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Research article

Peak fat oxidation rate during walking in sedentary overweight men and women

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Abstract

The aim of this study was to determine the relative exercise intensity that elicits maximal fat oxidation during walking in inactive and overweight men and women and evaluate any possible sex differences. Forty six healthy, sedentary, overweight men (age: 36.3±1.3 years, body fat: 28.8 ± 0.8%, n = 28, mean ± SE) and women (age: 36.6±1.8 years, body fat: 37.1 ± 0.8%, n = 18) participated in the study. Fat oxidation was calculated from expired air analysis using indirect calorimetry during an incremental treadmill walking test. Peak fat oxidation rate (PFO) was higher in men compared to women (0.31 ± 0.02 vs. 0.20 ± 0.02 g·min^{-1}; $p < 0.001$), but this difference disappeared when PFO was scaled per kg fat-free mass (4.36 ± 0.23 vs. 3.99 ± 0.37 mg·kg fat free mass^{-1}·min^{-1}). Also, the relative exercise intensity at which PFO occurred was similar for men and women and corresponded to 40.1 ± 1.8 and 39.5 ± 2.3% of maximal oxygen uptake (VO_{2max}) and 60.0 ± 1.4 and 57.8 ± 1.4% of maximal heart rate, respectively. The walking speed corresponding to PFO was 5.5 ± 0.2 and 5.0 ± 0.1 km·h^{-1} for men and women, respectively. Regression analysis showed that sex, FFM and VO_{2max} were significant predictors of PFO expressed in g·min^{-1} (adjusted $R^2 = 0.48$, $p = 0.01$). However when PFO was scaled per kg FFM, only a small part of the variance was explained by VO_{2max} (adjusted $R^2 = 0.12$, $p < 0.05$). In conclusion, peak fat oxidation rate and the corresponding relative exercise intensity were similar in male and female overweight and sedentary individuals, but lower compared to those reported for leaner and/or physically active persons. Walking at a moderate speed (5.0-5.5 km·h^{-1}) may be used as a convenient way to exercise at an intensity eliciting peak fat oxidation in overweight individuals.

Key words: Exercise intensity, calorimetry, substrate utilisation.

Introduction

Physical activity in the form of regular exercise is often prescribed to facilitate weight loss and improve health and fitness of overweight individuals (Bensimhon et al., 2006). Walking is the most popular activity among adults of all ages because it is easy to perform and has a low risk of injury (Hardman, 1999). Several studies have reported that apart from weight management (Hill and Peters, 1998), walking may be an effective form of exercise to improve lipoprotein profile and insulin sensitivity in patients with increased body fat (Dumortier et al., 2003; Hardman, 1999). However, the choice of the most appropriate exercise intensity for overweight individuals is a challenge. Previous studies have shown that training at a low intensity (40% of maximal oxygen consumption; VO_{2max}) results in increased fat oxidation during exercise in a group of obese male subjects, while a higher training intensity (70% VO_{2max}) had no effect on total fat oxidation during exercise or rest (Van Aggel-Leijssen et al., 2002). A recent study in obese individuals (Venables and Jeukendrup, 2008) has shown that that insulin sensitivity and the contribution of fat to substrate oxidation during exercise were increased by 27% and 44%, respectively, following a period of training using continuous exercise at an intensity that elicited maximal fat oxidation (~44% VO_{2max}). Interestingly, no changes in these parameters were seen after a eucaloric interval training protocol at higher exercise intensity (~65% VO_{2max}; Venables and Jeukendrup, 2008). Thus, exercising at an intensity that elicits peak fat oxidation rate (PFO) may be preferable in obese persons. However, there is large variation of the relative exercise intensity at PFO and there is evidence to suggest that this may be affected by body composition, exercise mode and sex (Achten et al., 2003; Perez-Martin et al., 2001; Tarnopolsky, 2008). Recent studies have shown that in young and healthy trained individuals maximal rates of fat oxidation are reached at intensities between 59% and 64% VO_2max (Achten and Jeukendrup, 2004), while these values were lower (48%VO_2max) in a large sample of the general population (Venables et al., 2005). Unfortunately, the majority of studies have been performed on relatively young individuals with moderate or high maximal oxygen uptake (VO_{2max}) and normal body composition, while there is little information regarding fat oxidation in obese individuals (Perez-Martin et al., 2001). Furthermore, most studies used cycling (e.g. Achten and Jeukendrup, 2003; 2004; Perez-Martin et al., 2001), that is a mode of exercise where fat oxidation is ~30% lower compared to walking at an equivalent intensity, possibly due to the relatively smaller muscle mass recruited (Achten et al., 2003).

