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Aerobic and Anaerobic Energy Contributions during Short-Duration Supramaximal Exercises with Different Exercise Intensities

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The study examined the relative energy contributions during 60-s supramaximal exercise with different exercise intensities. Nine male track and field sprinters performed a 60-s Wingate anaerobic test and a 60-s cycling tests at five intensities of 55%, 65%, 75%, 85%, and 95% mean power of the Wingate anaerobic test. The relative contributions of aerobic and anaerobic energy during the 60-s cycling tests were estimated by the ratio of O_2 uptake and O_2 deficit, the latter being calculated as the difference between O_2 demand and O_2 uptake. $\%\dot{V}O_2max$ of the 60-s cycling tests ranged from 100 ± 7 to $163 \pm 11\%\dot{V}O_2max$. As exercise intensity increased, O_2 uptake, O_2 deficit, and anaerobic energy contributions during the 60-s cycling tests increased ($p < 0.05$). In contrast, in the first ~40 s during the 60-s cycling, the anaerobic energy contributions were not significant differences between each intensity. O_2 uptake per 10 s increased with time course till 40 or 50 s in each intensity ($p < 0.05$). The different results of these at the first ~40 and 60 s during the 60-s cycling tests could be attributed to the insufficient increase in O_2 uptake during the last 20 s of the test. These results suggest that, as exercise intensity increases, the anaerobic energy contribution becomes more prominent in the latter half of the 60-s exercise (i.e., 50 and 60 s) compared to the first 30 and 40 s.

Keywords: energy system contribution, exercise intensity, sprint, O_2 uptake, O_2 deficit

1. Introduction

The energy utilized for exercise is provided by aerobic and anaerobic energy systems. Traditionally, aerobic energy supply during exercise has been determined by measuring O_2 uptake (Åstrand and Saltin, 1961). Conversely, the estimation of anaerobic energy supply established by Medbø et al. (1988) introduced the concept that the accumulated O_2 deficit, as determined by the difference in estimated O_2 demand and measured O_2 uptake, may reflect the anaerobic energy supply during exercise. Since then, researchers have evaluated O_2 uptake and O_2 deficit to estimate aerobic and/or anaerobic energy contributions during exhaustive exercises (Gastin, 2001). For example, Medbø and Tabata (1989) demonstrated that the aerobic energy contributions during exhaustive cycling lasting 30 s, 1 min, and 2-3 min (119 ± 2 to $186 \pm 5\%\dot{V}O_2max$) were $30 \pm 1\%$, $47 \pm 2\%$, and $65 \pm 2\%$, respectively. This result indicates that aerobic energy contributions during exercise are higher for longer durations. However, since exercise intensity was lower with prolonged duration in these previous studies, it cannot be concluded whether exercise intensity modulates the relative energy contributions. Fixed exercise duration experiments are necessary to assess the influence of exercise intensity on the aerobic and anaerobic energy contributions during exercise.

According to some guidebooks on sports sciences for athletes and coaches, the anaerobic energy contribution increases with exercise intensity (Hoffman, 2002; Reilly and Bangsbo, 1999). However, Shiraki et al. (2020) reported that the aerobic/anaerobic energy contributions during 30-s cycling did not differ across a wide range of seven intensities (74 ± 7 to 181 ± 18%$\dot{V}O_2$max). In addition, the reason for the unchanged energy contributions was that O_2 uptake increased with exercise intensity (Shiraki et al., 2020). Namely, the O_2 uptake did not reach a plateau during the 30-s exercises. Limited information is available on O_2 uptake during short-duration supramaximal exercise. Therefore, it remains to be determined whether the aerobic and anaerobic energy contributions during 40, 50, and 60-s exercises differ across a wide range of supramaximal intensities. Assessing relative energy contributions during ~60-s exercises across a wide range of intensities is important because intensities of training programs for anaerobic-type athletes, such as sprinters and team sports athletes, often vary over supramaximal. In other words, this assessment would advance our fundamental knowledge of metabolic responses during short-duration supramaximal exercises, which would help assess and design training programs for athletes and coaches.

Therefore, this study examined the relative energy contributions in 60-s supramaximal exercises with different intensities and fixed durations (i.e., the first 30, 40, and 50 s). We elected to adopt a 60-s exercise as there is a lack of information on energy profiles of 40, 50, and 60-s exercises, which is required in anaerobic training with supramaximal intensity (Iaia and Bangsbo, 2010).

