Does Power Indicate Capacity? 30-s Wingate Anaerobic Test vs. Maximal Accumulated O_2 Deficit

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Key words
- anaerobic performance
- anaerobic power
- anaerobic capacity
- maximal accumulated oxygen deficit
- supramaximal exercise
- sprint cycling

Abstract

The purpose of this study was to evaluate the relationship between anaerobic power and capacity. Seven men and seven women performed a 30-s Wingate Anaerobic Test on a cycle ergometer to determine peak power, mean power, and the fatigue index. Subjects also cycled at a work rate predicted to elicit 120% of peak oxygen uptake to exhaustion to determine the maximal accumulated O_2 deficit. Peak power and the maximal accumulated O_2 deficit were significantly correlated ($r = 0.782$, $p = 0.001$). However, when the absolute difference in exercise values between groups (men and women) was held constant using a partial correlation, the relationship diminished ($r = 0.531$, $p = 0.062$). In contrast, we observed a significant correlation between fatigue index and the maximal accumulated O_2 deficit when controlling for gender ($r = -0.597$, $p = 0.024$) and the relationship remained significant when values were expressed relative to active muscle mass. A higher anaerobic power does not indicate a greater anaerobic capacity. Furthermore, we suggest that the ability to maintain power output during a 30-s cycle sprint is related to anaerobic capacity.

Introduction

The 30-s Wingate Anaerobic Test (WAnT) is frequently applied with accuracy and reliability to compare anaerobic power (maximal rate of anaerobic ATP production) between genders [9, 28], generations [12], athletes [8,25], and various clinical populations [2,21]. In addition, the WAnT has been used to validate several other measures of anaerobic performance including; critical power tests [3], the Katch test [16], isokinetic tests [1], and 300-m running tests [25]. Nevertheless, there has been substantial criticism regarding the use of the WAnT for the measurement of anaerobic capacity (maximal amount of ATP produced anaerobically). Not only is the work duration too short to exhaust anaerobic energy sources [9,18], a significant percentage (9–40%) of the energy provided in the WAnT is aerobically derived and is not accounted for when quantifying anaerobic capacity as the total work performed [13,14,26].

Medbø et al. [17,18,20] described the determination of the maximal accumulated oxygen (AO_2) deficit as a valid measure of anaerobic capacity. During submaximal work rates performed below the anaerobic threshold, the steady-state oxygen uptake ($\dot{V}O_2$) reflects the total rate of energy released during exercise. Thus, for supramaximal exercise (performed at a work rate greater than that achieved at peak $\dot{V}O_2$ [$\dot{V}O_{2peak}$]), the rate of energy release or oxygen demand can be estimated by extrapolating the linear relationship between work rate and the steady-state $\dot{V}O_2$ value recorded during several [4–10] submaximal exercise bouts ($\dot{V}O_2$-work rate relationship). The AO_2 deficit for a supramaximal exercise bout performed at a constant work rate (MAOD test) is determined by subtracting the measured $\dot{V}O_2$ from the estimated oxygen demand [17]. The AO_2 deficit then represents energy that is derived anaerobically from intramuscular phosphagens, as well as energy derived via anaerobic glycolysis. Medbø and colleagues [17,18,20] demonstrated that the intensity of the supramaximal exercise bout must be such that the exercise duration is at least 2 min in order to achieve a maximal AO_2 deficit.

Although, the WAnT might not be a valid measure of anaerobic capacity, it is possible that the WAnT and maximal AO_2 deficit are associated. Medbø and Burgers [19] concluded that anaero-

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bic power and capacity are highly related, suggesting that there may be a common factor limiting the maximal amount of anaerobic energy and its peak rate of release. These conclusions were based on the observation of a similar increase in the maximal AO_2 deficit over a 6-wk training program between individuals participating in a sprint-training program (20-s "all-out" efforts) designed to stress the peak rate of anaerobic energy release, and individuals participating in an interval-training program (3 – 3.5-min efforts to exhaustion) designed to exhaust the capacity of the anaerobic energy systems. Therefore, it might be reasonable to suggest that an individual with an increased ability to rapidly produce ATP anaerobically also possesses a large anaerobic capacity. Indeed, Scott et al. [25] compared anaerobic capacity and power by measuring the maximal AO_2 deficit during 2 – 3 min of exhaustive treadmill running and $WAnT_{PP}$ for cycling in male track runners. A significant ($r = 0.69$, $p < 0.05$) correlation was found between the maximal AO_2 deficit and $WAnT_{PP}$ expressed relative to body mass. However, this result is not surprising given the wide range of athletes included in the correlational analysis; those athletes with a very high ability for anaerobic energy release (sprinters) and athletes with a reduced ability to produce energy anaerobically (distance runners [19]). Moreover, there was no attempt to scale these data for active muscle mass even though sprinters were about 4.5 and 7.5 kg heavier than middle-distance and distance runners, respectively. There is further uncertainty regarding the relationship between anaerobic power and capacity in the study by Scott et al. [25] due to the inclusion of both treadmill (MAOD test) and cycle exercise (WAnT).

