Higher Fat Oxidation in Running Than Cycling at the Same Exercise Intensities

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This study examined the differences in fat and carbohydrate oxidation during running and cycling at the same relative exercise intensities, with intensity determined in a number of ways. Specifically, exercise intensity was expressed as a percentage of maximum workload (WL\textsubscript{max}), maximum oxygen uptake (%VO\textsubscript{2max}), and maximum heart rate (%HR\textsubscript{max}) and as rating of perceived exertion (RPE). Ten male triathletes performed maximal running and cycling trials and subsequently exercised at 60%, 65%, 70%, 75%, and 80% of their WL\textsubscript{max}, VO\textsubscript{2}, HR, RPE, and plasma lactate concentrations were measured during all submaximal trials. Fat and carbohydrate oxidation were calculated from VO\textsubscript{2} and VCO\textsubscript{2} data. A 2-way ANOVA for repeated measures was used to determine any statistically significant differences between exercise modes. Fat oxidation was shown to be significantly higher in running than in cycling at the same relative intensities expressed as either %WL\textsubscript{max} or %VO\textsubscript{2max}. Neither were there any significant differences in VO\textsubscript{2max} and HR\textsubscript{max} between the 2 exercise modes, nor in submaximal VO\textsubscript{2} or RPE between the exercise modes at the same %WL\textsubscript{max}. However, heart rate and plasma lactate concentrations were significantly higher when cycling at 60% and 65% and 65–80% WL\textsubscript{max}, respectively. In conclusion, fat oxidation is significantly higher during running than during cycling at the same relative intensity expressed as either %WL\textsubscript{max} or %VO\textsubscript{2max}.

**Keywords:** carbohydrate oxidation, RER, fuel substrate

The physiological effects of running and cycling have been extensively studied, and it has been suggested that these two exercise modes may result in different physiological and metabolic responses (Achten, Venables, & Jeukendrup, 2003). One example of these differences is the relative contributions of fat and carbohydrate oxidation toward energy production at the same relative exercise intensity. Specifically, studies have shown fat oxidation to be significantly higher in running than in cycling at the same percentage of maximum oxygen uptake (VO\textsubscript{2max}; Achten et al.; Knechtle et al., 2004). Achten et al. (2003) demonstrated higher rates of fat oxidation during running than during cycling over a wide range of intensities, determined as %VO\textsubscript{2max}. In their study well-trained cyclists performed graded exercise tests on a cycle ergometer and treadmill after a 10- to 12-hr fast. Although the maximal rate of fat oxidation was significantly higher in running than in cycling, the relative intensity (%VO\textsubscript{2max}) at which the maximal rates of fat oxidation occurred was not different between the two exercise modes. Similarly, Knechtle et al. (2004) also showed significantly higher rates of fat oxidation during running than during cycling at the same %VO\textsubscript{2max}. However, unlike the participants in Achten et al.'s study, who were trained only in cycling, in this latter study participants trained regularly in both running and cycling. Data from these two studies therefore indicate that the rate of fat oxidation is higher in running than in cycling regardless of whether an individual is trained in both running and cycling or cycling alone.

Exercise intensity is one of the most important factors influencing the relative contributions of fat and carbohydrate toward energy production during exercise (Achten & Jeukendrup, 2004). However, there are many different methods to quantify exercise intensity besides %VO\textsubscript{2max} including percentage of maximum heart rate (%HR\textsubscript{max}), plasma lactate concentrations, rating of perceived exertion (RPE), and percentage of maximal workload (%WL\textsubscript{max}).
Investigating differences in energy expenditure using %HR\textsubscript{max} to set the exercise intensity in a group of physically active males, Thomas, Feiick, and Araujo (1989) found no significant differences in the fat energy expenditure between running and cycling at 65.2% HR\textsubscript{max}. However, absolute heart rates have been shown to be higher when cycling than when running at the same submaximal oxygen uptakes in healthy males with varying degrees of physical conditioning and training backgrounds (Hermansen, Ekbom, & Saltin, 1970; Hermansen & Saltin, 1969). This suggests that at the same heart rate or %HR\textsubscript{max}, VO\textsubscript{2} could be different and therefore the exercise trials would occur at different metabolic rates. This may account for the lack of differences observed in fat and carbohydrate oxidation.

