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Higher Peak Fat Oxidation During Rowing vs. Cycling in Active Men and Women

Todd A. Astorino, Chandler Oriente, Jill Peterson, Giannina Alberto, Erica Elena Castillo, Ulices Vasquez-Soto, Esmerelda Ibarra, Victoria Guise, Ivan Castaneda, Joel R. Marroquin, Rachel Dargis, and Jacob S. Thum

Department of Kinesiology, California State University, San Marcos, California

Abstract

Astorino, TA, Oriente, C, Peterson, J, Alberto, G, Castillo, EE, Vasquez-Soto, U, Ibarra, E, Guise, V, Castaneda, I, Marroquin, JR, Dargis, R, and Thum, JS. Higher peak fat oxidation during rowing vs. cycling in active men and women. *J Strength Cond Res* 35(1): 9–15, 2021—This study compared fat and carbohydrate oxidation (CHOOx) between progressive rowing and cycling. Initially, 22 active healthy adults (age = 27 ± 8 years) performed incremental cycling and rowing to volitional fatigue to assess maximal oxygen uptake ($\dot{V}O_2$max) and maximal heart rate (HRmax). The order of 2 subsequent sessions was randomized, performed 2 hours postmeal, and included a warm-up followed by three 8-minute stages of rowing or cycling at 60–65, 70–75, and 80–85 %HRmax. During exercise, power output was modified to maintain work rate in the desired range. Gas exchange data and blood samples were obtained to measure fat and CHOOx and blood lactate concentration. Fat oxidation (FOx) increased during exercise ($p < 0.001$) and there was a main effect of mode ($p = 0.03$) but no modeXintensity interaction ($p = 0.33$). Peak FOx was higher in response to rowing vs. cycling ($0.23 \pm 0.09\ g\cdot min^{-1}$ vs. $0.18 \pm 0.07\ g\cdot min^{-1}$, $p = 0.01$). Carbohydrate oxidation increased during exercise ($p < 0.001$) but there was no effect of mode ($p = 0.25$) or modeXintensity interaction ($p = 0.08$). Blood lactate concentration was lower ($p = 0.007$) at the end of rowing vs. cycling (3.1 ± 1.0 mM vs. 3.9 ± 1.6 mM, $d = 1.1$). Prolonged rowing having equivalent calorie expenditure and intensity vs. cycling elicits higher peak FOx, which is likely attributed to greater muscle mass used during rowing.

Key Words: lipid oxidation metabolism, rowing ergometry, blood lactate concentration, metabolic health

Introduction

The change in fat and carbohydrate oxidation (CHOOx) during graded exercise is well-understood. At low intensities, the contribution of fat oxidation (FOx) to ATP supply is dominant and peaks at intensities approaching 60 percent of the workload associated with maximal heart rate (HR), peak power output (PPO), or oxygen uptake ($\dot{V}O_2$max) (6,42,43). As work rate continues to increase, FOx declines and CHOOx becomes the primary substrate to fuel exercising muscle because of progressive activation of higher threshold motor units, increasing reliance on glycogenolysis, and enhanced sympathetic activity (9).

Besides exercise intensity, the ratio of FOx vs. CHOOx during exercise is altered by additional factors including exercise training (40), nutritional state (16), sex (15), and ambient temperature (22). Another factor altering this ratio is exercise modality. For example, Capostagno and Bosch (13) reported higher FOx during running vs. cycling at similar relative intensities in male triathletes. Similarly, higher FOx was exhibited during walking vs. cycling at similar ratings of perceived exertion in active women (29). This discrepancy is explained by the smaller exercising muscle mass characteristic of cycling which requires greater force generation per muscle fiber and epinephrine release, which promotes glycolytic metabolism (13,14).

