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Supramaximal test results of male and female speed skaters with particular reference to methodological problems

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Summary. Six male and six female elite speed skaters were tested during two bicycle ergometer tests: a 30 s sprint test and a 2.5 min supra maximal test. During the 2.5 min test oxygen consumption was measured every 30 s. The males showed 30–31% higher mean power output values both during the sprint test (1103 versus 769 Watt) and during the 2.5 min test (570 versus 390 Watt). Maximal oxygen consumption was 31% higher for the males than for the females (5.10 versus 3.50 $l \cdot min^{-1}$). However, when expressed per kilogram lean body weight (LBM), power output and oxygen consumption was equal for both sexes. Differences between present and previous results are most likely due to methodological problems with the estimation of load during the supra maximal test. Subjects appear to experience difficulties in distributing their power output over the 2.5 min if they are tested for the first time. For experienced skaters and cyclists, fixed levels of 19 $W \cdot kgLBM^{-1}$ as initial load setting for the sprint test and 8 $W \cdot kg\ LBM^{-1}$ for the 2.5 min test are recommended.

Key words: Power output – Oxygen consumption – Male/female comparison – Bicycle ergometer

Introduction

Differences in performance level between male and female athletes are often explained by differences in the liberation of metabolic power. Even when expressed per kilogram lean body mass (LBM), males are reported to have 8–15% higher aerobic capacity than females (Sparling 1980; Neuman and Buhl 1981; Dill et al. 1972; Ingen Schenau and de Groot 1983a). In a previous study Ingen Schenau and de Groot (1983a), however, found that elite female speed skaters can deliver more external power per kg LBM than elite male skaters when both are measured during supra-maximal cycling. It was suggested that females might have greater mechanical efficiency than males.

During the past three years many supra-maximal bicycle ergometer tests were performed by the skaters of the Dutch junior selection. From these tests the results of our previous study could not entirely be affirmed. The selection consists of six male and six female skaters who train together having the same training programs. In addition to our previous study the skaters also performed a 30 s sprint test (Geysel et al. 1984). The purpose of the present study is to publish the differences found between these male and female skaters, and to discuss methodological reasons for deviations of these results from those reported previously.

Subjects and methods

The junior selection consists of six males and six females all in the age range of 16–20 years. The subjects train about 15–20 h per week. The training consists of endurance training and high intensity training (in cycling, running and roller skating), skate jumps, duck walking and weight training. Some anthropometric measures are presented in Table 1. The subjects were completely familiar with the test protocol since they had been tested four times per year over the previous three years. From the tests in the season 1985/1986 the October 1985 test was choosen for the present comparison since this test was directly after summer training and prior to ice training. The test results of October 1985 are compared with the test results of June 1985 to get a measure of the reproducibility of the results. In

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Table 1. Mean body weight (BW), body length (BL), lean body mass (LBM) and percentage of fat (% fat) and standard deviations (SD) of both groups

	BW (kg)	BL (m)	% fat	LBM (kg)
Males ($n=6$)	78.1	1.85	11.7	68.9
SD	4.9	0.03	0.8	4.0
Females ($n=6$)	62.5	1.70	22.6	48.3
SD	7.9	0.05	1.5	5.8

both June and October the twelve subjects were tested during two running days; the first subjects in the morning, the last in the afternoon. Males and females were tested alternately to prevent differences in time of day influencing the results. Since the test results are used by their coach as a measure of physical condition, the subjects were highly motivated by their coach to prepare for the test as if it was a competition. Apart from small snacks the subjects had their last meals (breakfast or lunch) more than one hour before the test.

The tests. The tests were performed on an electrically braked bicycle ergometer (Mijnhardt) with constant brake force, allowing the subjects to regulate their power output by regulating pedal frequency. Two supra-maximal tests were performed, one an all out sprint test of 30 s and one an all out 2.5 min test. The power output during the sprint test was meant to yield a measure for anaerobic power. The 2.5 min test was 30 s shorter than the 3 min test used in our previous studies (Ingen Schenau et al. 1983; Ingen Schenau and de Groot 1983a) in order to achieve an exercise which resembles the 1500 m skating distance (the "key" distance in all round speed skating) more closely. During both tests the subjects were informed continuously about their instantaneous power output and about the time which was still to go.