There is no real evidence to suggest a strong relationship between the maximal rate of anaerobic energy release (anaerobic power) and the maximal amount of anaerobic energy released (anaerobic capacity). Furthermore, Saltin [24] hypothesized that anaerobic power and anaerobic capacity are two different entities. Information about the relationship between anaerobic power and capacity may be important not only to exercise scientists, but also to coaches, middle-distance athletes and team sport players for the prescription of training programs and the priorities placed on relevant energy systems. The current literature indicates that the WAnT and the determination of the maximal AO_2 deficit are "gold standards" in the measurement of anaerobic power and anaerobic capacity, respectively. The study by Scott et al. [25] is the only previous study that has compared the WAnT and the maximal AO_2 deficit. The purpose of the present study was to evaluate the relationships between the maximal AO_2 deficit values for cycling and three indices of the WAnT (peak power, mean power, fatigue index) when values are expressed in absolute terms and relative to body composition.

Methods

Subjects

Seven male and seven female adults volunteered to participate in the present study. Volunteers were considered recreationally active, but none were involved in any specific exercise-training program. **Table 1** presents the physical characteristics and peak exercise values for incremental cycling determined in both male and female subjects. Following familiarization with all testing equipment and experimental procedures, written informed consent was obtained from each subject. The Griffith University Ethics Committee for Human Experimentation approved the test procedures used in this study. All female subjects had regular menstrual cycles and performed all experimental exercise tests (WAnT and MAOD test) during the early follicular phase of their menstrual cycle. It has been demonstrated previously that the peak power output obtained during sprint cycling may be lower during the luteal phase compared with the follicular phase [22].

Table 1 Physical characteristics and peak exercise values for incremental cycling determined in adult male and female subjects

	Men (n = 7)	Women (n = 7)	Group (n = 14)
Age (yr)	24 ± 4	23 ± 7	23 ± 6
Height (cm)*	177 ± 5	169 ± 5	173 ± 6
Body mass (kg)*	80.8 ± 6.2	64.3 ± 4.3	72.6 ± 10.0
LBM (kg)*	59.5 ± 4.7	44.5 ± 4.4	52.0 ± 9.0
AMM (kg)*	29.6 ± 3.0	23.6 ± 1.0	26.6 ± 3.8
Peak work rate (W)*	379 ± 51	269 ± 35	324 ± 71
Peak HR (beat · min^{-1})	192 ± 7	193 ± 6	192 ± 7
$\dot{V}O_{2peak}$ (L · min^{-1})*	3.58 ± 0.50	2.55 ± 0.30	3.07 ± 0.66
$\dot{V}O_{2peak}$ (mL · kg^{-1} · min^{-1})	44.4 ± 6.4	39.6 ± 2.5	42.0 ± 5.3

Values presented are means ± SD. $\dot{V}O_{2peak}$ = peak oxygen uptake for cycling; LBM = the estimated whole body muscle mass; AMM = the estimated active muscle mass for cycling. LBM and AMM do not include fat mass or bone mineral content. HR = heart rate; * Men significantly different compared to women; $p < 0.05$

Experimental protocol

In the week preceding experimental testing, participants were familiarized to the exercise equipment and protocols. Their lean body mass (LBM) and active muscle mass (AMM) were measured using dual-energy X-ray absoptiometry (DXA). During the first two testing sessions, subjects performed six submaximal cycling tests to determine their $\dot{V}O_2$-work rate relationship and an incremental cycling test to exhaustion to determine their $\dot{V}O_{2peak}$. After testing during the second session, subjects were asked to perform a practice WAnT. Subjects were asked to return the next day to complete a practice supramaximal cycling test performed at the predetermined constant work rate of 120% of $\dot{V}O_{2peak}$. At least 3 d later, subjects were required to perform either the WAnT or the MAOD test, the order of which was randomized by flipping a coin. Subjects were then asked to return to the laboratory 48 h later to perform the remaining test. Four men and three women performed the WAnT on the first occasion.

Determination of lean body mass and the active muscle mass for cycling

Body composition was assessed using DXA (model XR36, Norland, Fort Atkinson, WI, USA; CV < 1.0%). An appropriately trained and certified technician (Australian Sonographer Accreditation Registry) operated the DXA machine. Whole-body values were presented as total mass (kg) and separately for lean body mass (LBM; kg). Regional measurements (legs, gluteals) were determined based on bony landmarks via manual analysis. The total lean mass for both legs and the gluteal muscle group was measured and reported as the AMM for cycling. The gluteal muscle mass has been shown to be one of the major muscle groups involved in cycling [23] and has been largely ignored when traditional methods of determining the AMM are used [29]. AMM is reported independently of fat mass and bone mineral content.

Determination of peak oxygen uptake

Peak $\dot{V}O_2$ for cycling was measured using a continuous ramp protocol conducted on a Lode electronically braked cycle ergometer (Excalibur Sport V2.0, Groningen, The Netherlands). Pedal rate was maintained at 70 rev · min^{-1} and the work rate was increased by 20 W · min^{-1} for women and by 25 W · min^{-1} for men until exhaustion. Heart rate (HR) was monitored continuously during exercise using an electrocardiograph (Lohmeier M 607, Munich, Germany) and $\dot{V}O_2$ was measured breath-by-breath (MedGraphics® Cardiorespiratory Diagnostic Systems, St. Paul, MN, USA) and averaged over 30-s intervals. The two highest consecutive 30-s values for $\dot{V}O_2$ were averaged and reported as the $\dot{V}O_{2peak}$ for cycling.

