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CYCLING AT 120 WHEN COMPARED TO 80 REV/MIN INCREASES THE ACCUMULATED OXYGEN DEFICIT BUT DOES NOT AFFECT THE PRECISION OF ITS CALCULATION

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ABSTRACT

CYCLING AT 120 WHEN COMPARED TO 80 REV/MIN INCREASES THE ACCUMULATED OXYGEN DEFICIT BUT DOES NOT AFFECT THE PRECISION OF ITS CALCULATION. **Russell AP, Le Rossignol PF, Snow RJ And Lo SK**. **JEPonline**. 2002;5(3):32-38. The aim of the present study was to determine the influence of pedal rate on the precision and quantification of the accumulated oxygen deficit (AOD). Eight trained male triathletes completed a lactate threshold test, VO_2 peak test, 10 x 3 min sub-maximal exercise bouts and a high-intensity exercise bout, all performed at 80 and 120 rev/min. For both pedal rates the intensities for the sub-maximal and high-intensity tests were relative to the lactate threshold and VO_2 peak work rates. The VO_2-power regressions were calculated using 5 intensities from above the lactate threshold combined with a y-intercept value with VO_2 measured after 3 min of exercise. For the 120 compared to the 80 rev/min tests, the lactate threshold work rate (255±13 versus 276±47 Watts) ($p<0.01$) and VO_2 peak work rate (352±17 versus 382±20, Watts) ($p<0.05$) were lower at 120 rev/m. Conversely, the VO_2 peak and the VO_2 measured during the exhaustive exercise were the same for both pedal rates ($p>0.05$). Using linear regression modelling the slope of the VO_2-power regression (0.0112 versus 0.010 L/Watt) ($p<0.01$), the estimated total energy demand (ETED) (5.13±0.75 versus 4.89±0.88 L/min) and the AOD (4.27±0.94 versus 3.66±1.25 L) ($p<0.05$) were greater at 120 rev/m. However, the 95% confidence interval for the ETED and the standard error of the predicted value were the same for both pedal rates ($p>0.05$). Our results demonstrate that pedal rate effects the size but not the precision of the calculated AOD and should therefore be considered when developing an AOD protocol.

Key words: Cycling, Anaerobic capacity, Exercise testing, Pedal rate.

INTRODUCTION

The accumulated oxygen deficit (AOD) has been used as a non-invasive tool to quantify anaerobic capacity for over 30 years (1-4). Several methodological factors affect the estimation of the total energy demand (ETED) required to complete approximately 2 min of exhaustive exercise and therefore the calculation of the AOD. These factors include; using individual linear VO_2-power regressions (5), the exercise duration for the submaximal tests required to establish the linear VO_2-power regression (6), the number of regression points used to develop the linear VO_2-power regression (7), the effect of a forced y-intercept (8) and the effect of the VO_2 slow component (4).

Another methodological factor that may influence the slope of the VO_2-power regression, the precision of the ETED and the AOD, is variation in pedaling rate when using a cycle ergometer. Several studies have observed that increasing pedal rates increases VO_2 at the same power (9-10). These increases are likely to be due to increases in internal work performed by the legs when moving at faster rates. Of more importance to the calculation of the AOD is the delta efficiency measured across increases in power at different pedal rates. A decrease and increase, respectively, in the slope of the VO_2-power regression and delta efficiency has been observed for pedal rates between 60 rev/min and 120 rev/min during exercise between 54 and 93% of VO_2max (11). Woolford et al. (20) also observed that increased pedal rates (120-130 rev/min) of a track cycle ergometer affected the slope of the relationship between VO_2 and power when compared to slower cycle rates (90-100 rev/min) of a road cycle ergometer. However, in contrast to previous research (11) the VO_2-power curve was moved upwards for the increased pedal rate which resulted in a larger ETED and calculated AOD. Unfortunately, Woolford et al. (20) did not use different pedal rates to measure the accumulated oxygen uptake during the high intensity AOD test nor was the exercise intensity set at the same supramaximal percentage for the respective pedal rates. Consequently, the precise effect of pedal rate on the AOD was not investigated. Therefore the major aims of this study were to investigate the effect of peal rate on the slope of the VO_2-power regression and the magnitude and precision of the AOD.

METHODS

The subjects included eight trained male triathletes (mean±SD), age=27±6 yr; mass=73.4±3.1 kg; VO_2peak at 80 and 120 rev/min, respectively=4.7±0.5 L/min and 4.7±0.4 L/min.