One alternative to cycling is rowing, which also supports the lower extremity. Similar to walking or running, this modality is characterized by use of a larger activated muscle mass that increases energy expenditure vs. small muscle mass exercise. There is increased popularity of rowing as a component of group fitness classes, and it may be used to benefit health status. Cross-sectional data report that 1 $h\cdot wk^{-1}$ of rowing reduces risk of heart disease by 18% (41). Previous data (20) showed significantly higher FOx during rowing vs. cycling at identical relative power outputs in trained rowers. However, these data were acquired in an athletic population ($\dot{V}O_2$peak = $57.5 \pm 1.5\ ml\cdot kg^{-1}\cdot min^{-1}$) during exercise in the fasted state, and the authors stated that additional study was merited in nonathletic adults performing testing in the postprandial state which may better represent the actual nutritional state of most exercisers before physical activity.

In addition, a reduced capacity to oxidize fat is associated with diabetes and obesity (17,27), and recent work (34) demonstrated a positive relationship between insulin sensitivity and maximal FOx, which is defined as the highest rate of fat utilization observed during exercise. There are also reports of diminished skeletal muscle and liver function in individuals with substantial fat deposition (38). Fat oxidation is lower in untrained compared with endurance-trained individuals (7), and in addition, low FOx has been associated with an unhealthy metabolic phenotype in men (36). Together, these findings establish the association between fat utilization and health status and emphasize the need to investigate the FOx response to exercise in various individuals.

Rowing and cycling are 2 nonweight bearing modes of physical activity that elicit substantial health- and fitness-related gains when performed chronically (5,10). However, there is limited work elucidating potential differences in energy metabolism across modes. The aim of the present study was to compare fat and CHO oxidation

Address correspondence to Todd A. Astorino, astorino@csusm.edu.

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in untrained healthy adults performing bouts of progressive rowing and cycling whose structure follows the Physical Activity guidelines to total 30 minutes of moderate intensity continuous exercise (23). It was predicted that rowing would elicit significantly higher FOx vs. CHOOx at all intensities, similar to prior work (20). These data will help practitioners identify the optimal non–weight-bearing exercise to augment FOx, which is associated with metabolic health and propensity for mass gain (36).

Methods

Experimental Approach to the Problem

Over a 2–3-week period, subjects completed 4 sessions separated by at least 48 hours, which were held at the same time of day within subjects. The initial 2 visits consisted of incremental exercise to volitional exhaustion on the cycle ergometer followed by the rowing ergometer to assess $\dot{V}O_2max$; whereas, the final 2 sessions consisted of continuous exercise whose order was randomized across subjects. During all bouts, gas exchange data were acquired. Subjects were instructed to eat a light meal 2 hours before all sessions and to meet our pretest guidelines, which required them to be well-rested, hydrated, and abstain from vigorous physical activity for 36 hours prior. Figure 1 denotes the experimental design used in the present study.

Subjects

Recreationally-active men ($n = 11$) and women ($n = 11$) completed the study who were recruited by word-of-mouth. They were healthy, nonobese adults who did not smoke. Subjects regularly performed resistance training, aerobic exercise, group exercise, or noncompetitive sport for greater than 150 min·wk^{-1} during the last year. Their age: >18 years old (mean ± SD), body mass index, and physical activity were equal to 27.8 ± 2.8 years, 24.5 ± 0.7 kg·m^{-2}, and 6.2 ± 0.8 h·wk^{-1}, and 27.0 ± 1.8 years, 22.7 ± 0.9 kg·m^{-2}, and 5.3 ± 0.7 h·wk^{-1}, respectively, for men and women. Only 3 subjects had prior rowing experience, and an additional 3 completed cycling, yet none was considered endurance-trained. The remaining 16 individuals had minimal experience with either modality. They completed a standard health-history questionnaire and provided written informed consent to participate in the study, whose procedures were approved by the California State University—San Marcos Institutional Review Board institutional review board.