Submaximal exercise bouts

Steady-state $\dot{V}O_2$ was measured at six submaximal work rates between 20 and 75% of $\dot{V}O_{2peak}$. Subjects cycled at 70 rev · min^{-1} for 10 min and the $\dot{V}O_2$ values measured at 9 and 10 min were averaged and reported as the steady-state $\dot{V}O_2$ for the corresponding work rate. Data collected from the six submaximal bouts were used to establish the $\dot{V}O_2$-work rate relationship for cycling. The linear regression of the $\dot{V}O_2$-work rate relationship was used to calculate the work rate that corresponded to 120% of $\dot{V}O_{2peak}$. This work rate was then used in the MAOD test. It is accepted that some error might be present when predicting the AO_2 demand of supramaximal work rates from the $\dot{V}O_2$-work rate relationship due to the nonlinear characteristics previously observed in work rates performed above the anaerobic threshold.

30-s Wingate Anaerobic Test (WAnT) for leg cycling

Participants warmed up for the WAnT by cycling at 70 rev · min^{-1} for 5 min at 50 W for men and 35 W for women. During the warm-up period, participants were asked to perform three, "all-out", 5-s sprints on the command of the chief investigator. Following the warm-up, subjects dismounted the cycle ergometer and rested quietly for 10 min. Subjects were then asked to sit quietly on the cycle for 5 min. Participants were then directed by the chief investigator to begin unloaded pedaling 10 s before the commencement of the test. Again, on the command of the chief investigator, the participant was instructed to accelerate maximally against no load. The predetermined resistance was then applied after 3 s of maximal acceleration. The resistance applied for men was 0.931 N · kg^{-1} compared to 0.833 N · kg^{-1} for women. Participants were instructed to remain seated throughout the duration of the test and were given strong verbal encouragement to maintain an all-out effort. The pedal-revolution count began the instant the resistance was applied. A microswitch triggered by an infrared beam on the pedal cogwheel and recorded into a computer processor signaled pedal revolutions. Revolutions were recorded for each 5-s period during the test. $WAnT_{PP}$ was the highest work rate produced in a 5-s segment of the test, whereas mean power ($WAnT_{MP}$) was calculated as the average work rate during the test duration. It is acknowledged that, given the low sample frequency (i.e., 6 × 5-s work rate values), the $WAnT_{PP}$ value may be less than a $WAnT_{PP}$ value obtained instantaneously. We can not accurately predict how this may affect correlations between $WAnT_{PP}$ and maximal AO_2 deficit. $WAnT_{PP}$ and $WAnT_{MP}$ were expressed in absolute terms (W), and relative to body mass (W · kg^{-1}), LBM (W · kg · LBM^{-1}) and AMM (W · kg · AMM^{-1}). The fatigue index ($WAnT_{FI\%}$) was calculated as the absolute difference between the highest and the lowest work rate expressed as a percent of the highest work rate. The duration of the WAnT was 30 s, but subjects continued to pedal at 70 rev · min^{-1} against no load for 5 min after the test to prevent venous pooling. HR was monitored continuously throughout the exercise bout.

The supramaximal cycling test performed at 120% of $\dot{V}O_{2peak}$ (MAOD test)

Subjects warmed up by cycling for 5 min at 50 W for males and at 35 W for females. Subjects were then asked to rest quietly on the cycle ergometer for 5 min. Following 2 min of unloaded cycling at 70 rev · min^{-1}, the predetermined work rate of 120% of $\dot{V}O_{2peak}$ was applied immediately. HR was monitored continuously while $\dot{V}O_2$ was measured breath-by-breath throughout the exercise bout. Subjects were required to maintain pedal cadence at 70 rev · min^{-1} throughout the MAOD test and the test was terminated when the subject could no longer maintain a pedal cadence of 60 rev · min^{-1} despite verbal encouragement. The AO_2 deficit was calculated as the difference between the AO_2 demand and the AO_2 uptake measured during the MAOD test [17]. The AO_2 deficit calculated for the MAOD test was reported as the "maximal AO_2 deficit" for cycling. Weber and Schneider [27] have demonstrated that this method of determining the maximal AO_2 deficit for cycling is highly repeatable in untrained male and female subjects (intra-class correlation coefficients of 0.983 for time to exhaustion and 0.968 for maximal AO_2 deficit values).

Statistical analyses

Pearson's product moment and partial correlation were used to determine the strength and direction of the relationships among physical characteristics and/or exercise variables. Partial correlations were used to control for effect of gender on absolute differences in exercise test values between male and female groups. For example, the partial correlation of $WAnT_{PP}$ and maximal AO_2 deficit adjusted for gender is the correlation between the residuals from regressing $WAnT_{PP}$ on gender and the residuals from regressing maximal AO_2 deficit on gender. Because the data are residuals, they are centered around zero. The values, then, are not similar to the original values. If the partial correlation approaches 0, the inference is that the original correlation is spurious; that is, there is no direct causal link between the two original variables (e.g., $WAnT_{PP}$ and maximal AO_2 deficit) because the control variable (e.g., gender) is either a common anteceding cause, or an intervening variable. It is not the purpose of this study to compare the strength and direction of the relationships among physical characteristics and/or exercise variables between men and women. An alpha level of 0.05 was used for all statistical tests.