2. Methods

2.1. Participants

The participants were nine competitive male track and field sprinters, including one dual player with decathlon (100-m sprint time, 11.20 ± 0.22 s). All participants were tested during the off-season. Their age, height, and body mass were 21.7 ± 2.6 years, 1.75 ± 0.06 m, and 65.6 ± 5.7 kg, respectively. All participants visited the laboratory before commencing the experiment and performed 40-s maximal effort cycling to become familiar with the exercise protocol. The seat and handlebar heights were recorded and kept constant in all the tests. This study was approved by the Human Ethical Committee of the University of Tsukuba in accordance with the Declaration of Helsinki. Written informed consent was obtained from all participants prior to their participation.

2.2. Procedures

This study consisted of one preliminary session and five subsequent experimental sessions. All sessions were completed within 3 weeks, each separated by ≥ 48 h. To minimize the potential impact of training adaptations and metabolic variations, the order of the five experimental sessions was randomized. All tests were performed using a mechanically braked cycle ergometer (Power max VIII, Combi Co., Tokyo, Japan) in an experimental room regulated to a room temperature of 24-26°C and relative humidity of ~ 60%. Before each session, the participants were instructed to avoid strenuous exercise, caffeine, and alcohol for at least 24 h. The participants were instructed not to eat any food 2 h before and during each session. They arrived at the laboratory at the same time during each session.

2.3. Preliminary session

2.3.1. Submaximal test

The participants performed a submaximal cycling test to estimate O_2 demands at different intensities. The submaximal test consisted of five 4-min submaximal exercises at 0.5-3.0 W/kg interspaced with 2-min rest periods. The exercise intensity, duration, and rest periods were determined based on previous studies (Finn et al., 2000; Green and Dawson, 1996). Blood samples were obtained from a fingertip immediately after the 5th stage to evaluate blood lactate concentrations. The blood lactate concentration and respiratory exchange ratio were confirmed to be within 4 mM and 1.00, respectively, because O_2 demand could be overestimated at intensities exceeding the lactate/ventilatory threshold or respiratory exchange ratio (Hill and Vingren, 2011; Wilkerson et al., 2004). The workload (kp) and pedal cadence during the submaximal test were determined using the following equations (Shiraki et al., 2020):

$$\text{Pedal cadence (rpm)} = 0.14 \times \text{Power (W)} + 37 \qquad \text{(Equation 1)}$$

$$\text{Workload (kp)} = \text{Power (W)}/[\text{Pedal cadence (rpm)} \times 0.98] \qquad \text{(Equation 2)}$$

The equations are based on an optimum pedal cadence for each workload, as reflected by the efficient cadence that requires the smallest increase in O_2 uptake (Shiraki et al., 2020). Moreover, optimum pedal cadence increases as power increases (Coast and Welch, 1985). Accordingly, pedal cadence increased as workload increased in the submaximal test in the present study. For each participant, a linear relationship between power and O_2 demand was established from the measured power and the steady-state O_2 uptake at each stage.

2.3.2. 60-s Wingate Anaerobic Test

The participants conducted the 60-s Wingate Anaerobic Test (WAnT) to determine the intensity of a 60-s cycling test. The workload for WAnT was 7.5% of the body weight × kp. Ten seconds before commencing the WAnT, the participants started cycling with a workload of 0.0 kp and a gradual increase in cadence to 100 rpm (the so-called rolling start) (Minahan et al., 2007). Once the WAnT commenced, the participants pedaled at the workload with maximal effort.

2.4. Experimental session

2.4.1. 60-s cycling test

The participants initially performed a 10-min warm-up at a 1.0 kp workload with a pedal cadence of 90 rpm. Thereafter, they completed a 20-min post-exercise rest period and performed the 60-s cycling test. The test was performed with a rolling start to reduce the effort required for the initial acceleration from zero to a target workload, as with the WAnT. Ten seconds before commencing the test, the participants started cycling with a workload of 0.0 kp and a gradual increase in cadence to 100 rpm. Once the test commenced, the participants cycled at a predetermined workload and a pedal cadence immediately for 60 s at 55%, 65%, 75%, 85%, and 95% relative mean power of WAnT. This 60-s cycling test was repeated five times with different target workloads and pedal cadences to obtain data on supramaximal exercises.