Though the 2.5 or 3 min supra-maximal test is scarcely used in the literature, it has some distinct benefits over longer lasting tests, in particular in evaluating athletes who are accustomed to perform supra-maximal exercises during their normal training and competition. These benefits concern:

a) The possibility for feed back of performance and time: The instantaneous power output is used as a measure to feed back performance, while the time covered expressed as a fraction of the (fixed) 2.5 min corresponds with the distance covered during a (skating-, cycling- or rowing-) race. The test thus resembles an actual race to a large extent.

b) Measures for aerobic and anaerobic power. In many middle distance events of endurance sports, athletes perform at a level higher than 100% $\dot{V}_{O_{2max}}$. In most events it is not possible to calculate the anaerobic contribution, since for example blood lactate measurements do not yield an absolute measure of anaerobic power (e.g. time-, subject- and exercise-dependent). The supra-maximal test provides measures for both the aerobic and anaerobic parts of the power output in one test. Figure 1 shows a typical example of instantaneous power output and oxygen consumption for one of the present subjects during this 2.5 m test. Next to the energy equivalent of the maximal oxygen consumption the ratio of mean power output and this aerobic energy equivalent is used as a measure of the contribution of anaerobic power (Ingen Schenau et al. 1983). The higher this ratio exceeds the value of 20—22% published for the maximal mechanical efficiency for cycling (Åstrand and Rodahl 1977), the higher the anaerobic contribution.

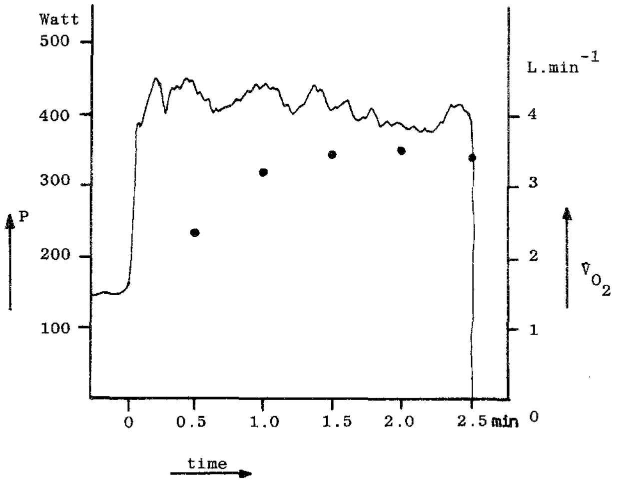

Fig. 1. Power output *(solid line)* and oxygen uptake values *(dots)* during the 2.5 min supra-maximal test. Typical example of one of the females

c) Short lasting test. Including warming up and cooling down, the supra-maximal test is performed within the time span of less than half an hour.

Warming up and cooling down. The sprint test was preceded by a warming up of 10 min cycling at 150 W interrupted by three 30 s bursts of approximately 500 W (Geysel et al. 1984). After this warm up the subjects took 2 min rest and had then to perform the 30 s all out test. After the test the subjects cycled for 5—10 min against a work load of 100—150 W in order to stimulate the break down of muscle and blood lactate. After a rest period of at least 30 min the subjects started the warm up for the 2.5 min test. This warming up consisted of 3 min at 100 W followed by 3 min at 70% of the estimated 100% $\dot{V}_{O_{2max}}$ load (Åstrand and Rodahl 1977; Ingen Schenau and de Groot 1983a; Geysel et al. 1984). There was no rest period between the warm up and the actual 2.5 min test in order to allow a quick levelling off of oxygen consumption during this relatively short lasting test.

According to an overview of Gollnick and Hermansen (1973) and according to Dolan and Sargeant (1983), the cooling down from the sprint test, the rest period of at least 30 min and the 6 min warm up for the second test ensures a regeneration from anaerobic stress from the sprint test at the onset of the 2.5 min test.