Procedures

Assessment of $\dot{V}O_2max$. Initially, height and body mass were measured to calculate body mass index. Subsequently, subjects began incremental exercise on an electrically-braked cycle ergometer (Velotron RacerMate, Quark, SD) during which power output was increased in a ramp-like manner by 20–35 W·min^{-1} after a 2 min-warm-up at 40–70 W (4). Volitional exhaustion occurred when pedal cadence was below 50 rev·min^{-1}. Heart rate was determined using telemetry (Polar, Woodbury, NY), and pulmonary gas exchange data ($\dot{V}O_2$, $\dot{V}CO_2$, V_E, and respiratory exchange ratio [RER]) were obtained during exercise every 15 seconds using a metabolic cart (ParvoMedics True One, Sandy, UT) that was calibrated before testing following manufacturer guidelines. Five minutes after this bout, subjects were familiarized with exercise on the rowing ergometer (Model E, Concept 2, Morrisville, VT) during which they exercised for 1 minute at power outputs equal to 40, 50, 60, 70, and 80 W. They were encouraged to use proper form and maintain a given cadence, which were demonstrated to them by the investigators. They returned at least 2 days later at the same time of day and completed incremental rowing starting with a 2-minute warm-up at 30–60 W. The change in work rate during rowing was individualized for each subject based on their duration of ramp cycling, body mass, and familiarity with rowing, and ranged from 10 to 20 W·min^{-1}. This was implemented as subjects increased their stroke rate or rowed with more effort. This protocol was created from pilot testing conducted in 4 men and women of various body size and cardiorespiratory fitness who had previously completed incremental cycling to $\dot{V}O_2max$. These data showed nearly identical estimates of HRmax (<2 b·min^{-1}), PPO (<3 W), and $\dot{V}O_2max$ (<1 ml·kg^{-1}·min^{-1}) between 2 trials. Our goal was to modify power output to bring the subject to volitional fatigue in approximately 8–12 minutes, which follows best practice for $\dot{V}O_2max$ testing (31) while cycling or running. Incremental exercise ensued until volitional exhaustion, which was confirmed by inability to maintain the desired intensity for 20 seconds. Attainment of $\dot{V}O_2max$ was confirmed using the following criteria: change in $\dot{V}O_2$ < 0.15 L·min^{-1} at $\dot{V}O_2max$; HRmax within 10 b·min^{-1} of 220–age, and RER >1.10 (4). Maximal HR and PPO were identified as the value consequent with volitional exhaustion for both modalities. Two independent investigators identified the ventilatory threshold (VT) using the method of Caiozzo et al. (11), which was expressed as %$\dot{V}O_2max$.

Exercise Sessions. Upon arrival, subjects completed a brief survey confirming that they met all pretest guidelines for the session. Subsequently, they completed a 6-minute warm-up at 20 %PPO followed by three 8-minute stages of continuous exercise at 60–65, 70–75, and 80–85 %HRmax that were determined from the incremental test. We initiated exercise at a low intensity (20% PPO) that may be coincident with MFO, and gradually increased power output to elicit 3 workloads showing the typical change in

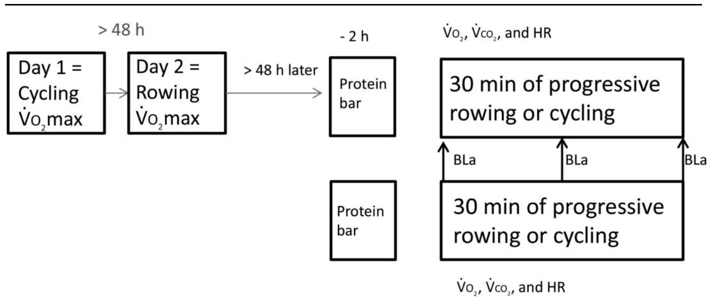

Figure 1. Experimental design.

fat and CHO oxidation with increased intensity and enable valid estimates of fat and CHO oxidation at a range of exercise intensities. This protocol was informed through pilot testing in the 4 men and women whose physical characteristics and $\dot{V}O_2$max were representative of the entire sample. We also used relatively long stages to be confident that a steady-state would be attained (8). During exercise, 15-second gas exchange data and HR were continuously recorded, and intensity was adjusted in increments of 5 %PPO to maintain HR in the desired zone.