To our knowledge, there are only three studies that determined peak fat oxidation during walking (Achten et al., 2003; Venables et al., 2005; 2008). However, walking speed in those studies was relatively fast (6.5 to 7.5 km·h^{-1}) and possibly not convenient for overweight and sedentary individuals. These speeds are closer to the transition speed from walking to running of 7.2 km·h^{-1} and much faster than the self-selected speed of around 5 km·h^{-1} (Minetti et al., 2003). Therefore, there is a lack of information regarding fat oxidation at walking speeds close to those that may be selected by overweight and obese individuals during walking (Browning et al. 2006). Also, there is still controversy regarding the importance of sex on fat oxidation and there are studies in which data of fat oxidation for males and females are pooled (Perez-Martin et al., 2001). There is strong evidence that the proportion of energy derived from fat during exercise is higher in

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women than in men due to differences at the hormonal as well at the skeletal muscle level (Blaak, 2001, Tarnopolsky, 2008). Women compared with men have higher mRNA content for genes involved in fat metabolism in skeletal muscle (Tarnopolsky, 2008), as well as higher content of intramuscular triglycerides that may contribute to the higher fat oxidation (Blaak, 2001). However, increased adiposity in combination with inactivity may affect fat metabolism (Perez-Martin et al., 2001) and thus it may be hypothesized that sex differences in fat oxidation may not be as pronounced in overweight and sedentary individuals. Therefore, the aim of the present study was to determine the relative exercise intensity that corresponds to PFO during walking in inactive and overweight men and women and examine any possible sex differences. It was hypothesized that PFO would occur at a lower intensity in obese adults. The evaluation of the individual PFO intensity during walking has significant practical applications since this mode of exercise is commonly used to reduce body fat and lower the risk of metabolic diseases in this population.

Table 1. Physical characteristics and predicted maximal oxygen uptake (VO_{2max}) expressed in absolute ($l·min^{-1}$) and relative units (per kg body mass and per kg FFM). Values are mean (±SE).

	MEN (n = 28)	WOMEN (n = 18)
Age (y)	36.3 (1.3)	36.6 (1.8)
Height (m)	1.77 (.01)	1.66 (.01)**
Body mass (kg)	97.9 (2.3)	78.3 (3.5)**
BMI ($kg·m^{-2}$)	31.2 (.7)	28.1 (1.0)**
Body Fat (%)	28.8 (.8)	37.1 (.8)**
FFM (kg)	69.5 (1.5)	49.0 (1.9)**
Fat mass (kg)	28.4 (1.2)	29.3 (1.8)
Waist to hip ratio	.89 (.01)	.77 (.01)**
VO_{2max} ($l·min^{-1}$)	3.14 (.11)	2.10 (0.12)**
VO_{2max} ($ml·Kg^{-1}·min^{-1}$)	32.3 (1.2)	27.2 (1.5)**
VO_{2max} ($ml·Kg\ FFM^{-1}·min^{-1}$)	45.2 (1.2)	43.2 (2.2)

FFM: fat free mass. ** $p < 0.01$ from MEN.

Methods

Participants

Forty six inactive overweight individuals (Table 1) gave their informed consent and volunteered to participate in the study that had Institutional Ethical Committee approval. All procedures conformed to the Code of Ethics of the World Medical Association. Body fat was estimated from skinfold thickness (biceps, triceps, subscapular, suprailiac) using the equations of Durnin and Womersley (1974). The criteria for participation were a body mass index (BMI in $kg·m^{-2}$) greater than 25 and a percent body fat above the 90th percentile of the respective age and sex group of the general population, according to the norms provided by the American College of Sports Medicine (ACSM) (ACSM, 2005). All participants were non – smokers and followed a sedentary lifestyle. Sedentary status (i.e. not participating in any regular exercise for at least one year prior to the study and sedentary job), was assessed via personal interviews. All participants were asked to abstain from food or caffeine containing beverages for at least four hours prior to the main test. They were also instructed to avoid intense and/or prolonged walking for two days before the main test. nd had not taken part in any systematic exercise program for at least one year before the start of the study