2.4.2. $\dot{V}O_2$max test

Twenty minutes after the 60-s cycling test with 55% relative mean power, the participants performed an incremental cycling test to obtain $\dot{V}O_2$max, an index of aerobic capacity. This test began with an initial workload of ~3.0 kp, which was increased by 0.1-0.2 kp every 1 min. Pedal cadence was maintained at 90 rpm throughout cycling until exhaustion. Exhaustion was defined as the inability to maintain a pedal cadence of >85 rpm for 5 s. All participants exhibited a leveling off of O_2 uptake despite an increase in intensity (difference <2.1 ml/kg/min, Midgley et al., 2007). Additionally, secondary criteria ware also employed to increase the validity of $\dot{V}O_2$max measurements, including heart rate reaching at least 90% of the age-predicted maximum (220-age) or respiratory exchange ratio exceeding 1.1 (Midgley et al., 2007; Poole and Jones, 2017). $\dot{V}O_2$max was defined as the highest $\dot{V}O_2$ value averaged over a 30-s interval.

2.5. Measurements

All tests were conducted on a mechanically braked cycle ergometer with an original mode that could transfer from 0.0 kp to target workloads (Power max VIII, Combi Co., Tokyo, Japan). The output data from the cycle ergometer were collected using a personal computer (Vostro 320, Dell Technologies Japan Inc., Japan) equipped with an A/D converter (KRS-3102FK, SANWA Co., Gunma, Japan) and an USB cable (BSUSRC0610BS, BUFFALO Inc., Aichi, Japan). Expired gas analysis was continuously performed using a gas analyzer (AE-310s, Minato Medical Science Co., Osaka, Japan) using a computerized standard open-circuit technique. The analysis mode was set to EXP mode, which is more valid in exercises with high respiratory frequency compared to the breath-by-breath mode (described in the user's manual). The obtained respiratory data were averaged over 5-s time intervals. Blood lactate concentrations were assessed using a lactate analyzer (YSI 1500 SPORT L-Lactate Analyser, YSI Inc., Yellow Springs, OH, USA). Heart rate was measured using standard telemetry (Polar S610i, Polar Electro Japan, Tokyo, Japan).

2.6. Data analyses

The expired gas in the submaximal test, $\dot{V}O_2$max test, WAnT, and 60-s cycling test were analyzed from 3 min before each exercise. The mean pedal cadence, mean power, steady-state O_2 uptake, heart rate, and respiratory exchange ratio during each stage in the submaximal test were evaluated as an average value over the last 2-min period. The O_2 demand during the WAnT and the 60-s cycling test was estimated by linear extrapolation of power data and steady-state O_2 uptake obtained in the submaximal test. The O_2 deficit during WAnT and the the 60-s cycling test was calculated as the difference between O_2 demand and O_2 uptake (**Figure 1**). Aerobic and anaerobic energy con-

