the values of 4% reported for an incremental treadmill test to exhaustion (Kyle et al., 1989), 1 to 3% documented for well-trained cyclists performing time trials (Hickey et al., 1992), and 10% calculated for trained cyclists during exercise to exhaustion at 120% $\dot{V}O_2$max (Graham and McLellan, 1989).

Several factors might account for the higher CV found for TE in the present study. First, our subjects certainly would not be considered trained cyclists, and thus it could be argued that the high CV was because they were not used to

Table 1 Mean Values (*SEM*) Following 5 min of Exercise at 80% $\dot{V}O_2$max for the High and Low Variability Groups During the 5 Trials

	High					Low				
	Tr. 1	Tr. 2	Tr. 3	Tr. 4	Tr. 5	Tr. 1	Tr. 2	Tr. 3	Tr. 4	Tr. 5
$\dot{V}O_2$ ($L \cdot min^{-1}$)	3.02 (0.17)	3.04 (0.17)	3.04 (0.16)	3.03 (0.17)	2.97 (0.18)	2.92 (0.23)	3.03 (0.26)	2.87 (0.24)	2.88 (0.24)	2.92 (0.24)
% $\dot{V}O_2$max	76.8 (2.8)	77.1 (2.3)	77.3 (2.2)	77.2 (2.9)	75.5 (2.9)	81.9 (1.7)	85.0 (1.7)	80.3 (1.1)	80.7 (1.1)	81.6 (1.2)
$\dot{V}_E$ ($L \cdot min^{-1}$,STPD)	77.7 (5.9)	77.9 (5.9)	76.7 (4.7)	76.8 (5.9)	76.3 (6.0)	76.1 (5.7)	79.8 (8.0)	77.2 (7.1)	77.2 (8.0)	80.8 (7.8)
R	1.06 (0.01)	1.08 (0.01)	1.06 (0.02)	1.06 (0.02)	1.07 (0.01)	1.08 (0.02)	1.08 (0.02)	1.10 (0.02)	1.10 (0.01)	1.11 (0.02)
T_{re} (°C)	37.4 (0.1)	37.4 (0.1)	37.4 (0.1)	37.2 (0.1)	37.3 (0.1)	37.3 (0.1)	37.3 (0.1)	37.3 (0.1)	37.2 (0.1)	37.3 (0.1)
pH	7.34 (0.01)	7.34 (0.02)	7.35 (0.03)	7.35 (0.01)	7.34 (0.01)	7.32 (0.01)	7.31 (0.01)	7.32 (0.01)	7.32 (0.01)	7.32 (0.01)
PCO_2 (mmHg)	35.7 (1.0)	36.9 (0.7)	35.6 (1.3)	35.6 (1.2)	36.3 (1.0)	34.8 (1.1)	34.8 (1.2)	35.4 (1.2)	36.4 (1.2)	34.8 (0.8)
La_b ($mmol \cdot L^{-1}$)	6.04 (0.69)	6.22 (0.77)	6.37 (0.72)	5.90 (0.76)	5.68 (0.47)	6.46 (0.50)	6.87 (0.47)	6.92 (0.62)	6.92 (0.45)	6.59 (0.51)

Table 2 Post hoc Determination of Power (1 − β) of Experimental Design Using All Subjects Combined or Separated Into Groups

	All subjects (n = 15)	High variability (n = 7)	Low variability (n = 8)
MS_{trials}	27.447	69.757	6.963
$MS_{S/trials}$	12.382	18.057	2.248
$\hat{\phi}^2_{trials}$	0.97	2.29	1.68
$df_{num,denom}$	4,56	4,24	4,28
power (1 − β)	0.4	0.7	0.55

Table 3 Post hoc Determination of Sample Size Required for a Power (1 − β) of 0.8

	All subjects' data	High variability group	Low variability group
s' required for $1 - \beta = 0.8$	40	9	13

exhaustive exercise. The significant improvement in TE during later trials, compared with Test 1 for both variability groups, would support such reasoning. However, similar improvements were not observed for untrained and moderately trained individuals during three incremental treadmill tests to exhaustion (Kyle et al., 1989). Therefore it is possible that the type of exercise test used to determine TE influences the measured coefficient of variation. It would appear that time trials (Hickey et al., 1992), incremental tests to exhaustion (Kyle et al., 1989), or running to exhaustion at speeds eliciting $\dot{V}O_2max$ (Billat et al., 1994) involve less variation than exercise tests to exhaustion at a fixed percentage of $\dot{V}O_2max$ (Graham and McLellan, 1989; the present study). It is also conceivable that running tests involve less variation than cycling for moderately active subjects (Kyle et al., 1989; the present study). Finally, the CV for TE during these tests at a given $\%\dot{V}O_2max$ was greater at lower relative exercise intensities. The mean CV of 12% for the low variability group who exercised at 85% $\dot{V}O_2max$ is similar to the value of 10% reported during performance tests at 120% $\dot{V}O_2max$ (Graham and McLellan, 1989). In contrast, during exercise at 80% $\dot{V}O_2max$ for the high variability group, the CV for TE increased to 24%. These results suggest that the longer the performance test, the greater the variability. As the time of the performance test increases, it is possible that factors in addition to energy demand and O_2 utilization, such as diet and hydration, influence the results. In the present study, however, there was no indication from R values or T_{re} that diet or hydration biased the data systematically.