VO_2peak test

The VO_2peak tests required the subjects to ride at 80 rev/min or 120 rev/min on separate days on an electronically braked cycle ergometer (Lode Excalibur). The subjects began cycling at 100 Watts for 10 min followed by an increase in work rate of 25 Watts/min until the respiratory exchange ratio (RER) was above 1.1 for one min. The work rate was then increased by 13 Watts/min until the subjects could no longer maintain the desired pedal rate. Expired gases were collected and analyzed by a Medical Graphics metabolic cart (CardiO2 and CPX/D System) to determine VO_2 and the RER. The metabolic cart was calibrated prior to each test using alpha calibrated gases that have an error of 0.01%. VO_2peak was established either when a plateau in VO_2 with increasing work rates was observed or as the highest 30 second VO_2 value measured during the test. A plateau was deemed to be reached when VO_2 did not increase by more than 100 mL/13 Watts increase. The work rate at which VO_2peak occurred was also recorded.

Lactate threshold test

A lactate threshold (LT) test was performed at 80 rev/min and 120 rev/min on separate days to determine the exercise intensity that caused an accumulation of lactate in the plasma. After a 10 min warm up at 100 Watts the subjects began exercising at 60% of VO_2peak for four min. The work rate was then increased by 5% up to 90% of VO_2peak every four min. Prior to exercise a 22-gauge catheter was inserted in an antecubital forearm vein. A 2.5 mL blood sample was obtained immediately after the warm-up and at the end of each four min work rate. The blood samples collected during the LT test were spun in a centrifuge and 10 μL of plasma was added to 600 μL of 3 M perchloric acid and spun again. The supernatant (10 μL) was then analysed for plasma lactate in triplicate, using an enzymatic fluorometric technique (12). The work rate at which plasma lactate accumulation increased by 1 mmol/L above baseline was defined as the lactate threshold (13).

Submaximal tests

Each subject completed 10 x 3 min constant load cycling tests while cycling at 120 rev/min or 80 rev/min. Five tests were below the lactate threshold (BLT) and 5 test were above the lactate threshold (ALT) as determined for each pedaling frequency. The data concerning the 80 rev/min tests has been reported recently (4) and were collected using the same methods as for the 120 rev/min tests. The tests were performed on separate days in a randomly selected order for both exercise intensity and pedal rate. Prior to each testing session a two min resting sample of expired gas was measured and used as the individual y-intercept value. At the conclusion of the two min of rest the subjects began cycling at the required power output and pedal rate. VO_2 was measured breath-by-breath using the Medical Graphics metabolic cart as previously described.

Measuring the accumulated oxygen deficit

After a 10 min warm up at 100 W the subjects cycled to exhaustion at their individual intensities which corresponded to 110% of VO_2peak power for both pedal rates. Exhaustion was determined when the subjects could no longer maintain either 80 or 120 rev/min. The AOD was established as the difference between the estimated total energy demand and the VO_2 measured during the exhaustive exercise test (5,6). VO_2 was measured breath-by-breath using the Medical Graphics metabolic cart as previously described.

Establishing the estimated total energy demand during the AOD test

The ETED during the exercise trial at 110% of VO_2peak power was extrapolated using the regression equation derived from the relationship between submaximal VO_2 and power (3) for both pedal rates. For both the 80 and 120 rev/min test the regressions consisted of 5 points ALT. A y-intercept value was also included in all regressions as we have previously observed that the inclusion of a y-intercept value reduced the variability around the estimated value (4,8). The exhaustive intensity test was set at 110% of VO_2 peak power for each pedal rate as this intensity has been shown to exhaust subjects in approximately two min (6,14). Reaching exhaustion at approximately two min has been shown to reduce to the influence of the aerobic system when calculating the AOD (3).

Statistics

Analysis of variance (ANOVA) with linear contrasts were used to determine whether the slope of the VO_2-power regression remained constant when using intensities from BLT, ALT or a combination of BLT and ALT when cycling at 120 rev/min. A linear regression was fitted on individual data to determine the "goodness of fit" as indicated by the r-square for the VO_2-power relationship. Paired t-tests were used to establish the influence of cycling at 80 and 120 rev/min on the slope of the VO_2-power relationship, the ETED, the AOD, the r-square value, the standard error of the predicted value (SEP) and the length of the 95% CI. All analysis was performed using SPSS statistical software. Statistical significance was set at $p \leq 0.05$ for all t-tests while the Bonferoni adjustment was made for the ANOVA with contrasts, therefore changing the significance level to $p<0.016$. All data are reported as mean±standard deviation (SD).