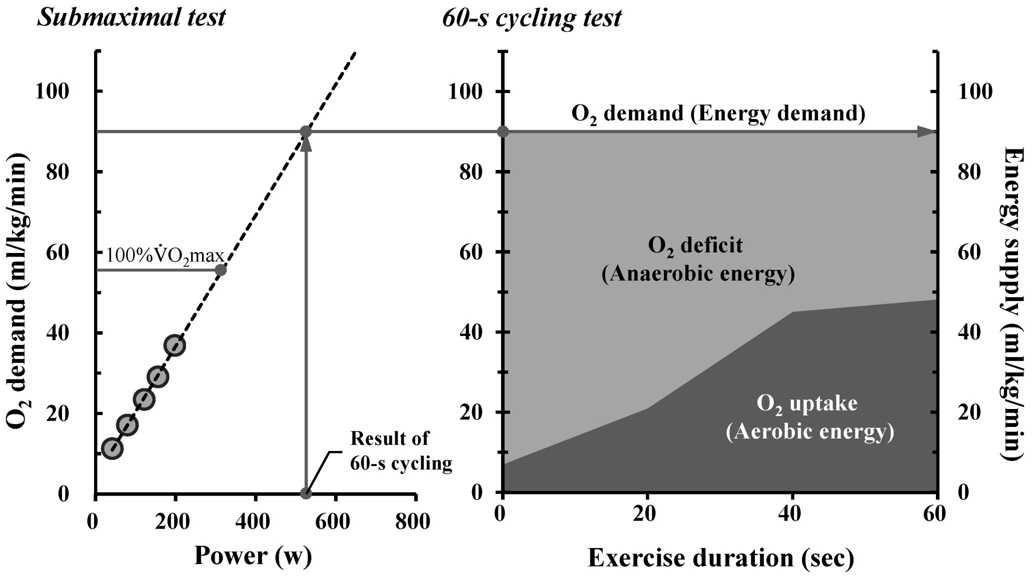

Figure 1 A model of calculating O_2 demand and O_2 deficit for the 60-s cycling test
The O_2 demand during each 60-s cycling test was estimated by linear extrapolations of power data and steady-state O_2 uptake obtained in the submaximal test. The O_2 deficit during the 60-s cycling test was calculated as the difference between O_2 demand and O_2 uptake.

tributions were estimated using the ratio of O_2 uptake to O_2 deficit. Linear extrapolation was used to calculate the relative intensity index of %$\dot{V}O_2$max (**Figure 1**). The mean power and heart rate during the WAnT and the 60-s cycling test were evaluated as an average value over the entire 60-s period. To characterize the O_2 response during the 60-s cycling test, data was averaged over 10-s time intervals. As the averaging bins were used, the influence of breaths variability has been considered (Thomas et al., 2016). The mean power was evaluated as power per body weight. Blood lactate concentrations in the WAnT and the 60-s cycling test were measured before each exercise and 1, 3, and 6 min during the post-exercise recovery period. The highest blood lactate concentration was defined as the peak value. The mean power output during the 60-s cycling test is presented relative to that of the WAnT (%).

2.7. Statistical analyses

Values are presented as the mean ± standard deviation. The linear relationship between power and O_2 demand was analyzed using the coefficient of determination. All variables presented in **Table 1** were analyzed using repeated-measures one-way analysis of variance with a factor of the relative mean power of the WAnT. O_2 uptake responses at each level of the relative mean power of the WAnT were analyzed using repeated-measures two-way analysis of variance with factors of the relative mean power and time course during the 60-s cycling test. The relative energy contributions at each level of the relative mean power of the WAnT were also analyzed using repeated-measures two-way analysis of variance with factors of the relative mean power and time (0-30, 40, 50, 60 s) in the 60-s cycling test. A post hoc analysis was performed using the Holm–Bonferroni test when a significant F value was detected. The significance level for all comparisons was set at $p < 0.05$.

3. Results

The mean, peak power of WAnT, and $\dot{V}O_2$max were 8.2 ± 0.3 W/kg, 12.6 ± 1.0 W/kg, and 57.0 ± 4.2 ml/kg/min, respectively. R^2 value of the linear relationship between the power and the O_2 demand was 0.997 ± 0.001.

The mechanical and metabolic variables assessed during the 60-s cycling test are presented in **Table 1**. The main effect of the relative mean power on the aerobic energy contribution was significant ($F = 21.2$, $p < 0.05$). The aerobic/anaerobic energy contribution decreased/increased with increasing intensity (55 vs. 75-95%; 65 vs. 85-95%; 75% vs. 95%; $p < 0.05$). %$\dot{V}O_2$max, mean power, mean heart rate, O_2 uptake, O_2 deficit, and peak blood lactate concentration during each exercise increased significantly with increasing