Assessment of Fat and Carbohydrate Oxidation and Blood Lactate Concentration. Data from the last minute of the warm-up stage and the subsequent 3 stages of exercise were used to assess FOx and CHOOx. Oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) were calculated from these data and used to calculate RER. To determine FOx and CHOox, we used the following equations developed by Frayn (21): FOx (g·min^{-1}) = 1.67 $\dot{V}O_2$–1.67 $\dot{V}CO_2$; CHOOx (g·min^{-1}) = 4.55 $\dot{V}CO_2$–3.21 $\dot{V}O_2$. The peak FOx was identified as the highest 1-minute averaged value obtained at any point during exercise. It is apparent that the highest rate of FOx is associated with resting FOx and insulin concentration in young active men (3). Energy expenditure (in kcal) was estimated using values provided by the metabolic cart which assume that the role of protein is negligible.

Before exercise after 5 minutes of seated rest, a 0.7 μL blood sample was acquired from a fingertip using a lancet (Owen Mumford Inc., Marietta, GA) and portable monitor (Lactate Plus, Sports Research Group, New Rochelle, NY) to assess blood lactate concentration (BLa). The fingertip was cleaned with a damp towel, dried, the first drop of blood was wiped away, and the second drop was placed on the strip that was inserted into the monitor. This measure was repeated 4 minutes into exercise at 70–75 %HRmax when subjects stopped exercise for approximately 20 seconds, and 3 minutes postexercise following similar procedures.

Monitoring of Dietary Intake. Subjects completed a 24-hour food diary before the first experimental session. They were asked to write down all food and drink ingested and to list portion sizes and brands of all items. This diary was photocopied and returned to each subject to be followed before the final visit. They were provided a standardized dinner to be ingested the night before each trial (small sandwich and chips from Jersey Mike's, Manasquan, NJ, 980–1,240 kcal, 95–115 g CHO, 45–60 g fat, 40–50 g protein equal to 39% CHO, 40% fat, and 20% protein) and a light meal to be ingested 2 hours before, which consisted of a protein bar (Zone Perfect, Abbott, Abbott Park, IL, 210 kcal, 24 g CHO, 7 g fat, 14 g protein equal to 45 %CHO, 30% fat, and 25% protein).

Statistical analyses

Data are reported as mean ± *SD* and were analyzed using SPSS Version 24 (Armonk, NY). Normality of all variables was determined using the Shapiro-Wilks test. To identify differences in outcomes between modalities, three-way repeated measures analysis of variance (ANOVA) (mode = 2 levels, intensity = 4 levels, sex = 2 levels) was used. Paired *t*-test was used to assess differences in peak FOx and calorie expenditure between rowing and cycling. Independent t-test was used to compare $\dot{V}O_2$max and PPO between men and women. If a significant F ratio was obtained, Tukey's post-hoc test was used to identify differences between means. The Greenhouse-Geisser correction was used if the sphericity assumption was violated. Cohen's *d* was used as a measure of effect size. Statistical significance was set at $p < 0.05$.

Results

Table 1 exhibits that $\dot{V}O_2$max ($p = 0.36$) and HRmax ($p = 0.41$) were not different between modes, although PPO was higher ($p < 0.001$) in response to cycling vs. rowing. Similarly, maximal values of V_E ($p = 0.009$) and RER ($p < 0.001$) were higher in response to cycling. Men displayed higher $\dot{V}O_2$max ($p < 0.001$) on the cycle ergometer (43.3 ± 4.0 vs. 34.2 ± 4.8 ml·kg^{-1}·min^{-1}) and rowing ergometer (43.0 ± 4.4 vs. 36.0 ± 3.8 ml·kg^{-1}·min^{-1}) compared with women. A similar outcome ($p < 0.001$) was shown for PPO on the cycle ergometer (310 ± 40 vs. 220 ± 39 W) and rowing ergometer (248 ± 58 vs. 155 ± 30 W) between men and women.