Plasma lactate concentrations have been shown to be higher in cycling than running at the same submaximal workload in healthy males (Hermansen et al., 1970; Hermansen & Saltin, 1969), male and female endurance athletes who trained regularly in running and cycling (Knechtle et al., 2004), and recreationally active participants (Carter et al., 2000). Therefore, if running and cycling tests are performed at exercise intensities set according to lactate concentration, the metabolic demand will be higher in running than in cycling (Hill, Halcomb, & Stevens, 2003). However, the well-trained cyclists in Achten et al.'s (2003) study had similar lactate concentrations at the same %VO\textsubscript{2max} when running and cycling. It remains unknown whether athletes who are well trained in both running and cycling demonstrate differences in plasma lactate concentrations when running and cycling at the same relative intensities.

RPE may be influenced by training status, as well as the mode of training (Hassmen, 1990). In this regard, Hassmen showed that cyclists rated cycling as less strenuous than running, and, vice versa, runners rated running less strenuous than cycling when exercising at the same workload or treadmill speed. These data show the importance of sport-specific training. Thus, triathletes or duathletes, who train in both running and cycling, would be ideal participants to investigate physiological differences between the two exercise modes when training status is the same in both. To the best of our knowledge, no studies have examined the differences in fat and carbohydrate oxidation during running and cycling performed at the same RPE or extensively investigated the relationships of substrate oxidation in relation to various measures of exercise intensity.

Therefore, the aim of this study was to determine the possible differences in fat and carbohydrate oxidation when running and cycling at the same %WL\textsubscript{max}, VO\textsubscript{2max}, HR\textsubscript{max}, and RPE in individuals well trained in both running and cycling.

**Methods**

**Participants**

Ten well-trained male triathletes were recruited to participate in this investigation, which was approved by the Research and Ethics Committee of the Faculty of Health Sciences of the University of Cape Town. The criterion for participation in the study was the ability to complete a standard triathlon (1.5-km swim, 40-km cycle, and 10-km run) in 2 hr 30 min or less. The participants were informed of the nature of the exercise trials, all potential risks and benefits were explained to them, and informed written consent was obtained before participation in the study. Triathletes were chosen as participants because they are well trained in both running and cycling.

**Preliminary Testing**

**Peak Power Output and VO\textsubscript{2max} During Cycling.** Peak power output (W\textsubscript{peak}) and VO\textsubscript{2max} were measured on an electronically braked cycle ergometer (Computrainer Pro 3D, RacerMate, Seattle, WA, USA). The Computrainer ergometer allows cyclists to use their own bicycle for testing and ensured that the participants were accustomed to the setup of the bicycle. Participants performed a 10-min self-paced warm-up before beginning the test, after which the W\textsubscript{peak} test started at a workload of 2.5 W/kg body mass and followed a continuous ramp protocol increasing 20 W every minute. Participants were classified as having reached exhaustion when they could no longer maintain a cadence of at least 70 rpm. W\textsubscript{peak} was taken as the highest workload reached before the cadence dropped below 70 rpm. The W\textsubscript{peak} values were used to determine the intensities of the subsequent submaximal experimental trials.

**Peak Treadmill Running Speed and VO\textsubscript{2max} During Running.** Peak treadmill running speed (PTRS) and VO\textsubscript{2max} were measured on a motorized treadmill (Viasys, LE 500 CE, Nussdorf-Traunstein, Germany). Before the start of the test, the participants performed a 10-min self-paced warm-up. The test is a modified version of the progressive speed protocol employed by Noakes, Myburgh, and Schall (1990), with participants starting the test running at a speed of 1 km/hr slower than their running pace during their long training runs. The treadmill was set at an incline of 0.5% to account for the absence of wind resistance. After a minute running at the initial speed, the speed of the treadmill was increased by 0.5 km/hr. This speed was maintained for 30 s before being increased by another 0.5 km/hr. This was continued until the participant could no longer keep up with the treadmill. PTRS was taken as the last speed at which the participant could run for the entire 30 s and was used to determine the treadmill running speeds in the experimental trials that followed. The order of the PTRS and W\textsubscript{peak} tests was randomized.

During both cycling and running tests, VO\textsubscript{2} was measured over 15-s intervals using an online breath-by-breath gas-analyzer system (Oxycon, Viasys, Hoechberg, Germany). Before each test, the volume transducer was calibrated with a 3-L syringe, and the analyzers, with room air and a 4% CO\textsubscript{2}–96% N\textsubscript{2} gas mixture. HR\textsubscript{max} was determined using a Suunto (Öy, Vantaa, Finland) T6 heart-rate monitor. The preliminary tests were separated by at least a week.
Training History. Participants were asked to complete a retrospective questionnaire detailing their training history and athletic performance. They supplied detailed information about their training distances.