Results

▼

When the relationships between the maximal AO_2 deficit values and indices of the WAnT ($WAnT_{PP}$, $WAnT_{MP}$, $WAnT_{FI\%}$) were considered separately for gender, all correlation values were of similar strength and direction for men and for women (e.g., ▶ **Fig. 1 A**). Therefore, it can be assumed that the relationships described between the maximal AO_2 deficit and indices of the WAnT are independent of gender. However, we controlled for gender when calculating correlation coefficients for the whole group (n = 14) to eliminate the variation in absolute exercise val-

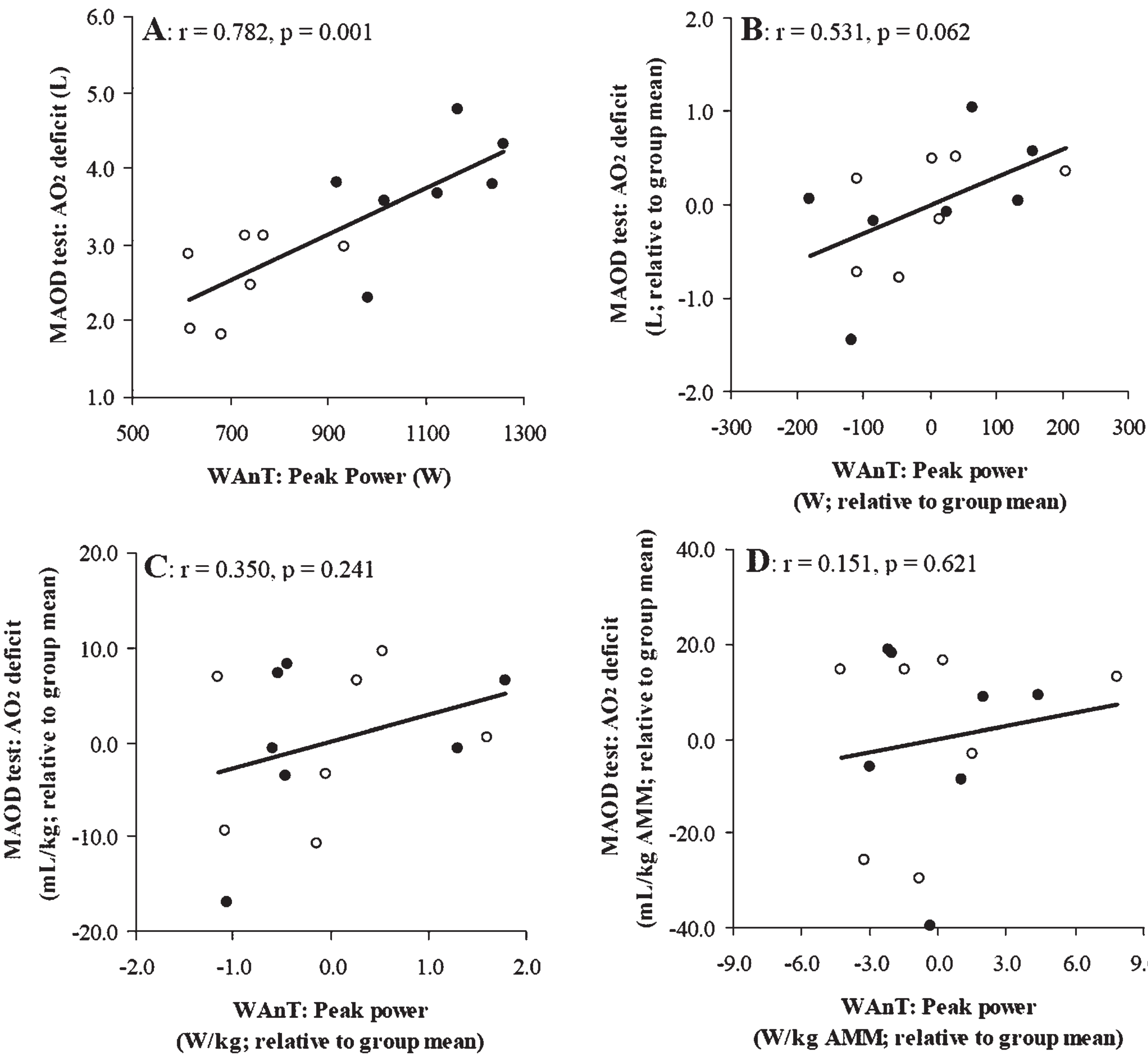

Fig. 1 A to **D** Relationship between peak power, determined in men (closed circles) and women (open circles) during a 30-s Wingate Anaerobic Test ($WAnT_{PP}$), and the maximal accumulated oxygen (AO_2) deficit, determined during supramaximal cycling at 120% of peak oxygen uptake (MAOD test). **A** Absolute values for $WAnT_{PP}$ and maximal AO_2 deficit. **B** Absolute values for $WAnT_{PP}$ and maximal AO_2 deficit with the effect of gender held constant. **C** $WAnT_{PP}$ and maximal AO_2 deficit values relative to body mass (BM) with the effect of gender held constant. **D** $WAnT_{PP}$ and maximal AO_2 deficit values relative to active muscle mass (AMM) for cycling with the effect of gender held constant. Controlling for the effect of gender is achieved by expressing the absolute values (e.g., MAOD test: AO_2 deficit) relative to group mean, i.e., plot the residuals of the variable after considering the effect of gender.