Table 1 Mechanical and metabolic variables during the 60-s cycling test

	60-s cycling test (relative mean power of 60-s WAnT)						60-s WAnT
	55%	65%	75%	85%	95%		
% mean power relative to WAnT	55.4 ± 0.9	65.1 ± 1.3	75.0 ± 0.6	85.6 ± 1.4	94.8 ± 0.9	*	100.0 ± 0
%$\dot{V}O_2$max	100 ± 7	115 ± 9	131 ± 9	149 ± 11	163 ± 11	*	172 ± 11
Mean power (W)	299 ± 33	351 ± 38	405 ± 44	462 ± 50	511 ± 52	*	539 ± 56
Mean heart rate (beats/min)	127 ± 4	129 ± 7	133 ± 9	141 ± 8	150 ± 9	†	158 ± 7
Peak blood lactate concentration (mM)	4.3 ± 0.6	5.7 ± 0.4	7.2 ± 0.8	8.6 ± 0.6	10.1 ± 0.7	*	12.1 ± 1.1
O_2 demand (ml/kg)	56.6 ± 2.8	65.4 ± 3.2	74.5 ± 3.3	84.4 ± 4.0	92.8 ± 4.4	*	97.6 ± 4.3
O_2 uptake (ml/kg)	25.4 ± 1.4	28.5 ± 2.7	30.6 ± 1.9	33.5 ± 2.3	35.7 ± 2.6	*	37.7 ± 3.6
O_2 deficit (ml/kg)	31.2 ± 2.7	37.0 ± 2.8	44.0 ± 2.6	50.9 ± 3.3	57.1 ± 4.1	*	59.9 ± 4.2
Aerobic energy contribution (%)	44.9 ± 2.7	43.5 ± 3.5	41.0 ± 2.1	39.7 ± 2.3	38.5 ± 2.6	‡	38.6 ± 3.3
Anaerobic energy contribution (%)	55.1 ± 2.7	56.5 ± 3.5	59.0 ± 2.1	60.3 ± 2.3	61.5 ± 2.6	‡	61.4 ± 3.3

Date are mean ± standard deviation

*, all values differed each other in the 60-s cycling test ($p < 0.05$)

†, all values differed each other with the exception that relative mean power of 55 vs. 65-75%, 65% vs 75%, and 75 vs. 85% ($p < 0.05$)

‡, all values differed each other with the exception that relative mean power of 55 vs. 65%, 65% vs 75%, 75 vs. 85%, 85 vs. 95% ($p < 0.05$)

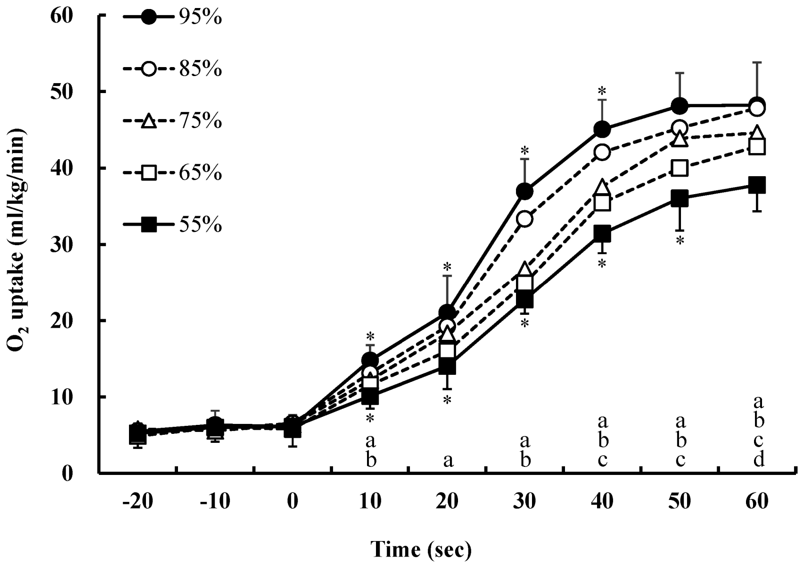

Figure 2 Mean O_2 response at each level during the 60-s cycling test
The each level was expressed in relative mean power of the 60-s WAnT.
SD was exhibited to only the 55% and 95% levels for more clarity.
*, vs. the previous points in the 55% and 95% levels ($p < 0.05$)
a, 55% vs. 95% ($p < 0.05$)
b, 55% vs. 85% ($p < 0.05$)
c, 55% vs. 75% ($p < 0.05$)
d, 55% vs. 65% ($p < 0.05$)

intensity (F = 1220.9, F = 3301.9, F = 29.4, F = 107.3, F = 457.8, and F = 296.9, respectively; all variables were $p < 0.05$; **Table 1**).