Food Diaries. Participants were instructed to complete a 3-day food diary for the 3 days preceding the first experimental trial. They were then asked to replicate this diet as closely as possible before the second experimental trial.

Experimental Trials

The order of the submaximal experimental trials followed the same (randomized) order as the preliminary Wpeak and PTRS tests. Participants reported to the laboratory at the same time each morning for both trials to avoid circadian variance. Before the start of each trial a cannula was placed in an antecubital forearm vein for blood sampling. A needle-free valve port (Smartsite, Cardinal Health) was attached to a high-pressure extension line (Mediveins Alpha, 1-mm internal diameter, 3-mm external diameter) and attached to the cannula to make blood sampling possible without the participant having to stop exercising. An initial (t = 0) blood sample (1 ml) was taken for baseline lactate analysis. All blood samples were collected into Vacutainers (Becton Dickinson, Rutherford, NJ) containing sodium fluoride and potassium oxalate. After sampling, the extension line and cannula were flushed with a 0.9% sodium chloride solution (SABAX, Adcock Ingrim Critical Care Ltd.) to keep patent. Heart rate was constantly measured during the trials using a Suunto T6 heart-rate monitor. Participants performed a 10-min self-paced warm-up before the start of the submaximal exercise trials.

Submaximal Cycling Trial. The cycling trials started at 60% of each participant’s Wpeak. Once a steady state, defined as a plateau in VO2, had been reached, the participants were asked their RPE using the 15-point Borg scale (Borg, 1970). Heart rate and VO2 data were recorded and a 1-ml blood sample was drawn before increasing the load. The workload was increased in 5% increments to 65%, 70%, 75%, and 80% Wpeak.

Submaximal Treadmill Running Trial. The trials started at a speed equal to 60% of each participant’s PTRS. Once steady state had been reached, the participants were asked RPE, VO2 data and heart rate were recorded, and a 1-ml blood sample was drawn before increasing the treadmill speed. As with the cycling protocol, speed was increased in 5% increments until 80% of PTRS had been reached.

Analyses

Blood samples were placed on ice immediately after collection, and plasma subsequently separated by centrifugation at 4,000 rpm for 10 min and stored frozen (−20 °C) until analysis on a YSI 2300 STAT Plus glucose and lactate analyzer.

Rates of fat and carbohydrate oxidation at each exercise intensity were computed and compared between both exercise modes by statistical analysis. VO2 and VCO2 values were substituted into the equations developed by Frayn (1983):

\[
\text{Carbohydrate oxidation (g/min) = } (4.55 \times VCO2) – (3.21 \times VO2) - 2.87 n
\]

\[
\text{Fat oxidation (g/min) = } (1.67 \times VO2) – (1.67 \times VCO2) - 1.92 n
\]

The VO2 and VCO2 values are in liters per minute. For the purposes of this study, nitrogen excretion (n) was regarded as negligible and therefore was excluded in the calculation.

Statistical Analysis

Statistical analyses were performed using Statistica software (StatSoft, Inc.). Differences between the preliminary testing data (maximal tests) were determined using paired t tests. Statistical significance of differences between exercise modes during the submaximal trials were assessed using a two-way analysis of variance (ANOVA) with repeated measures examining both intensity and mode effects. Tukey’s honestly significant difference (HSD) post hoc tests were performed when there was a significant interaction effect. Linear-regression analysis was used to determine differences in fat oxidation at the same percentage of VO2max, HRmax, RPE, and plasma lactate concentrations. Linear-regression analysis was performed on the data of each participant, and the slope and y intercept recorded. The average slope and y intercept were then used to plot a straight line using x values that fell within the range of measured values. A t test for individual samples was used to determine significant differences between the slopes and y intercepts between exercise modes. The level of statistical significance was taken at p < .05.

Results

Participants

Of the 10 participants recruited for this study, 9 completed all of the exercise trials. One withdrew from the study because of illness. Thus, the data presented are for the 9 participants who completed the study. Participant characteristics are presented in Table 1.

Preliminary Testing

The results from the preliminary tests are presented in Table 2. There was no significant difference in either VO2max or HRmax between the two exercise modes, although they both tended to be slightly higher in running than in cycling.