ues (e.g., maximal AO_2 deficit, $WAnT_{PP}$) between gender groups and avoid presenting an artificially high correlation coefficient. **Table 2** presents the peak exercise values obtained during the 30-s Wingate Anaerobic Test and during the 2–3-min constant-work rate (120% of $\dot{V}O_{2peak}$) cycling test to exhaustion (MAOD test) in male and female subjects.

Correlations among subject characteristics and exercise variables

With the effect of gender controlled, correlation coefficients determined between $WAnT_{PP}$ and the three measures of body composition (BM, LBM, AMM) were all significant ($r \geq 0.703$, $p < 0.05$). There was a similar model for $WAnT_{MP}$ where a significant relationship was determined between $WAnT_{MP}$ and all measures of body composition ($r \geq 0.620$, $p < 0.05$). In contrast, the AMM for cycling was the only physical characteristic that was significantly correlated with the maximal AO_2 deficit ($r = 0.699$, $p = 0.008$). Therefore, when examining relationships between maximal AO_2 deficit and indices of the WAnT, normalization using body composition was applied.

Correlations among WAnT and MAOD test variables

A Pearson's correlation determined that $WAnT_{PP}$ (W) and the maximal AO_2 deficit (L) were significantly correlated (A: $n = 14$, $r = 0.782$, $p = 0.001$). However, when gender was held constant (partial correlation), this relationship diminished (B: $r = 0.531$, $p = 0.062$). Further analyses of this correlation when gender was held constant and values were expressed relative to BM (C:

Table 2 Peak exercise values obtained during a 30-s Wingate Anaerobic Test and during a 2–3-min constant-work rate (120% of $\dot{V}O_{2peak}$) cycling test to exhaustion (MAOD test) in untrained men and women

	Men (n = 7)	Women (n = 7)	Group (n = 14)
Wingate Anaerobic Test			
Peak HR (beat·min^{-1})	186 ± 7	184 ± 6	185 ± 5
Peak power (W)	1 100 ± 130	728 ± 108	914 ± 225
▸ (W·kg^{-1})*	13.6 ± 1.1	11.3 ± 1.0	12.4 ± 1.6
▸ (W·kg·LBM^{-1})*	18.5 ± 1.5	16.3 ± 1.0	17.4 ± 1.7
▸ (W·kg·AMM^{-1})*	37.1 ± 2.7	30.8 ± 4.0	34.0 ± 4.6
Mean power (W)	770 ± 81	519 ± 120	645 ± 163
▸ (W·kg^{-1})*	9.5 ± 0.8	8.0 ± 1.3	8.8 ± 1.3
▸ (W·kg·LBM^{-1})*	12.9 ± 0.8	11.6 ± 1.5	12.2 ± 1.4
▸ (W·kg·AMM^{-1})*	26.0 ± 1.4	22.0 ± 4.6	24.0 ± 3.9
Fatigue index (%)	51.7 ± 5.6	53.4 ± 9.1	52.6 ± 7.3
MAOD test			
Peak HR (beat·min^{-1})	187 ± 7	188 ± 7	187 ± 7
Work rate (W)	376 ± 56	263 ± 34	320 ± 74
Time to exhaustion (s)	175 ± 43	167 ± 38	171 ± 40
AO_2 demand (L)*	12.50 ± 3.35	8.49 ± 2.05	10.5 ± 3.4
AO_2 uptake (L)*	8.75 ± 2.61	5.88 ± 1.68	7.31 ± 2.58
AO_2 deficit (L)*	3.75 ± 0.77	2.61 ± 0.56	3.18 ± 0.87
AO_2 uptake: AO_2 deficit (%)	70:30	69:31	70:30
AO_2 deficit (L·kg^{-1})	46.4 ± 8.8	40.5 ± 8.1	43.4 ± 8.7
AO_2 deficit (L·kg·LBM^{-1})	62.8 ± 11.3	58.7 ± 12.1	60.8 ± 11.4
AO_2 deficit (L·kg·AMM^{-1})	126.1 ± 20.5	110.1 ± 20.0	118.1 ± 21.1

Values presented are means ± SD. HR = heart rate; AO_2 = accumulated oxygen; AO_2 uptake: AO_2 deficit (%) = the percent contribution of the aerobic (AO_2 uptake) and anaerobic (AO_2 deficit) energy systems to the total energy demand (AO_2 demand); LBM = whole body muscle mass; AMM = active muscle mass for cycling; * Men significantly different compared to women; $p < 0.05$

$r = 0.350$, $p = 0.241$), LBM ($r = 0.259$, $p = 0.393$), and the AMM (D: $r = 0.151$, $p = 0.621$) indicated a progressive weakening of the relationship between $WAnT_{PP}$ and the maximal AO_2 deficit. ▶ **Fig. 1** shows the significant relationship between $WAnT_{PP}$ and the maximal AO_2 deficit expressed in absolute terms (A) and in contrast, the random scattering of points when the effect of gender is held constant (B) and when values are expressed relative to BM (C) and the AMM (D) for cycling in men and women.