Changes in $\dot{V}O_2$, $\dot{V}CO_2$, Heart Rate, and Respiratory Exchange Ratio in Response to Progressive Exercise

Multiple three-way ANOVAs were performed on our sample of 22 subjects to examine the effect of sex, level of intensity, and exercise mode on each variable. Table 2 demonstrates changes in these outcomes during rowing and cycling. $\dot{V}O_2$ and $\dot{V}CO_2$ increased during exercise ($p < 0.001$) but there was no main effect of mode ($p = 0.71$; $p = 0.92$) or modeXintensity interaction ($p = 0.27$; $p = 0.17$). There was an increase in HR ($p < 0.001$) in response to exercise and a main effect ($p = 0.03$) and interaction ($p = 0.045$). Post-hoc analyses showed that compared with rowing, HR in response to cycling was lower during the warm-up (55.8 ± 6.4 %HRmax vs. 58.8 ± 6.3 %HRmax, $d = 0.72$), yet was similar at other intensities. Respiratory exchange ratio showed that CHO was the primary substrate oxidized during exercise at all intensities (Figure 2). This outcome increased during exercise ($p < 0.001$) and there was a main effect of mode ($p = 0.03$), but no modeXintensity ($p = 0.24$), intensityXsex ($p = 0.82$), modeXsex ($p = 0.14$), or intensityXmodeXsex interaction ($p = 0.51$) was evident.

Changes in Fat and Carbohydrate Oxidation in Response to Progressive Exercise

Figure 3 demonstrates changes in FOx and CHOOx in response to rowing and cycling. Fat oxidation increased during exercise ($p < 0.001$) and there was a main effect of mode ($p = 0.03$), but no modeXintensity ($p = 0.33$), intensityXsex ($p = 0.11$), modeXsex

Table 1

Comparison of data from $\dot{V}O_2$max testing between cycling and rowing (mean ± *SD*).*

Parameter	Cycling	Rowing	*p*
$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})	38.7 ± 6.3	39.4 ± 5.4	0.36
PPO (W)	265 ± 60	201 ± 65	<0.001
HRmax (b·min^{-1})	183 ± 12	181 ± 9	0.41
RERmax	1.29 ± 0.08	1.17 ± 0.07	0.009
$V_E$max (L·min^{-1})	119 ± 30	103 ± 27	<0.001
Duration (min)	10.1 ± 1.1	11.4 ± 1.1	<0.001
VT (%$\dot{V}O_2$max)	69.9 ± 7.7	71.6 ± 7.9	0.24

*PPO = peak power output; HR = heart rate; RER = respiratory exchange ratio; V_E = ventilation; VT = ventilatory threshold.

Table 2

Physiologic responses to progressive cycling and rowing (mean ± *SD*).*†

Parameter	Modality	Warm-up	60–65 %HRmax	70–75 %HRmax	80–85 %HRmax
$\dot{V}O_2$ (L·min^{-1})	Cycling	0.92 ± 0.17	1.19 ± 0.37	1.55 ± 0.47	1.93 ± 0.58
	Rowing	0.99 ± 0.23	1.20 ± 0.24	1.53 ± 0.40	1.93 ± 0.47
$\dot{V}CO_2$ (L·min^{-1})	Cycling	0.82 ± 0.15	1.08 ± 0.35	1.46 ± 0.45	1.91 ± 0.58
	Rowing	0.88 ± 0.22	1.09 ± 0.22	1.42 ± 0.39	1.88 ± 0.48
RER	Cycling	0.90 ± 0.04	0.92 ± 0.04	0.95 ± 0.03	0.99 ± 0.04
	Rowing	0.88 ± 0.05	0.91 ± 0.04	0.92 ± 0.03	0.96 ± 0.04‡
HR (%HRmax)	Cycling	56.0 ± 6.0	64.0 ± 3.0	72.4 ± 3.0	83.6 ± 2.4
	Rowing	59.0 ± 6.0‡	65.0 ± 3.0	72.7 ± 3.0	84.9 ± 2.6

*$\dot{V}O_2$ = oxygen consumption; $\dot{V}CO_2$ = carbon dioxide production; RER = respiratory exchange ratio; HR = heart rate.
†Note that these data are collapsed across sex.
‡$p < 0.05$ vs. cycling.