Intensity Matching Between the Running and Cycling Trials

WLmax refers to both Wpeak in the cycle test and PTRS in the treadmill test. The relationship between the %WLmax and %VO2max is shown in Figure 1. The %VO2max was...
Table 1  Physical Characteristics of the Participants, M ± SD, N = 9

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Value</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>32.3 ± 6.0</td>
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<tr>
<td>Height (cm)</td>
<td>179.3 ± 6.0</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>76.6 ± 4.1</td>
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Table 2  Results From the Preliminary Tests, M ± SD, N = 9

<table>
<thead>
<tr>
<th></th>
<th>Cycling</th>
<th>Running</th>
<th>Significance</th>
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</thead>
<tbody>
<tr>
<td>VO₂ max (ml O₂ · kg⁻¹ · min⁻¹)</td>
<td>58.2 ± 6.2</td>
<td>59.0 ± 5.6</td>
<td>NS (p = .41)</td>
</tr>
<tr>
<td>Maximum heart rate (beats/min)</td>
<td>179.7 ± 11.2</td>
<td>182.1 ± 10.7</td>
<td>NS (p = .24)</td>
</tr>
<tr>
<td>Peak power output (W)</td>
<td>376.7 ± 41.9</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Peak treadmill running speed (km/hr)</td>
<td>—</td>
<td>19.3 ± 1.4</td>
<td>—</td>
</tr>
</tbody>
</table>

The %HR max in both cycling and running at the same %WL max is presented in Figure 2. Two-way ANOVA with repeated measures showed an Exercise Mode × Intensity interaction of p = .002. A subsequent Tukey’s HSD post hoc analysis revealed a significantly higher %HR max during the cycling trial at 60% (p = .00016) and 65% (p = .015) of WL max. The %HR max at the same %WL max appeared higher in cycling than running at the remaining three exercise intensities, but these differences were not significant.

RPEs when running and cycling at different %WL max are shown in Figure 3. Although the RPE scores appeared higher during cycling than running at the same %WL max, the differences between the two modes were not significant (p = .311), despite the RPE scores being consistently 1 point higher in cycling than in running. The RPE increased in a linear fashion with increases in exercise intensity (%WL max) in both exercise modes.

The differences in plasma lactate concentrations when running or cycling at the same %WL max are shown in Figure 4. Blood samples were taken from only 8 of the 9 participants, so the lactate data are for 8 participants. Baseline lactate was 1.074 ± 0.216 mmol/L before the cycle-ergometer trial and 0.992 ± 0.313 mmol/L before the treadmill trial. These differences were not significant (p = 1.000). Two-way ANOVA with repeated measures showed an Exercise Mode × Intensity interaction (p = .009). A subsequent Tukey’s HSD post hoc analysis revealed significant differences in the plasma lactate concentrations between the two exercise modes at intensities of 65% (p = .007), 70% (p < .001), 75% (p < .001), and 80% (p < .001) of WL max. The coefficient of variance of the lactate measurements was 2.5%.

The energy expenditure (kJ/min) when running and cycling at identical %WL max is presented in Figure 5. There were no significant differences (p = .428), although the energy expenditure was somewhat higher during cycling than running. Therefore, %WL max appears to be an accurate way to match intensities between running and cycling.

Differences in Fat and Carbohydrate Oxidation Between Running and Cycling at Equivalent Percentages of WL max

Although respiratory-exchange ratio appeared to be higher during cycling than running at the same %WL max, these differences were not significant (p = .149; Figure 6). Neither was carbohydrate oxidation significantly different between the two exercise modes, despite being higher when cycling than when running at the same %WL max (p = .752; Figure 7).

Fat oxidation was found to be higher during running than during cycling over a wide range of intensities. Two-way ANOVA with repeated measures revealed an Exercise Mode × Intensity interaction (p = .002). A subsequent Tukey’s HSD post hoc analysis revealed that fat oxidation was higher when running than when cycling at 60% (p < .001), 65% (p < .001), 70% (p = .01), and 75% (p = .02) of WL max (Figure 8). Therefore, although the energy expenditure was not different at any %WL max between exercise modes, a significantly larger amount of energy was derived from fat during running than during cycling at any given %WL max up to 75% WL max.