$WAnT_{MP}$ and the maximal AO_2 deficit were significantly correlated ($n = 14$, $r = 0.829$, $p < 0.001$), and the relationship, while substantially weaker, remained significant when the effect of gender was held constant ($r = 0.649$, $p = 0.012$). Nevertheless, when values were expressed relative to BM ($r = 0.530$, $p = 0.051$), LBM ($r = 0.480$, $p = 0.083$), or the AMM ($r = 0.425$, $p = 0.130$), the relationship between $WAnT_{MP}$ and the maximal AO_2 deficit was not significant.

▶ **Fig. 2A** illustrates a significant correlation ($r = -0.597$, $p = 0.024$) between $WAnT_{FI\%}$ and the maximal AO_2 deficit (controlled for gender). Furthermore, the relationship remains significant when maximal AO_2 deficit values were expressed relative to the AMM for cycling ($r = -0.712$, $p = 0.006$). In addition, $WAnT_{FI\%}$ was negatively related to $WAnT_{MP}$ when $WAnT_{MP}$ values were controlled for gender and expressed in absolute terms (▶ **Fig. 2B**) and normalized for BM, LBM and AMM ($r \leq -0.643$, $p < 0.05$), whereas the relationship between $WAnT_{FI\%}$ and $WAnT_{PP}$ (controlled for gender) was not significant ($r = -0.328$, $p = 0.253$), and this was consistent regardless of how $WAnT_{PP}$ was normalized (e.g., BM, LBM, AMM). We also determined that $WAnT_{FI\%}$ was not correlated to any indices of aerobic power such as; i) the AO_2 uptake measured during the MAOD test (controlled for gender; ▶ **Fig. 2C**; $r = -0.439$, $p = 0.134$), or ii) $\dot{V}O_{2peak}$ (controlled for gender; ▶ **Fig. 2D**) expressed in absolute terms and all levels of body composition ($-0.344 \leq r \leq 0$, $p > 0.05$).

Discussion

Peak power measured during the 30-s Wingate Anaerobic Test ($WAnT_{PP}$) has been previously used to indicate the peak rate of anaerobic energy release (anaerobic power) during cycling [13, 25]. In addition, the maximal AO_2 deficit measured during exhaustive supramaximal exercise (> 2 min) has been used to determine the maximal amount of anaerobic energy released (anaerobic capacity [17,27]). The present study demonstrated that there is no significant relationship between $WAnT_{PP}$ and the maximal AO_2 deficit. This suggests that there may be separate, or several factors limiting the total amount of anaerobic energy and the peak rate of anaerobic energy release.

Our finding is in contrast to the results presented by Scott et al. [25] that demonstrated a significant correlation between $WAnT_{PP}$ and the AO_2 deficit among male distance runners, middle-distance runners, and sprinters. Scott et al. [25] suggested that significant correlations found between tests of anaerobic power and capacity indicate commonalities in the ability of an individual to produce a high rate, and a high total amount of anaerobic energy. Scott et al. [25] demonstrated a weak ($r^2 = 0.48$), but significant relationship between the AO_2 deficit measured during running, and peak power determined during a 30-s WAnT for cycling. At best, this result indicates that male sprinters with a relatively higher anaerobic capacity for running will also perform better than their distance counterparts on an unfamiliar task of anaerobic power. Scott et al. [25] also proposed that stronger correlations between tests of anaerobic performance may be evident if the motor skill task of the two tests were similar. The present study examined correlations between tests of anaerobic performance where the motor skill task (cycling) was the same, and in individuals' possessing limited, yet similar physical training backgrounds. In contrast to the findings of Scott et al. [25], anaerobic power for cycling measured during the WAnT, and anaerobic capacity measured using the maximal AO_2 deficit, were not related in the present study.

Medbø and Burgers [19] employed two subject groups to perform a 6-wk training program involving either eight, 20-s sprints per session or three, 2-min runs per session. The two programs were assumed to increase the peak rate of anaerobic energy release or increase anaerobic capacity, respectively. In accordance with the findings of Scott et al. [25], Medbø and Burgers [19] concluded that the amount of anaerobic energy release (anaerobic capacity) and its peak rate (anaerobic power) are closely related. However, the peak rate of anaerobic energy release was determined by measuring the AO_2 deficit during a constant work rate run of "approximately 30 s". Therefore, it is reasonable to suggest that a mean rate of anaerobic energy release over a 30-s period was determined rather than a peak rate. It is well-established that peak power is achieved within 0–5 s of an all-out effort and that this power output can not be sustained for 30 s [13].