The load-setting. In a supra-maximal test where mean and peak power output (maximum in instantaneous power) in a fixed time span is taken as the main test result, the estimation of the initial brake force is crucial. In the past, heart rates during the warming up periods for the 2.5 min test were used to predict the load setting of 120—130% of the $\dot{V}_{O_{2max}}$ load (Ingen Schenau et al. 1983; Ingen Schenau and de Groot, 1983a) using nomograms for males and females, respectively (Åstrand and Rodahl 1977). Most likely due to large differences in maximal heart rates (Hf-max) and to significant shifts in mean Hf-max during the season, this method appeared to lead to substantial under- and overestimations of the load setting. Moreover one can not use such nomograms to estimate the brake force for the sprint test. In the past six years the present authors have used the supra-maximal test in different experiments with a total of 90—100 well trained cyclists and

Table 2. Mean peak power (P_p) and average power ($\bar{P}$) during the 30 s sprint test as well as the power values expressed per kg body weight (BW) and lean body weight (LBM)

	P_P (Watt)	$\bar{P}$ (Watt)	P_P/BW (Watt·kg^{-1})	$\bar{P}$/BW (Watt·kg^{-1})	P_P/LBM (Watt·kg^{-1})	$\bar{P}$/LBM (Watt·kg^{-1})
Males ($n=6$)	1348	1103	17.3	14.2	19.58	16.01
SD	138	93	1.7	1.0	1.98	1.14
Females ($n=6$)	927	769	14.8	12.3	19.13	15.87
SD	140	109	0.8	0.4	1.26	0.83
Difference (%)	31[a]	30[a]	14.4[a]	13.4[a]	2.3	0.9

Differences are expressed relative to the value of the males.
[a] Significant differences are denoted

speed skaters of different performance levels. From these experiences it appeared that a much more reliable estimate is obtained when a certain work level of Watts per kg body weight or kg lean body weight (LBM) is used. For well trained skaters and cyclists a value of 12 and 14 W · kg BW^{-1} can be used for the sprint test for females and males respectively. For the 2.5 min test 6 and 7 W · kg BW^{-1} were used for the females and the males as estimates for the initial load. The brake force settings were calculated on the basis of these loads and with a pedal frequency of 100 rpm for the sprint test and 90 rpm for the 2.5 min test. Small adjustments to these general rules were performed on the basis of heart rates during warming up and on the basis of previous test results. As a result of this methodology the actual pedal frequencies varied between 90 and 110 rpm.

Calculations and measurements. The percentages of fat were calculated from four skinfold measurements (Durnin and Rahaman 1967). Oxygen consumption during the 2.5 min test was measured each 30 s with help of an Oxycon 4 (Mijnhardt) gas analyser. The gas analyser was calibrated prior to each test.

From the instantaneous power output during the sprint test the maximal value which was reached within 5—7 s from the start was taken as peak power value. For both tests the mean power output was calculated by integration.

Differences between the males and females were tested for significance using *t* statistics. The June tests were compared with the October tests by a simple calculation of the correlation coefficient.

For all statistics a significance level of $p < 0.05$ (two tailed) was taken.

Results

The results of the sprint tests are summarised in Table 2. The males differ from the females in absolute power values. These differences are still significant if the power output values are taken relative to total body weight. Expressed per kilogram lean body weight however, the males are no longer superior to the females. Table 3 shows the results of the 2.5 min test. These results show the same type of differences between the male and female skaters: significant differences in absolute values, in values expressed per kilogram body weight but no differences when differences in both body weight and fat are taken into account.

The maximal oxygen uptake values (Table 3) of both groups are in good agreement with the values published previously for elite senior skaters (Ingen Schenau et al. 1983; Ingen Schenau and de Groot 1983a).

In contrast to previously published results, however, the females in the present study show no higher power output per kg LBM and no higher ratios between power output and oxygen consumption than the males.

Table 3. Mean absolute and relative values of power and oxygen consumption measured during the 2.5 min supra-maximal test. Hf is the maximal heart frequency and R is the ratio between power and the energy equivalent of oxygen consumption. RQ is the respiratory quotient

	P (Watt)	P/BW (Watt·kg^{-1})	P/LBM (Watt·kg^{-1})	$\dot{V}_{O_2}$ (l·min^{-1})	$\dot{V}_{O_2}$/BW (ml·min^{-1}·kg^{-1})	$\dot{V}_{O_2}$/LBM (ml·min^{-1}·kg^{-1})	Hf (s^{-1})	R (%)	RQ
Males ($n=6$)	570	7.3	8.29	5.10	65.5	74.1	188	31.75	1.30
SD	32	0.5	0.66	0.30	4.5	5.4	3	1.32	0.08
Females ($n=6$)	391	6.3	8.11	3.50	56.1	72.4	197	32.05	1.27
SD	39	0.3	0.66	0.46	2.1	2.4	9	2.44	0.07
Difference (%)	31[a]	13.7[a]	2.2	31.[a]	14.3[a]	2.3	−4.7	−0.9	2.3

[a] See Table 1 and 2 for further explanations

When comparing the mean power output of the June test with the mean power output during the October test, the sprint test results show a correlation coefficient of $r=0.97$ and the 2.5 min test results a coefficient of $r=0.98$, showing that apart from shifts in the mean power output of the total group, the results appear to be highly reproducible.