It may initially seem mathematically impossible for there to be differences in fat oxidation but not in carbohydrate oxidation and energy expenditure. However, because the rate of carbohydrate oxidation is so much greater than that of fat oxidation (Figure 9) and carbohydrate oxidation was not significantly different between the two exercise modes, the significant differences in fat oxidation between the exercise modes...
Figure 1 — Percentages of cycling and running VO$_{2\text{max}}$ relative to percentages of workload maximum. Values are $M \pm SD; N = 9$.

Figure 2 — Percentages of cycling and running maximum heart rates at specific percentages of workload maximum. Values are $M \pm SD; N = 9$. *Significantly different from the treadmill trial, $p < .05$.

Figure 3 — Ratings of perceived exertion (RPE) when running and cycling at specific percentages of workload maximum. Values are $M \pm SD; N = 9$. 
Figure 4 — Plasma lactate concentrations when running and cycling at specific percentages of workload maximum. Values are $M \pm SD; N = 8$. *Significantly different from the treadmill trial, $p < .01$.

Figure 5 — Energy expenditure when running and cycling at submaximal intensities determined by percentage of workload maximum. Values are $M \pm SD; N = 9$.

Figure 6 — Respiratory-exchange ratio (RER) when cycling and running at specific percentages of workload maximum. Values are $M \pm SD; N = 9$. 
Figure 7 — Carbohydrate oxidation rates when running and cycling at specific percentages of workload maximum. Values are $M \pm SD; N = 9$.

Figure 8 — Fat oxidation rates when running and cycling at specific percentages of workload maximum. Values are $M \pm SD; N = 9$. *Significantly different from the cycling trial, $p < .05$.

Figure 9 — Fat and carbohydrate oxidation rates for both exercise modes at the same percentage of workload maximum. CHO = carbohydrate.
are obscured when the comparison of energy expenditure between the two exercise modes is made.

**Differences in Fat and Carbohydrate Oxidation Between Running and Cycling at Identical Percentages of VO₂max and HRmax**

Because %VO₂ max was not significantly different between running and cycling at any given %WL max, any differences in %HR max, plasma lactate concentration, respiratory-exchange ratio, or carbohydrate or fat oxidation found between running and cycling at the same %WL max will also apply when expressed at specific %VO₂ max. This is shown in Figure 10, in which the linear-regression analysis between fat oxidation rates and %VO₂ max shows differences in fat oxidation (as shown also in Figure 8 when expressed as %WL max). The slopes of the lines (Figure 10) were significantly different (p = .030), as were the y intercepts (p = .030).

The %HR max was not significantly different between the two exercise modes at 70%, 75%, or 80% WL max (Figure 2). Figure 11 illustrates the differences in fat oxidation between the two exercise modes at the same %HR max. The slopes of the two lines were not significantly different (p = .329), and neither were the y intercepts (p = .280). Therefore, although it appears higher during running, fat oxidation did not differ between the two exercise modes at the same %HR max.

![Figure 10](https://example.com/figure10.png)

**Figure 10** — Linear-regression analysis of fat oxidation rates at specific percentages of maximum oxygen uptake (VO₂ max); N = 9. *Slopes of the lines were significantly different between the two exercise modes, as were the y intercepts, p < .05. r² = 1 for both lines.

![Figure 11](https://example.com/figure11.png)

**Figure 11** — Linear-regression analysis of fat oxidation rates at specific percentages of maximum heart rate; N = 9.
Fat Oxidation in Running Versus Cycling

Differences in Fat and Carbohydrate Oxidation Between Running and Cycling at the Same RPE

Although fat oxidation tended to be higher in running than in cycling at intensities that elicit an RPE of less than 18 (Figure 12), these differences only approached significance, with the slopes of the lines having a p value of .053 and y intercepts a p value of .057.

Discussion

The main finding of this study was that fat oxidation is higher during running than cycling at certain relative intensities expressed as either %WL_max or %VO_{2\text{max}}. Although higher rates of fat oxidation in running than in cycling have been shown previously in studies in which exercise intensity was expressed as a %VO_{2\text{max}} (Knechtle et al., 2004; Achten et al., 2003), in one of these studies participants were not equally trained in both cycling and running, whereas the participants in the current study were well trained in both disciplines.