RESULTS

When cycling at 120 rev/min the slope of the VO_2-power regression was greater ($p=0.003$) when using five intensities BLT + y intercept value (slope=0.013±0.001 L/Watt) compared with five intensities ALT+ y intercept (slope=0.012±0.001 L/Watt) or a combination of the regression points from BLT and ALT (slope=0.0120±0.002 L/Watt). There was no difference between the slopes of the latter two regressions (Figure 1).

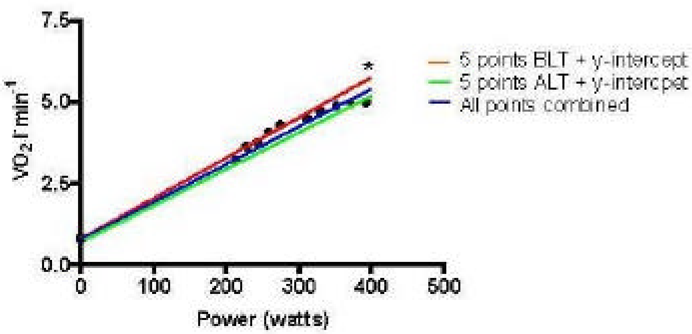

Figure 1. VO_2-power regression slopes. VO_2 was measured after 3 min of exercise and all regressions included an individual resting y-intercept value. Values are means± SD, n=8; * p<0.016, slope different from the other two regressions. BLT, exercise intensities from below the lactate threshold; ALT, exercise intensities from above the lactate threshold.

The regression developed from 5 intensities ALT including a y-intercept was chosen for the determination of the AOD when cycling at 120 rpm as these intensities would be more representative of the whole muscle efficiency during the exhaustive AOD test than the other regressions (see discussion). Additionally, this regression equation is suitable for the 80 rev/min tests as we have previously demonstrated that a VO_2-power-regression consisting of intensities from either BLT, ALT or a combination of both does not affect calculation or the precision of the AOD when cycling at 80 rev/min (4).

Using linear regression, the slope of the VO_2-power regression ($p<0.01$), the ETED and the AOD ($p<0.05$) where all lower when cycling at 80 rev/min compared with 120 rev/min. There was no difference in the length of the 95% CI for the ETED, SEP or the PCC between pedal rates ($p>0.05$). Time to fatigue during the exhaustive test was longer at 80 rev/min when compared to 120 rev/min (Table 1).

Table 1. Influence of pedal rate on the slope of the *V*O$_2$-power regression, ETED, AOD, 95% CI, SEP and the PCC.

Parameter	80 rev/min	120 rev/min
Slope (L/Watt)	0.010±0.001 **	0.012±0.001
ETED (L/min)	4.89±0.88 *	5.13±0.75
AOD (L)	3.66±1.25 *	4.27±0.94
95%CI (L)	0.79±0.34	0.66±0.34
SEP (L/Watt)	0.07±0.03	0.06±0.03
PCC	0.997±0.003	0.999±0.004
Time to fatigue (sec)	158.7±6.0	130.1±6.1

Values are means±SD, n=8, * $p<0.05$; different from 120 rev/min,** $p<0.01$; different from 120 rev/min. The regression for both the 80 and 120 rev/min tests respectively, consisted of a combination of 5 regression points + a y-intercept value. *V*O$_2$ was measured after 3 min of exercise at all intensities. ETED, estimated total energy demand; AOD, accumulated oxygen deficit; 95% CI, 95% confidence interval for the ETED; SEP, standard error of the predicted value; PCC, and the Pearson correlation coefficient; time to fatigue, the duration of the high-intensity exercise test.

Pedal rate did not influence *V*O$_2$ peak or the accumulated oxygen uptake measured during the high intensity AOD test ($p>0.05$), however the work rates at *V*O$_2$ peak and lactate threshold were lower when cycling at 120 rpm compared to 80 rev/min (Figure 2).