Discussion

The results of this study show that male and female athletes who have the same training background do not show a difference in power output and in oxygen uptake when these values are taken relative to lean body mass. Therefore it seems likely that the origin of differences in absolute performance in these tests is entirely due to a difference in the total amount of skeletal muscle mass. It was stated before that a difference in absolute power output does not necessarily lead to a difference in speed in endurance sports. Large cyclists or skaters with much muscle mass will experience more friction than their smaller collegues. A previous study has shown that the performance in speed skating is entirely dependent on the power per kilogram of body weight which the skater can apply in overcoming air- and ice friction (Ingen Schenau and de Groot 1983b). So the results of the present study seem to affirm our previous suggestion that differences in performance level between males and females in speed skating are due to a difference in percentage of fat only (Ingen Schenau and de Groot 1983a and b). The same might be true for cycling.

The present test results, however, do not affirm that females can deliver more power per kg LBM than the males. This deviation of the previous results is most likely due to methodological factors. As stated before, the estimation of the initial load setting is crucial in supra-maximal tests. Though both the males and the females in our previous study were tested using the same methodology, it seems likely that the elite males were systematically underestimated with respect to the estimation of the initial load. Three out of the five males in that study were tested only once, while in the estimation of the initial load of the females the experimentors and the subjects know the results of previous tests. From our later experiences we learned that it is difficult for subjects to optimise their mean power output during the 2.5 min test when they are tested for the first time. They need at least one test to learn to distribute the power output during the 2.5 min. Knowing these methodological aspects, the supra-maximal tests can have distinct benefits over longer lasting tests as indicated in the methods section. For experienced cyclists and skaters one can even use one value for both males and females for the estimation of initial load settings. When expressed per kilogram lean body weight both sexes appear to be able to deliver approximately 19 W · kg LBM^{-1} at 100 rpm in the sprint test and 8 W · kg LBM^{-1} in the 2.5 min test.

Though these values are also found in other groups of well trained skaters and cyclists, we recommend the assessment of such values for each other group of subjects before using supra-maximal tests in the evaluation of the physical condition of athletes.

References

Åstrand PO, Rodahl K (1977) Textbook of work physiology. McGraw-Hill, New York

Dill DB, Muhre LG, Greer SM, Richardson JC, Singleton KJ (1972) Body composition and aerobic capacity of youth of both sexes. Med Sci Sports 4:198—204

Dolan P, Sargeant AJ (1983) Effect of prior exercise on maximal short-term power output of human muscle. J Physiol 343:107—108

Durnin JVGA, Rahaman MM (1967) The assessment of the amount of fat in the human body from measurement of skinfold thickness. Br J Nutr 21:681—689

Geysel J, Bomhoff G, van Velsen J, de Groot G, van Ingen Schenau GJ (1984) Bicycling ergometry and speed skating performance. Int J Sports Med 5:241—245

Gollnick PD, Hermansen L (1973) Biochemical adaptions to exercise: anaerobic metabolism In: Wilmore JH (ed) Exercise and sport science Rev, vol. no. 1. Academic Press, New York, pp 1—45

Ingen Schenau GJ van, de Groot G, Hollander AP (1983) Some technical, anthropometrical and physiological aspects of speed skating. Eur J Appl Physiol 50:343—354

Ingen Schenau GJ van, de Groot G (1983a) Differences in oxygen consumption and external power between male and female skaters during supra-maximal cycling. Eur J Appl Physiol 51:337—345

Ingen Schenau GJ van, de Groot G (1983b) On the origin of differences in performance level between elite male and female speed skaters. Human Mov Sci 2:151—159

Neumann G von, Buhl H (1981) Biologische Leistungsvoraussetzungen und Trainingsphysiologische Aspekte bei trainierenden Frauen. Med Sport 21:154—160

Sparling PB (1980) A meta-analysis of studies comparing maximal oxygen uptake in men and women. Res Q 51:542—552

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