Relative exercise intensity can be determined using a variety of parameters, including %WL\_max, %VO\_2\text{max}, %HR\_max, and plasma lactate concentration. In order for a valid comparison of fat and carbohydrate oxidation between running and cycling, it is critical that the relative intensities between the two exercise modes be well matched. If not, any difference observed in substrate oxidation could merely be the result of differences in the WL\_max attained. Therefore, it was important to first determine whether there were any differences between %VO\_2\text{max} and %WL\_max. Note that there were no significant differences in either VO\_2\text{max} (Table 2) or %VO\_2\text{max} at the same %WL\_max between running and cycling (Figure 1). This is similar to some previous studies on triathletes (Hue, Le Gallais, Chollet, & Prefaut, 2000; Laursen, Rhodes, Langill, Taunton, & McKenzie, 2005; O’Toole, Hiller, Crosby, & Douglas, 1987), but not all; some studies have reported that triathletes obtain higher VO_{2\text{max}} values when running than when cycling (Basset & Boulay, 2000; Houmard et al., 1991; Kohrt, Morgan, Bates, & Skinner, 1987; Kohrt, O’Connor, & Skinner, 1989; Nieman et al., 1998; Schneider, Lacroix, Atkinson, Troped, & Pollack, 1990). Exercise involving a larger muscle mass (running involves a larger muscle mass than cycling) generally produces higher VO_{2\text{max}} values in untrained individuals (Millet, Vleck, & Bentley, 2009). However, it has been shown that athletes who have trained in cycling can either equal or exceed their VO_{2\text{max}} obtained in treadmill running on a maximal cycle-ergometer test (Pechar, McArdle, Katch, Magel, & DeLuca, 1974; Stromme, Ingjer, & Meen, 1977). The value of VO_{2\text{max}} depends on the protocol used and the exercise mode (running or cycling) used in training, as well as the exercise mode used to test it, with the highest values normally obtained during treadmill running (Kohrt et al., 1987; Kohrt et al., 1989). If there were differences in VO_{2\text{max}} between running and cycling, setting exercise intensity according to %VO_{2\text{max}} would have resulted in exercise being performed at two different absolute VO_{2} values, and thus the metabolic rate would have been different, even though intensity as determined by %VO_{2\text{max}} was the same. However, the exercise intensities in the current study were well matched between the two exercise modes, with no significant differences between %WL\_max, %VO_{2\text{max}} (Figure 1), or energy expenditure (Figure 5). Despite these similarities, rates of fat oxidation were significantly higher during running. Because there were no differences in VO_{2}, the differences in fat oxidation between the two exercise modes can be attributed to differences in VCO_{2}, because fat oxidation produces different amounts of CO_{2} to carbohydrate oxidation (Jeukendrup, Saris, & Wagenmakers, 1998).

Therefore, the differences seen in substrate oxidation...
between the two exercise modes are caused by factors other than a difference in exercise intensity (because the VO₂ is the same).

The higher fat oxidation rates in running than in cycling at the same %WL_max were significant at all exercise intensities except 80% WL_max. At this high %WL_max, fat oxidation rates were minimal in both exercise modes, as would be expected, because at even higher %WL_max fat oxidation will become zero.

Achten et al. (2003) found higher rates of fat oxidation in running than in cycling in a group of well-trained cyclists. However, the exercise intensities in Achten et al.’s study were fixed according to percentages of VO₂max, and because the participants attained a significantly higher VO₂ during the treadmill test than the cycle test, the absolute VO₂ at each of the intensities was therefore different between the two exercise modes. This difference could have caused the differences in substrate oxidation found. However, Knechtle et al. (2004) also showed higher fat oxidation rates in running than in cycling at the same percentages of VO₂max in men and women who trained regularly in both running and cycling. In contrast to Achten et al.’s study, there were no statistically significant differences in the VO₂max or %VO₂max values in either exercise mode in the current study, so the running and cycling trials can be considered to have been at the same VO₂ (which was probably not the case in Achten et al.’s study.).

In the current study, the %HR_max between the two exercise modes was significantly different at intensities of 60% and 65% WL_max. Figure 11 shows a linear-regression analysis of fat oxidation and %HR_max. Neither the slope nor the y-intercept was different between the two exercise modes, indicating that at the same %HR_max, fat oxidation is not significantly different between running and cycling. This is supported by the findings of Thomas et al. (1989), who showed no significant differences in the fat energy expenditure between treadmill walking and cycling at 65.2% HR_max in a group of physically active males. However, they did show that fat energy expenditure tended to be higher in treadmill walking than in cycling, but these differences were not significant. This may be because of the small number of participants used in the study (N = 5).