($p = 0.33$), or intensityXmodeXsex interaction ($p = 0.94$). Compared with cycling, FOx at all intensities was higher during rowing and in men compared with women, albeit these differences were nonsignificant. Peak FOx was significantly higher in rowing vs. cycling (0.23 ± 0.09 g·min^{-1} [95% CI = 0.20–0.27 g·min^{-1}] vs. 0.18 ± 0.07 g·min^{-1} [95% CI = 0.15–0.22 g·min^{-1}]), ($t(21) = 2.84$, $p = 0.01$, $d = 0.65$), with individual differences in this outcome shown in Table 3. All subjects who habitually performed rowing demonstrated higher peak FOx during this modality compared with cycling, similar to those who tended to engage in running or running combined with resistance training. Carbohydrate oxidation increased during exercise ($p < 0.001$) but there was no effect of mode ($p = 0.25$), modeXintensity ($p = 0.08$), modeXsex ($p = 0.79$), or intensityXmodeXsex interaction ($p = 0.77$), although there was a significant intensityXsex interaction ($p < 0.001$). CHO oxidation in response to both modalities was significantly higher at all intensities in men compared with women ($d = 0.6$–1.7), likely attributed to differences in body size and $\dot{V}O_2$max. In addition, results exhibited nonsignificantly greater CHOOx during cycling at all intensities with exception of the warm-up.

Changes in Blood Lactate Concentration and Energy Expenditure

Figure 4 exhibits the change in BLa during exercise. There was a main effect of intensity ($p < 0.001$) and modeXintensity interaction ($p = 0.007$), although there was no main effect of mode ($p = 0.17$). Post-hoc results showed that all values differed from each other, and the postexercise BLa value was higher ($d = 1.1$) in response to cycling vs. rowing. Energy expenditure was similar between cycling and rowing (199 ± 55 vs. 204 ± 47 kcal, $p = 0.43$).

Discussion

Augmenting FOx is important to spare muscle glycogen (25) and potentially prevent chronic disease because of its association with indices of metabolic health (33,34,36). Data acquired in trained rowers show significantly greater FOx during progressive rowing vs. cycling (20). The present study advanced this topic by recruiting untrained adults, whose capacity for FOx is lower vs. athletes (39), and performing testing in the fed state which better simulates recommended dietary practice preceding exercise (3).

Table 3

Individual differences in peak fat oxidation for 22 active adults participating in progressive rowing and cycling.*

Subject	Training	Peak FOx_R (g·min^{-1})	Peak FOx_{Cyc} (g·min^{-1})
M	Sports, RT, and cycling	0.20	0.22
M	Running and RT	0.36	0.17
F	Dance and RT	0.09	0.13
M	Cycling and hiking	0.34	0.23
F	Running	0.20	0.27
M	Cycling and RT	0.25	0.27
F	Rowing	0.15	0.04
M	Cycling	0.25	0.28
F	Running	0.13	0.16
M	Rowing and RT	0.35	0.29
F	Rowing and RT	0.26	0.11
F	Running	0.34	0.26
M	RT and sports	0.28	0.23
F	Running and surfing	0.30	0.24
M	RT and basketball	0.33	0.09
F	RT and group exercise	0.11	0.08
M	Running and soccer	0.11	0.11
F	RT and group exercise	0.21	0.16
M	RT	0.18	0.20
F	Running	0.20	0.12
F	Running	0.28	0.14
M	RT and sports	0.21	0.20

*M = male; F = female; Training = various modes of habitual activity; RT = resistance training; FOx = fat oxidation; R = rowing; Cyc = cycling.

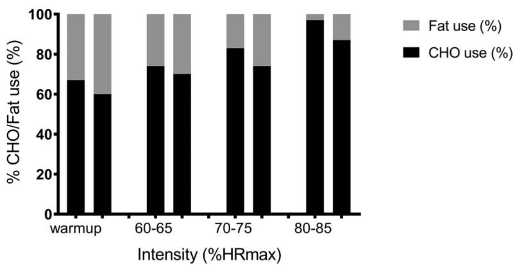

Figure 2. Change in fat and CHO contribution during progressive rowing and cycling. During each stage, the bar on the left corresponds to cycling and the bar on the right represents rowing.