The O_2 uptake responses and aerobic energy contributions during the 60-s cycling test are presented in **Figures 2** and **3**, respectively. The interaction effect of the relative mean power of the WAnT and O_2 uptake over time was significant (F = 5.0, $p < 0.05$). The O_2 uptake increased with time course till 40 or 50 s ($0 < 10 < 20 < 30 < 40 <$ 50-60 s in 55% and 75% level, $p < 0.05$; $0 < 10 < 20 < 30 < 40$ s in 65%, 85%, and 95% level, $p < 0.05$). O_2 uptake also increased with increasing intensity (**Figure 2**). The interaction effect of the relative mean power and aerobic energy contribution over time was significant (F = 24.8, $p < 0.05$). The aerobic energy contribution increased with time (0-30 < 0-40 < 0-50 < 0-60 s at all levels, $p < 0.05$). The anaerobic energy contributions also

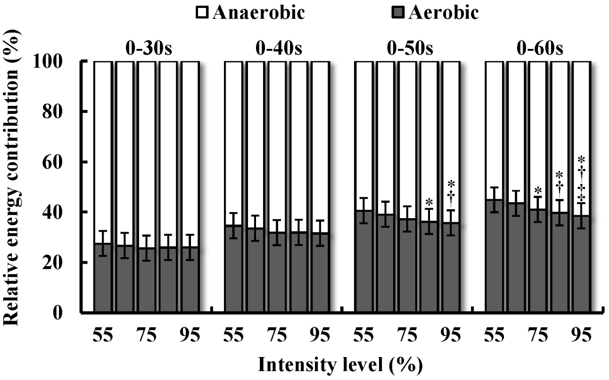

Figure 3 Relative aerobic contribution at each level during the 60-s cycling test
The each level was expressed in relative mean power of the 60-s WAnT.
*, vs. 55% ($p < 0.05$)
†, vs. 65% ($p < 0.05$)
‡, vs. 75% ($p < 0.05$)

increased with increasing intensities in the first 50 and 60 s ($p < 0.05$), but there were not significant differences across the intensities in the first 30 and 40 s ($p > 0.05$, **Figure 3**).

4. Discussion

The purpose of the present study was to examine whether different exercise intensities modulate relative energy contributions during a fixed duration of supramaximal exercise. We demonstrated that higher intensities in 60-s exercises resulted in higher values of O_2 uptake, O_2 deficit, and anaerobic energy contributions. However, in the first 30 and 40 s of the 60-s exercises, there were no significant differences in the aerobic and anaerobic energy contributions between each intensity.

Here, O_2 uptake during the 60-s cycling test increased as exercise intensity increased from 100 ± 7 to 163 ± 11%$\dot{V}O_2$max (**Table 1**). This result suggests that the aerobic energy supply increases in an exercise intensity-dependent manner. Similarly, Sousa et al. (2017) demonstrated that O_2 uptake during the first 60 s of constant-intensity exercises increased as exercise intensity increased from 95 to 105%$\dot{V}O_2$max. Notably, our results demonstrated that exercise intensity-dependent elevations in O_2 uptake occurred far above 100%$\dot{V}O_2$max. Comprehensively, O_2 uptake responses seem to exhibit three phases over time (**Figure 2**). In general, the O_2 kinetics exhibit three phases: cardiodynamic, primary, and steady-state phases (Poole and Jones, 2012). In the present study, the first, second, and final phases seem to occur in the first 20 s, 20 to 40 s, and last 20 s, respectively. Similarly, Wittekind and Beneke (2011) showed the three phases in O_2 uptake during a 60-s WAnT. Exercise intensity-dependent elevations in O_2 uptake seem to occur mainly in the second phase (**Figure 2**). This may reflect exercise intensity-dependent rapid increases in O_2 uptake upon short exercises, which requires further scrutiny.

The O_2 deficit during the 60-s cycling test increased with exercise intensity, as was observed for aerobic energy supply (**Table 1**). Along these lines, the peak blood lactate concentration, an indirect indicator of anaerobic energy supply (Jacobs, 1986), increased with elevations in the intensities (4.3 ± 0.6 to 10.1 ± 0.7 mM, $p < 0.05$) (**Table 1**). Hence, these results suggest that the anaerobic energy supply from the glycolysis system increases with increasing exercise intensity.

The aerobic and anaerobic energy contributions during the 60-s cycling test decreased and increased with increasing intensities, respectively (**Table 1**, **Figure 3**). However, in the first 30 and 40 s, the relative energy contributions did not differ across all intensity levels. It is generally thought that the aerobic energy contribution decreases as exercise intensity increases (Hoffman, 2002; Reilly and Bangsbo, 1999), but this is not true according to our results. Additionally, Shiraki et al. (2020) showed a result similar to that in this study, which was the unchanged aerobic and anaerobic energy contributions during 30-s cycling with seven intensities (73.4 ± 7.4 to 180.9 ± 18.2% $\dot{V}O_2$max). The lack of changes in relative energy contributions across a wide range of supramaximal in the first 30 and 40 s was due to the fact that both aerobic and anaerobic energy supplies increased as exercise intensity increased. Conversely, the changes in relative energy contributions during the first 50 to 60 s of the 60-s cycling test could be attributed to the insufficient increase in O_2 uptake during the last 20 s of the test (**Figure 2**).