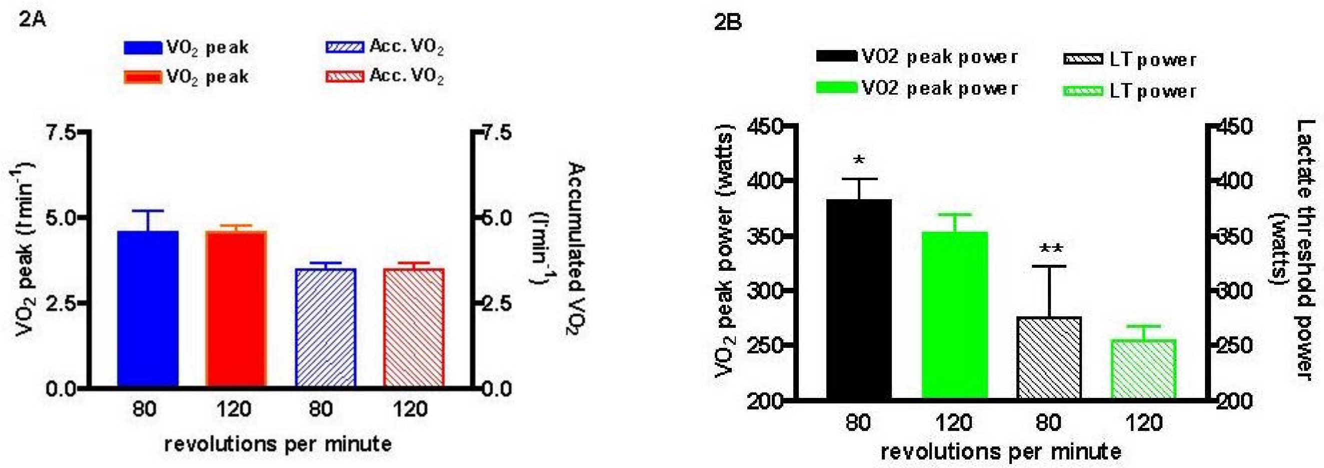

Figure 2. (A) *V*O$_2$peak and the accumulated *V*O$_2$ (accumulated *V*O$_2$, oxygen uptake measured during the high-intensity exercise test). (B) The maximal and lactate powers measured during the *V*O$_2$peak and lactate threshold tests. All tests were completed at both 80 and 120 rev/min. Values are means±SD, n=8; *, $p<0.05$, different from 120 rev/min; **, $p<0.01$, different from 120 rev/min.

DISCUSSION

The significant findings from the present study are as follows. When cycling at 120 rev/min, the slope of the $\dot{V}O_2$-power regression is greater when using intensities from BLT when compared to ALT or a combination of both. The slope of the *V*O$_2$- power regression, the ETED and the calculated AOD is greater when cycling at 120 compared with 80 rev/min. The precision of the AOD as measured by the length of the 95% CI for the ETED was not affected by pedal rate.

The decrease in the slope of the *V*O$_2$-power relationship for intensities ALT compared to intensities BLT indicates an increase in delta efficiency at higher intensities with a pedal rate of 120 rev/min. It is probable that the increase in delta efficiency was due to fast twitch fiber recruitment at the higher intensities (15) combined with a higher contractile efficiency for these fast twitch fibers at the faster pedal rate (16). The VO_2-power regression developed from the intensities ALT was chosen to calculate the AOD as these intensities are closer to the exhaustive intensity used for the AOD test and are more likely to represent the mechanical efficiency of the whole muscle when exercising at 110% of VO_2peak power.

Mathematical modelling has indicated that the VO_2-power relationship is linear for intensities between 38-100% of VO_2 max when VO_2 is measured at the end of the VO_2 fast component and at the start of the VO_2 slow component (SC) (17). Since it is not always practical to use modelling to estimate the end of the fast component, measuring VO_2 after three min of exercise is a compromise which appears to eliminate enough of the SC to allow best fit linear regressions to be equally as good as the curvilinear approach. The SC is the main cause for the non-linear increase in VO_2 from intensities BLT to ALT (9,18,19) which is a major factor that challenges the key assumption of linearity of the AOD method. In the present study we demonstrate that measuring VO_2 after 3 min of exercise at intensities above the ALT allows for the development of a linear VO_2-power regression to estimate the total energy demand with the same amount of precision when cycling at 80 and 120 rev/min. Previously we have shown that measuring VO_2 after 3 min as compared to 6 min of exercise, when cycling at 80 rev/min, removes a significant amount of the SC which allows for the development of a linear VO_2-power regression (4). We assume that measuring VO_2 after 3 min of exercise when cycling at 120 rev/min also removed a significant amount of the SC.