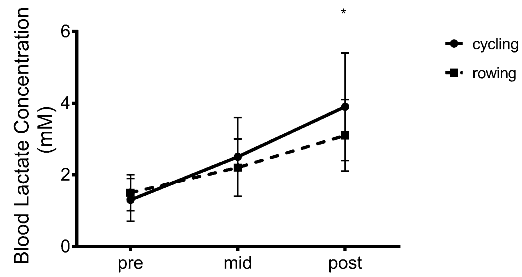

Figure 4. Change in blood lactate concentration during progressive cycling and rowing (mean ± *SD*). **p* < 0.05 vs. cycling.

Results show similar FOx during rowing compared with cycling at 4 submaximal intensities that refute prior work showing a significantly higher FOx during running and rowing vs. cycling (13,20). However, peak FOx was significantly higher in response to rowing vs. cycling.

One challenge when comparing responses between rowing and cycling is the significantly greater $\dot{V}O_2$ observed during rowing vs. cycling at identical absolute intensities (24). This result is attributed to the greater contracting muscle mass and lower efficiency of rowing (24). Our results show no significant difference in calorie expenditure, $\dot{V}O_2$, or $\dot{V}CO_2$ between rowing and cycling (Table 2), which reduces any potential effect of differences in metabolic rate or energy expenditure on our data and allows us to better examine the effect of exercise mode on our outcomes.

In contrast to a previous study showing significantly higher FOx at 5 work rates ranging from 43–84 %$\dot{V}O_2$max (20), our data reveal no difference in FOx between rowing vs. cycling. However, peak FOx was greater in response to rowing vs. cycling, which we attribute to less variability in this outcome across subjects. This difference in peak FOx was moderate in magnitude, greater than our lab's (~0.05 g·min^{-1}, 6) and others' day-to-day variability in FOx (18), and similar to training-induced changes in FOx previously demonstrated (5,30). One potential explanation for this lack of difference across all intensities is our inclusion of men and women, because sex is a mediator of substrate metabolism (16). Hormonal fluctuations characteristic of the menstrual cycle may modify FOx (12); however, Horton et al. (26) reported no effect of the menstrual cycle on energy metabolism. This discrepancy may have caused greater variability in our data and in turn, a reduced ability to detect consistent differences in energy metabolism between modes. Second, rowing at the lowest intensity was very awkward for many subjects, and it is possible that their inability to efficiently row at workloads equal to 20 % PPO (~35 W) may alter $\dot{V}O_2$ and $\dot{V}CO_2$ and mask any potential differences in FOx at this intensity. Third, the study by Egan et al. (20) used club-level rowers whose muscles were likely more familiar with rowing vs. cycling. They only performed 1.5 h·wk^{-1} of cycling, and this greater familiarity with rowing may have increased their capacity to oxidize more fat during this modality. It is apparent that chronic endurance training elicits mitochondrial adaptations in the trained muscle (25) that augment FOx. In the present study, 16/22 subjects had little experience with rowing and cycling, and their cycling-derived $\dot{V}O_2$max is classified as average for young adults (27). It is plausible that extensive training in certain muscles, including the trunk and upper body in rowing and quadriceps in cycling, may lead to differences in energy metabolism between different exercise modes. However, most of our subjects did not complete habitual training in either modality, so it likely that they lack these adaptations leading to minimal differences in FOx between modes.

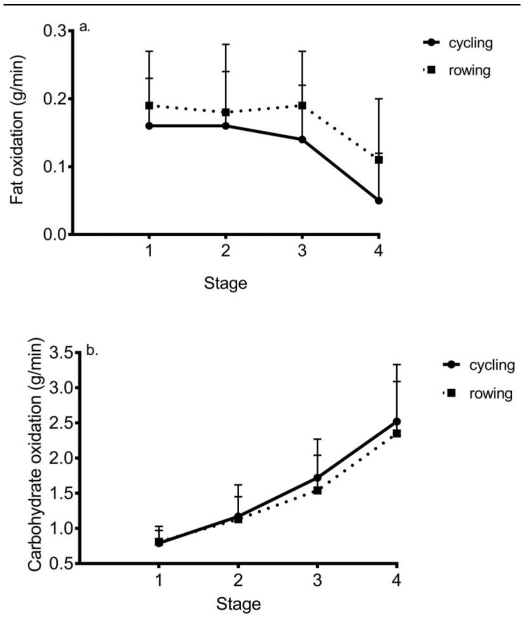

Figure 3. Change in fat and carbohydrate oxidation during progressive cycling and rowing (mean ± *SD*).