It is unknown why both aerobic and anaerobic energy supplies increased in an exercise intensity-dependent manner, but our results are in line with those of studies showing that O_2 uptake during exercise is correlated to anaerobic energy supply (de Aguiar et al., 2015; Korzeniewski and Zoladz, 2004; Whipp et al., 1999). Whipp et al. (1999) reported that changes in O_2 uptake paralleled those in creatine phosphate, with the latter reflecting anaerobic energy supply. Additionally, the mitochondria, which play a critical role in aerobic energy production, are related to intracellular metabolites, such as adenosine diphosphate, creatine phosphate, and inorganic phosphate (Korzeniewski and Zoladz, 2004). Thus, the O_2 uptake response can be stimulated by an increase in the metabolites involved in the anaerobic energy system (de Aguiar et al., 2015). Therefore, O_2 uptake and O_2 deficit can similarly increase with elevation in exercise intensity.

We conducted a comparison of the relative energy contributions across a wide range of intensities and durations in 60-s supramaximal exercises (100 ± 7 to 163 ± 11%$\dot{V}O_2$max; **Table 1**) using male sprinters. These insights could be useful for sprinters, team sports athletes, and their coaches in assessing and designing anaerobic training programs, as relative energy contributions are influenced by exercise intensity depending on exercise duration. For instance, anaerobic-type athletes may benefit from training that specifically targets the anaerobic energy system, using higher-intensity 60-s exercises or supramaximal exercises less than 40 s. However, it is important to note that these findings are only one piece of the puzzle when it comes to designing training programs for athletes. Other factors, such as individual differences, training history, and sport-specific demands, should also be considered.

5. Conclusion

We show that the aerobic and anaerobic energy contributions during 60-s exercises decreased and increased, respectively, across a wide range of intensities from 100 ± 7 to 163 ± 11%$\dot{V}O_2$max. However, no significant differences were observed in the first 30 and 40 s during the 60-s exercises. Therefore, our results suggest that, as exercise intensity increases, the anaerobic energy contribution becomes more prominent in the latter half of the 60-s exercise (i.e., 50 and 60 s) compared to the first 30 and 40 s.

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References

Åstrand, P. O. and Saltin, B. (1961). Oxygen uptake during the first minutes of heavy muscular exercise. J. Appl. Physiol., 16: 971-976.

Coast, J. R. and Welch, H. G. (1985). Linear increase in optimal pedal rate with increased power output in cycle ergometry. Eur. J. Appl. Physiol. Occup. Physiol., 53: 339-342.

de Aguiar, R. A., Lisboa, F. D., Turnes, T., Cruz, R. S., and Caputo, F. (2015). The Effects of Different Training Backgrounds on VO_2 Responses to All-Out and Supramaximal Constant-Velocity Running Bouts. PLoS One, 10: e0133785.

Finn, J., Gastin, P., Withers, R., and Green, S. (2000). The estimation of peak power and anaerobic capacity of athletes. In: C. J. Gore. (ed.) Physiological tests for elite athletes (pp. 37-49). Champaign: Human kinetics.

Gastin, P. B. (2001). Energy System Interaction and Relative Contribution During Maximal Exercise. Sports Med., 31: 725-741.

Green, S. and Dawson, B. T. (1996). Methodological effects on the VO_2-power regression and the accumulated O_2 deficit. Med. Sci. Sports Exerc., 28: 392-397.

Hill, D. W. and Vingren, J. L. (2011). Maximal accumulated oxygen deficit in running and cycling. Appl. Physiol. Nutr. Metab., 36: 831-838.

Hoffman, J. (2002). Metabolic system and exercise. In J. Hoffman (ed.), Physiological Aspects of Sport Training and Performance (pp. 27-37). Champaign: Human Kinetics.

Iaia, F. M. and Bangsbo, J. (2010). Speed endurance training is a powerful stimulus for physiological adaptations and performance improvements of athletes. Scand. J. Med. Sci. Sports, 20 Suppl 2: 11-23.