The fact that our subjects showed an improvement in TE during later trials, compared with Test 1, would substantiate the need for a familiarization session that replicates all experimental procedures but does not include the results of the test in the subsequent data analyses. Although some investigators have recognized the need to include such a procedure as part of their experimental design (Murray et al., 1989), it is more common to provide no information about familiarization procedures (Bredle et al., 1988; Coggan and Coyle, 1987; Meeuwisse et al., 1992; Yaspelkis and Ivy, 1991) or to include a statement implying that subjects were familiarized with the testing environment and procedures (Brewer et al., 1988; Coyle et al., 1991). For the present study we cannot isolate the focus of specific familiarization. For example, we do not know whether the improvement in TE represents a greater familiarization with the discomfort of an exercise test to exhaustion or a greater acceptance of the discomfort associated with such invasive procedures as the venous catheterization or the insertion of the rectal thermistor. It is interesting to note that Gleser and Vogel (1971) associated a nonsignificant reduction in TE with a test session that involved venous catheterization for the first time. A typical familiarization session at our laboratory has not included catheterization (McLellan et al., 1993), however, since this has been considered an unnecessary risk to the subject. Given the results of the present study, this policy may have to be reviewed.

Gleser and Vogel (1971) also reported that TE increased progressively for the first 5 weeks of evaluation for inactive subjects who were unaccustomed to regular exercise tests to exhaustion. However, their submaximal tests lasted longer (1 to 2 hrs) and the improvements in TE were reflected by lower heart rates and blood lactate levels indicating that a training effect had occurred. An 8% increase in $\dot{V}O_2$max was recorded at the end of the test sessions, but the individual changes in $\dot{V}O_2$max were not related to the improvements in TE (Gleser and Vogel, 1971). In the present study, heart rates, blood lactate, pH and P_{CO_2} levels, and R values were not different at a given time period among the trials (see Table 1), thus providing no physiological evidence for a training effect. In addition, $\dot{V}O_2$max did not change as a result of the repeated testing.

The different pattern of improvement in TE for the low and high variability groups merits consideration. The former group was characterized by an optimum performance during Test 3, with a subsequent decrease recorded for their last trial. These changes in TE could represent the benefits of familiarization with the testing environment during the initial sessions, followed by a progressive loss of interest with the experiment due to the total number of tests. In contrast, the high variability group was characterized by recording their best performance during the last test of the experiment. We can only speculate as to why the two groups responded differently and recorded their best performance during different tests. Motivation has been shown to influence maximal work performance (Wilmore, 1968), and for reasons that are not clear, our subjects appear to have been motivated at different times during the experiment to produce their best effort. We also cannot preclude that the groups differed with regard to physiological variables we did not measure.

The importance of the post hoc determination of the power of the experimental design is revealed in the calculations presented in Table 2. Normally a sample size of 15 would be considered more than adequate to address an exercise physiology research question with human subjects. However, because of the

individual differences in the variability of TE, the risk of a Type II error was substantial with all subjects considered as one group. If the trials represented different dosages of a nutritional supplement, would one conclude that there was no effect of treatment on TE with all subjects considered together? Certainly further testing would be warranted before one could accept the null hypothesis (see Table 3).

One should also be aware of the factors that influence the power of an experimental design. From the calculations shown in Tables 2 and 3 and from the discussion above, the sample size is an important consideration. However, it should also be apparent that the magnitude of the difference between the treatment (MS_{trials}) and measurement variances ($MS_{S/trials}$) influences the calculation. If the measurement variance is low, indicating that the experiment is well controlled, but the difference between the treatment and measurement variances is small, the power of the design will be low. Nevertheless, the researcher should feel confident in accepting the null hypothesis without having to increase the sample size of the experiment.

In summary, the results of this investigation have revealed that there are substantial individual differences in the variability of the dependent measure TE during submaximal exercise at 80% $\dot{V}O_2$max. If possible, we would recommend that other dependent measures in addition to TE be used in evaluating a research hypothesis. Also, we would recommend that the calculation of the power of the experimental design become a more common practice for research in the exercise sciences.

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