The work rates which elicited the lactate threshold and VO_2 peak were lower for the 120 than for the 80 rev/min trials and support observations by others (20). Cycling at increased pedal rates incurs recruitment of more fast twitch muscle fibers at the same cycle intensity (21). Furthermore, increased pedal rates require an increase in the rate of muscular contractions, which further stimulates glycolysis, resulting in an increased production of lactate and associated acidosis and a faster time to fatigue (22). The accumulated oxygen uptake measured during the exhaustive exercise bouts was not different when cycling at either 80 or 120 rev/min. These observations demonstrate that the protocols used for both the VO_2 peak and the high-intensity AOD exercise tests stressed the aerobic energy system to the same degree regardless of pedal rate. Furthermore, the AOD values were not confounded by the influence of pedal rate on VO_2 during the exhaustive exercise test.

We observed that the slope of VO_2-power regression, and therefore the ETED, was greater when determined from the 120 rev/min as compared to the 80 rev/min exercise tests. As the accumulated oxygen uptake was not different when measured during both the exhaustive tests performed at 120 and 80 rev/min, it was not surprising that the AOD was different between the two pedal rates. Our observation of a greater calculated AOD when cycling at 120 when compared to 80 rev/min is consistent with the findings of Woolford et al. (20). However, when comparing the results from the present study with those of Woolford et al. (20) it is important to note the different methodologies used in the respective studies. Unlike Woolford et al. (20), we included a resting y-intercept value in the VO_2-power regression as this has been shown to increase the precision of the ETED and the therefore the AOD (8). It is possible that the inclusion of a resting y-intercept value resulted in a steeper slope of the VO_2-power regression when cycling at 120 as compared to 80 rev/min. Additionally, we used a constant power output at 110% of the maximum power output specific for both pedal rates while Woolford et al. (20) used an all-out test with varying pedal rate. It has been shown that there are no differences in the AOD when using a constant load or an all-out protocol (23). However, when comparing the greater AOD values measured using faster as compared to slower pedal rates, our increase of 16% from a constant load test is almost 3 times lower than the 47% observed by Woolford et al. (20) when using an all-out test. The AOD is not affected by a constant versus an all-out protocol when using the same pedal rate [23]. However the AOD may be affected by the use of a constant load or all-out protocol if different pedal rates are used.

The delta efficiency measured in the present study was greater at 80 compared to 120 rev/min for intensities above the ALT. Previous investigations have indicated that the changes in delta efficiency due to pedal rate is probably related to muscle fibre recruitment (24) and the optimal movement efficiency for the fibers recruited (13,25). Slow twitch fibres are more economical than fast twitch fibres when cycling at 80 rev/min (contraction velocity of ~200 °/s) (13,25). The subjects used in the present study were endurance trained triathletes and their muscle fiber composition would be expected to be predominantly slow twitch. It is therefore reasonable to speculate that the higher delta efficiency observed at the slower pedal rate was because the contracting velocity of 80 rev/min was close to the velocity of peak efficiency for a greater percentage of the respective fibres recruited than would occur at 120 rev/min.

The accuracy of the AOD method relies on the precision of the ETED. The magnitude of the 95% CI of the ETED provides a measure of precision (26) with a smaller magnitude indicting a more precisely estimated value. There was no difference in the magnitude of the 95% CI for the ETED or the SEP of the VO_2-power regression between pedal rates. These data demonstrate that for a group of endurance trained male triathletes the ETED and therefore the AOD can be determined with the same level of confidence when using pedal rates of 80 and 120 rev/min.

Conclusion

In summary, for a group of endurance trained male triathletes VO_2 peak is not influenced by pedal rate, although the power eliciting VO_2 peak and the lactate threshold is lower at 120 compared to 80 rev/min. The slope of the VO_2-power regression, the ETED and the AOD was also greater when cycling at 120 compared to 80 rev/min. Pedal rate did not influence the precision of the ETED and therefore the precision of the calculated AOD. Our results demonstrate that pedal rate affects the size but not the precision of the calculated AOD and should therefore be considered when developing an AOD protocol. Until standardised protocols are used caution should be taken when comparing AOD values calculated using different rates of movement.

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