Although there were no significant differences in the RPE scores between the two exercise modes at any particular %WL_max, the participants consistently rated their exertion 1 point higher during cycling than during running. For example, at 60% WL_max the mean RPE score was 10 for running and 11 for cycling. This difference was constant for all exercise intensities. Hassmen (1990) showed that athletes generally rate the sport they are accustomed to as less strenuous than the sport they are unaccustomed to. However, the triathletes who participated in the current study were equally trained in both running and cycling. Therefore, any differences in RPE between the two exercise modes must be attributable to factors other than unfamiliarity with the exercise mode. For example, the more localized muscle tension during cycling (Achten et al., 2003; Carter et al., 2000) may have caused a higher RPE.

Although Figure 12 suggests a trend for fat oxidation to be higher in running than in cycling at any given RPE, this was not significant. To the best of our knowledge, no other studies have reported fat oxidation rates at specific RPE scores between running and cycling.

Plasma lactate concentrations were significantly higher in cycling than in running at the same %WL_max and thus, by inference from Figure 1, %VO₂max. This is similar to the findings of Knechtle et al. (2004), who showed higher plasma lactate concentrations in cycling than running at the same %VO₂max. In contrast, Achten et al. (2003) showed no significant difference in lactate concentration at submaximal intensities between these exercise modes. These two studies differ in the type of participants used, with the Achten group using well-trained male cyclists who were trained in only one of the exercise modes, whereas the Knechtle group used men and women who trained regularly in both running and cycling.

Although the purpose of the current study was not to determine the mechanisms responsible for the differences in fat oxidation between running and cycling, it is possible to speculate on possible causes. Because lipolysis is activated by the catecholamines, it is possible that the higher rates of fat oxidation measured in running than in cycling at the same relative intensity could have a biochemical etiology if catecholamine responses differ between running and cycling at the same relative intensity. However, this seems unlikely because Nieman et al. (1998) found no significant differences in norepinephrine and epinephrine levels after 2.5 hr of running at 75% VO₂max compared with 2.5 hr of cycling at the same relative intensity.

Achten et al. (2003) suggest another possible cause for the differences in fat and carbohydrate oxidation between running and cycling. They suggest that during cycling the workload may be divided over a smaller number of muscle fibers than in running. Therefore, the muscle strain during cycling is more localized, resulting in a higher relative workload on the muscles during cycling than during running at the same equivalent workload (Roberts & Alsphaugh, 1972). Thus, the metabolic stress on each muscle fiber is greater, and the energy requirement of each individual fiber is higher during cycling. It is possible that this increased energy requirement can only be met by the quick release of energy from carbohydrate stores. This may result in higher oxidation of carbohydrates with an associated higher production of lactate and a decrease in fat oxidation (Carter et al., 2000). In addition, Carter et al. propose that the eccentric muscle action in running may result in the recruitment of fewer Type II motor units during running than during cycling at the same relative intensity. Tsintszas, Simpson, Seeveratnam, and Jones (2003) also suggest that there is a greater recruitment of Type I fibers (reduced recruitment of Type II) during running than cycling. These authors also suggest that muscle glycogen utilization appears to
be higher in Type II fibers during cycling than during running in the first hour of submaximal exercise, which may be explained by the higher recruitment of Type II fibers in cycling than running. Findings by Arkinstall, Bruce, Nikolopoulos, Garnham, and Hawley (2001) support this—they showed a greater disappearance of muscle glycogen during cycling than during running at lactate threshold. Since it appears that more Type II fibers are recruited in cycling than running at submaximal intensities, and because Type II fibers are glycolytic fibers, resulting in a higher flux through the glycolytic pathway when recruited, an increase in carbohydrate oxidation and greater production of lactate would be expected. The findings of the current study support this possibility because lactate concentrations were higher during cycling than during running at the same relative intensities, and fat oxidation was lower. Type II fibers are glycolytic fibers, and a higher flux through the glycolytic pathway would result in an increase in carbohydrate oxidation and greater production of lactate. Further research is recommended to determine the causes of the differences observed.

The current study has shown that rates of fat oxidation are higher in running than in cycling at a wide range of exercise intensities. These differences occurred even though there were no significant differences in energy expenditure between the two exercise modes at the same relative intensities. The reasons for the observed differences in substrate oxidation, however, remain unclear.

Acknowledgments

Professors Mike and Vicki Lambert’s assistance with statistical analysis is greatly appreciated. Dr. J. Swart and R. Lamberts and Mrs. H. Victor are acknowledged for their technical assistance.

References