The inclusion of several groups of subjects (e.g., sprinters, middle-distance runners and distance runners) with large variations in their ability to produce energy anaerobically might produce artificially high linear correlation coefficients. A reanalysis separating sprinters from distance runners might illustrate nonsignif-

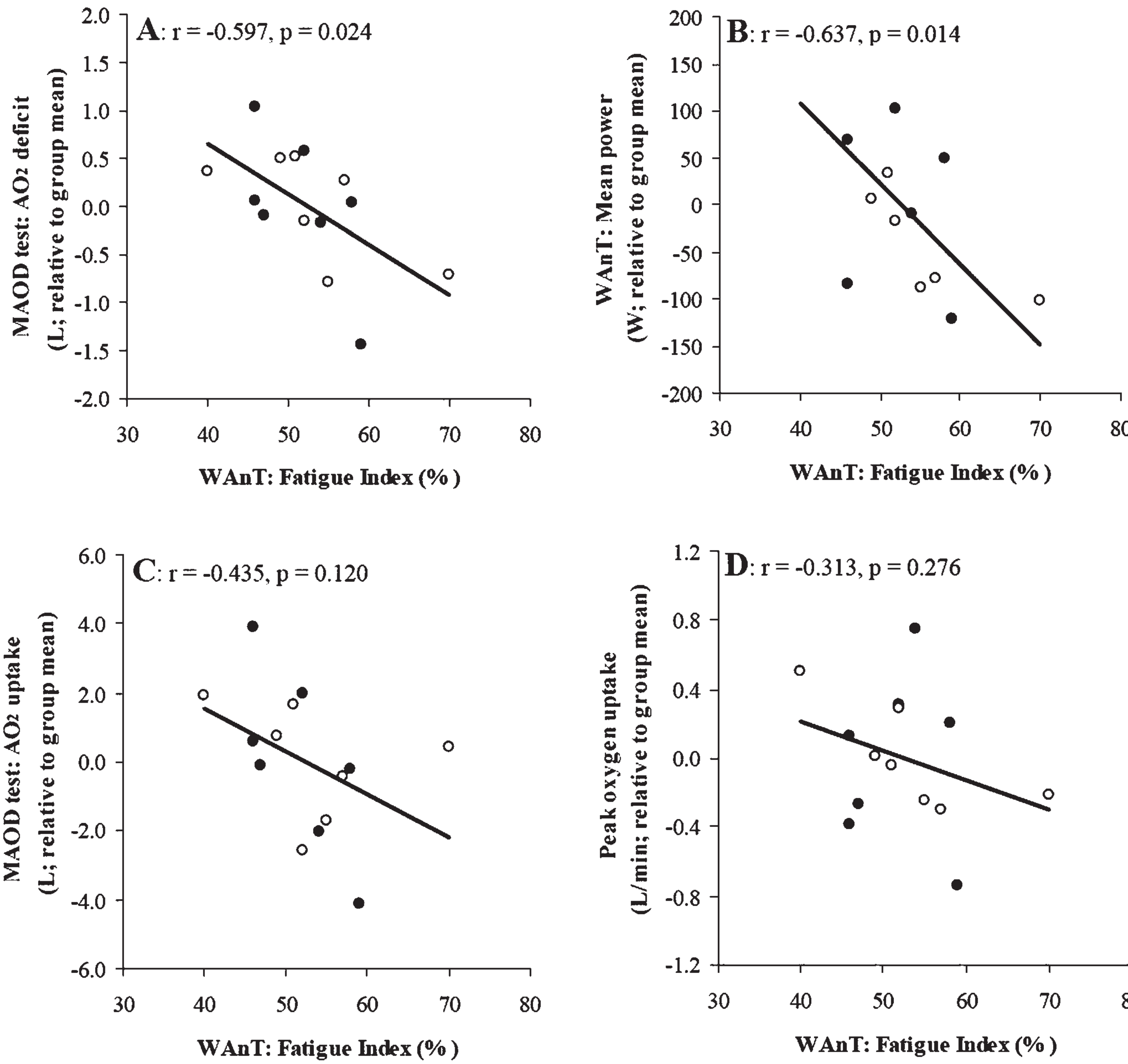

Fig. 2 A to **D** Relationship between the relative decline in power over the duration of a 30-s Wingate Anaerobic Test (fatigue index; $WAnT_{FI\%}$) and, **A** maximal accumulated oxygen (AO_2) deficit determined during supramaximal cycling at 120% of peak oxygen uptake (MAOD test), **B** mean power determined during the 30-s Wingate Anaerobic Test ($WAnT_{MP}$), **C** AO_2 uptake determined during the MAOD test, **D** peak oxygen uptake determined during an incremental cycling test to exhaustion. All dependent variables have been controlled for the group effect of gender (men: closed circles; women: open circles). Controlling for the effect of gender is achieved by expressing the absolute values (e.g., MAOD test: AO_2 deficit) relative to group mean, i.e., plot the residuals of the variable after considering the effect of gender.

icant correlation coefficients; not because the random error increases, but because the variation between the athletic groups is controlled. Although Scott et al. [25] scaled the data by expressing $WAnT_{PP}$ and AO_2 deficit values relative to BM, training status rather than BM is likely to have been more important in accounting for the variability in the regression. In the present study, we reduced variability in three ways by: i) including only recreationally active subjects, thus controlling the effect of training status on anaerobic energy production; ii) using partial correlations to control for the effect of gender on absolute differences in exercise values (e.g., maximal AO_2 deficit, $WAnT_{PP}$); and iii) expressing values relative to BM, LBM or AMM. Consequently, the artificial linear relationship illustrated between $WAnT_{PP}$ and the maximal AO_2 deficit in the present study (**Fig. 1 A**) is diminished when the effect of gender is controlled and when values are expressed relative to BM, LBM, and AMM. A nonsignificant partial correlation coefficient between $WAnT_{PP}$ ($W \cdot kg \cdot AMM^{-1}$) and the maximal AO_2 deficit ($mL \cdot kg \cdot AMM^{-1}$) demonstrated in the present study (**Fig. 1 D**), suggests that mechanisms responsible for a high anaerobic power are different from the mechanisms responsible for a high anaerobic capacity.