Jacobs, I. (1986). Blood lactate. Implications for training and sports performance. Sports Med., 3: 10-25.

Korzeniewski, B. and Zoladz, J. A. (2004). Factors determining the oxygen consumption rate (VO_2) on-kinetics in skeletal muscles. Biochem. J., 379: 703-710.

Medbø, J. I., Mohn, A. C., Tabata, I., Bahr, R., Vaage, O., and Sejersted, O. M. (1988). Anaerobic capacity determined by maximal accumulated O_2 deficit. J. Appl. Physiol., 64: 50-60.

Medbø, J. I. and Tabata, I. (1989). Relative importance of aerobic and anaerobic energy release during short-lasting exhausting bicycle exercise. J. Appl. Physiol., 67: 1881-1886.

Midgley, A. W., McNaughton, L. R., Polman, R., and Marchant, D. (2007). Criteria for determination of maximal oxygen uptake: a brief critique and recommendations for future research. Sports Med., 37: 1019-1028.

Minahan, C., Chia, M., and Inbar, O. (2007). Does power indicate capacity? 30-s Wingate anaerobic test vs. maximal accumulated O_2 deficit. Int. J. Sports Med., 28: 836-843.

Poole, D. C. and Jones, A. M. (2012). Oxygen uptake kinetics. Compr. Physiol., 2: 933-996.

Poole, D. C. and Jones, A. M. (2017). Measurement of the maximum oxygen uptake $\dot{V}O_2$max: $\dot{V}O_2$peak is no longer acceptable. J. Appl. Physiol., 122: 997-1002.

Reilly, T. and Bangsbo, J. (1999). Anaerobic and aerobic training. In B. Elliott (ed.), Training in sport: Applying sport science (pp. 351-409). New York: Wiley.

Shiraki, S., Fujii, N., Yamamoto, K., Ogata, M., and Kigoshi, K. (2020). Relative Aerobic and Anaerobic Energy Contributions during Short-Duration Exercise Remain Unchanged over A Wide Range of Exercise Intensities. Int. J. Sport and Health Sci., 18: 253-260.

Sousa, A., Vilas-Boas, J. P., Fernandes, R. J., and Figueiredo, P. (2017). VO_2 at Maximal and Supramaximal Intensities: Lessons to High-Intensity Interval Training in Swimming. Int. J. Sports Physiol. Perform., 12: 872-877.

Thomas, C., Delfour-Peyrethon, R., Bishop, D. J., Perrey, S., Leprêtre, P. M., Dorel, S., and Hanon, C. (2016). Effects of pre-exercise alkalosis on the decrease in VO_2 at the end of all-out exercise. Eur. J. Appl. Physiol., 116: 85-95.

Whipp, B. J., Rossiter, H. B., Ward, S. A., Avery, D., Doyle, V. L., Howe, F. A., and Griffiths, J. R. (1999). Simultaneous determination of muscle 31P and O_2 uptake kinetics during whole body NMR spectroscopy. J. Appl. Physiol., 86: 742-747.

Wilkerson, D. P., Koppo, K., Barstow, T. J., and Jones, A. M. (2004). Effect of work rate on the functional 'gain' of Phase II pulmonary O_2 uptake response to exercise. Respir. Physiol. Neurobiol., 142: 211-223.

Wittekind, A. and Beneke, R. (2011). Metabolic and performance effects of warm-up intensity on sprint cycling. Scand. J. Med. Sci. Sports, 21: e201-207.

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2021-2022: Assistant, Ibaraki Christian University
2022-Present: Researcher, Japan Institute of Sports Sciences

Main Works:

- Shiraki, S., Fujii, N., Yamamoto, K., Ogata, M., and Kigoshi, K. (2020). Relative aerobic and anaerobic energy contributions during short-duration exercise remain unchanged over a wide range of exercise intensities. Int. J. Sport and Health Sci., 18: 253-260.
- Shiraki, S., Mitsugi O., Yamamoto, K., and Kiyonobu, K. (2022). Energy profile of repetition sprint exercises with different rest durations. Japan J. Phys. Educ. Hlth. Sport Sci., 67: 199-211. (in Japanese)

Membership in Learned Societies:

- Japan Society of Physical Education, Health and Sport Sciences
- Japan Society of Athletics