One prevailing explanation for greater FOx during rowing vs. cycling is the activation of a larger muscle mass. The exercise-induced release of catecholamines including epinephrine and norepinephrine, which activates lipolysis, is related to the size of working muscle mass (19), so it is likely that rowing is characterized by greater muscle catecholamine concentration. Nevertheless, one study (32) showed no difference in catecholamine levels after 2.5 hours of moderate cycling and running, so it is unclear whether this mediates potential differences in energy metabolism, especially during a relatively brief session of exercise. An additional explanation related to the different amount of working muscle is that cycling requires greater energy production per fiber to maintain contraction, which may increase reliance on carbohydrate utilization (2) which was evident in our results (Figures 1 and 2), although the difference in CHOOx was not significant. A prior study in endurance athletes (3) also showed that BLa accumulation is strongly related to a reduction in FOx. A third explanation has to do with potential differences in contraction type between rowing and cycling. Cycling requires concentric contraction of the quadriceps; whereas, rowing involves rapid extension of the lower extremity followed by use of the upper extremity and then a recovery phase (24). It is possible that the mechanics of rowing induce a stretch-shortening cycle that conserves energy, delays peripheral fatigue, and reduces activation of fast twitch motor units, which has been speculated to explain part of the higher FOx seen during running vs. cycling (13). Additional study characterized by measurement of concentrations of free fatty acids, muscle glycogen, and catecholamines is needed to better understand potential differences in energy metabolism between rowing and cycling at equivalent intensities.

Our study has a few limitations. First, these data do not apply to older adults who are sedentary or obese. Second, the exercise protocol began at intensities between 55–60 %HRmax, so we cannot identify whether maximal FOx was attained in our subjects. We chose to implement exercise according to %HRmax rather than $\%\dot{V}O_2$max, as used in a prior study (2). This was done as we believed that selecting exercise intensity based on HR is more applicable to the health and fitness practitioner than a select fraction of $\dot{V}O_2$max. Typically, FOx reveals a bell-shaped or parabolic curve (1) which was not shown by our results or data from a prior study in untrained men (9). The final stage of exercise elicited approximately 75 $\%\dot{V}O_2$max, slightly above subjects' VT, and was attendant with BLa equal to 3–4 mM. This value is likely associated with additional CO_2 production from bicarbonate buffering at this intensity, which may lead to an underestimation of FOx. However, Romijn et al. (37) demonstrated that indirect calorimetry was valid to identify whole-body fat and CHO oxidation up to 85 $\%\dot{V}O_2$max in cyclists. Finally, our estimations of energy expenditure assume a nonprotein RER. Nevertheless, our study is strengthened by strict consideration of food intake in the 24 hours before each session and use of identical exercise intensities, energy expenditure, and $\dot{V}O_2$max between the rower and cycle ergometer. We acknowledge that to identify maximal FOx, testing needs to be performed in the fasted state; however, we conducted testing in the fed state to better simulate typical nutritional practices followed (eating a light meal) before exercise (35). In addition, we used 6- and 8-minute stages that will elicit a steady-state and hence more reliable determinations of fat and CHOOx compared with shorter stages, especially in untrained adults (8).

Practical Applications

Fat oxidation is related to onset of obesity and diabetes that contribute to metabolic health. Rowing ergometry is becoming a more popular exercise modality in many fitness centers, partially because it requires a larger muscle mass than cycling that may reduce leg pain and subsequent enjoyment of exercise. Our results show that compared with cycling, a 30-minute bout of submaximal rowing leads to higher peak FOx and lower blood lactate accumulation. Adults aiming to burn more fat should choose rowing rather than cycling to achieve this goal.

Acknowledgments

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