The mean power calculated during the 30-s WAnT has been used to reflect the "total anaerobic ATP supply (capacity)" [4,15]. However, this inference has been discredited by several researchers [9,17,24,26] who suggest that the work duration is too short, and that energy provided by the aerobic energy system is not accounted for [13,14,26]. Alternatively, the measurement of the maximal AO_2 deficit has been demonstrated as a valid and reliable measure of anaerobic capacity [20,27]. Although $WAnT_{MP}$ can not be considered as a valid measure of the total amount of energy released anaerobically, it may provide a reliable prediction of anaerobic capacity. The present study found that a significant relationship exists between $WAnT_{MP}$ and the maximal AO_2 deficit even when the effect of group variance (gender) was controlled. However, this finding should be considered with caution as this relationship between $WAnT_{MP}$ and the maximal AO_2 deficit was only steadfast for absolute values of anaerobic capacity. When $WAnT_{MP}$ and the maximal AO_2 deficit values were normalized for BM, LBM, and AMM, the relationship diminished. This suggests that the relationship between absolute values of $WAnT_{MP}$ and maximal AO_2 deficit is highly influenced by a common variable (muscle mass) that interrelates the two measures, rather than the assumption that $WAnT_{MP}$ is determined by similar skeletal muscle qualities as the maximal AO_2 deficit. This finding is potentially important for coaches and exercise physiologists when designing specific exercise training programs. For example, in a sport such as lightweight rowing, where a small body mass is imperative and a large anaerobic capacity is a priority, we can not assume a high anaerobic capacity from more easily determined measures of anaerobic power.

The relative decline in power over 30 s ($WAnT_{FI\%}$) has been previously related to an individuals skeletal muscle fiber type [5,7, 11]. These researchers demonstrated that individuals, who obtained a lower $WAnT_{FI\%}$, also possessed a higher proportion of type I skeletal muscle fibers – perhaps suggesting an increased ability to produce energy aerobically. In contrast, we did not find any relationship between a low $WAnT_{FI\%}$ and the ability to produce energy aerobically in recreationally active adults. Peak aerobic power ($\dot{V}O_{2peak}$), determined during incremental cycling to exhaustion, was not related to the $WAnT_{FI\%}$ in the present study. Furthermore, an improved ability to deliver and utilize O_2 during short-term exhaustive supramaximal exercise would result in an increased contribution from the aerobic energy system and consequently a larger AO_2 uptake. In the present study, $WAnT_{FI\%}$ was not related to AO_2 uptake measured during the MAOD test. The findings of the present study indicate that the ability to maintain power output during 30 s of sprint cycling, is not an indication of increased aerobic power. Since the WAnT is not long enough to allow an individual to reach their peak rate of aerobic energy production (i.e., $\dot{V}O_{2peak}$), the ability to maintain power during the WAnT could be related more closely to the anaerobic energy systems.

Esbjornsson et al. [6] demonstrated that $WAnT_{PP}$ is directly related to anaerobic metabolic properties of skeletal muscle, including a high proportion of type II fibers and a high activity of phosphofructokinase. Earlier studies also revealed that a greater proportion of type II muscle fibers is associated with higher $WAnT_{PP}$ values [5,11], and a greater decline in power during the WAnT ($WAnT_{FI\%}$ [7]). Collectively, these studies suggest that individuals who possess the ability to produce a high rate of energy anaerobically might be unable to sustain power over the 30-s duration of the WAnT (high $WAnT_{FI\%}$ value). However, the results of the present study do not support this notion as there was no significant correlation observed between $WAnT_{PP}$ and $WAnT_{FI\%}$ in the present study. Therefore, the inability to sustain power during a 30-s WAnT (high $WAnT_{FI\%}$ value) is not related to a decreased aerobic power, or an elevated peak power. Conversely, we demonstrated that the ability to sustain power during the WAnT was highly dependent on an individual's anaerobic capacity. The maximal AO_2 deficit was significantly related to $WAnT_{FI\%}$ and this relationship remained strong even when maximal AO_2 deficit values were expressed relative to the AMM for cycling.

The findings of the present study show that power does not indicate capacity. That is, recreationally active individuals with the ability to produce a high rate of energy anaerobically do not necessarily possess the ability to produce a large amount of energy anaerobically. Therefore, $WAnT_{PP}$ is not a good predictor of anaerobic capacity when measured using the maximal AO_2 deficit. Nevertheless, if the WAnT is used to estimate an individual's anaerobic capacity, the fatigue index should be used rather than measures of $WAnT_{PP}$ or $WAnT_{MP}$.

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