Procedures

Prior to the exercise test, participants performed a 5 min warm-up at a comfortable speed (4.0-4.5 $km·h^{-1}$), followed by a 5 min stretching period. The exercise test included five continuous, 4-minute stages of treadmill walking under neutral environmental conditions (ambient temperature: 20.5-22 °C, relative humidity: 45-55%). The initial speed was defined subjectively so that the participant could walk easily at a slow pace. The speed was increased by 0.3-0.5 $km.h^{-1}$ at each stage, while during stages 3-5 the gradient was also increased by 1-2% if necessary. Gradient was increased in order to raise exercise intensity without potentially altering normal gait kinematics due to an unreasonably fast walking speed [>7.2 $km·h^{-1}$ according to Minetti et al. (2003)]. This was Oxygen uptake (VO_2) and carbon dioxide (CO_2) output were measured breath-by breath (SensorMedics 29Vmax system) and averaged over the last minute of each stage. Non-protein substrate oxidation was calculated using indirect calorimetry following the stoichiometric equations of Jeukendrup and Wallis (2005). From these data, the intensity of exercise at which energy derived from oxidation of carbohydrate equals that derived from fat, i.e. the crossover point (Brooks and Mercier, 1994) and the intensity at which the highest rate of fat oxidation was observed (i.e. PFO) were obtained for each individual. Heart rate (HR) was continuously monitored by telemetry (Polar Vantage HR monitor, Finland). VO_{2max} was estimated by linear extrapolation of the linear regression between VO_2 and HR values at each stage to the theoretical maximal HR of each individual according to age (Miller et al., 1993).

Statistical analysis

Comparisons between men and women for oxygen uptake, respiratory exchange ratio (RER), fat and carbohydrate oxidation during the five stages of exercise, were performed by two-way ANOVA (sex × stage) with repeated measures on one factor (sex). Significant differences between means were determined using Tukey's Post hoc tests for unequal groups (Spjotvoll/Stoline adjustment). Also, unpaired Students's t-tests were used to compare physical characteristics, VO_{2max} and PFO between men and women. Statistical analysis was performed using the SPSS statistical package (SPSS, v. 15, Chicago, IL). Effect size was estimated for main effects and interaction by calculating partial eta squared (η^2) values using the SPSS v. 15 statistical package. Effect size for pairwise comparisons between men and women was assessed with Cohen's d using the pooled standard deviation of the two means compared. Effect sizes were classified as small (0.2), medium (0.5) and large (>0.8).

Bivariate correlations were performed between PFO in $g.min^{-1}$ and relative to FFM with the following independent variables: sex, BMI, FFM, percent body fat,

Table 2. Relative exercise intensity (%VO_{2max}), respiratory exchange ratio (RER) and absolute oxygen uptake (VO_2) for the five stages of the incremental treadmill test. Values are mean (±SE) for men (n = 28) and women (n = 18).

	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
			% VO2max		
Men	33.6 (1.3)	38.4 (1.6)	44.3 (1.7)	50.5 (1.7)	58.7 (1.7)
Women	36.1 (2.0)	42.4 (2.4)	46.8 (2.9)	51.7 (2.9)	57.7 (3.9)
			RER		
Men	.84 (.01)	.86 (.01)	.89 (.01)	.92 (.01)	.95 (.00)
Women	.85 (.01)	.88 (.01)	.91 (.01)	.93 (.01)	.95 (.01)
			VO2 ($l·min^{-1}$)		
Men	1.05 (.050)	1.198 (.062)	1.384 (.066)	1.579 (.075)	1.842 (.082)
Women	.738 (.048)**	.863 (.053)**	.951 (.059)**	1.052 (.06)*	1.172 (.077)**

** $p < 0.01$ from Men.

waist-to-hip ratio, VO2max per kg body mass ($ml·Kg^{-1}·min^{-1}$) and per kg FFM ($ml·Kg\ FFM^{-1}·min^{-1}$). Stepwise multiple linear regression analysis was then used to determine the predictors of PFO in absolute and relative terms with independent variables that were significantly correlated with PFO in the bivariate analysis (SPSS, v. 15, Chicago, IL). Results are presented as mean and standard error of the mean (SE).

Results

Physical characteristics and the predicted VO_{2max} of the participants are shown in Table 1. The calculated maximal heart rate was similar for men and women (182 ± 1 $b·min^{-1}$). As expected, men were heavier and had greater FFM and VO_{2max} in absolute units ($l·min^{-1}$) and per kg body mass compared to women. However, VO_{2max} was not different between men and women when it was expressed per kg FFM (Table 1).

The average speed for men was 5.0±0.1 $km·h^{-1}$ in the first stage and was increased to 6.5 ± 0.2 $km·h^{-1}$ in the last stage, with an average inclination of 3.0 ± 0.2 %. The corresponding values for women were 4.6 ± 0.1 to 6.1 ± 0.1 $km·h^{-1}$ with an inclination of 2.0 ± 0.1 %. The relative exercise intensity (%VO_{2max}) and RER in each stage of the graded exercise protocol were similar in men and women (Table 2). Thus, the percent contribution of fat to the total energy expenditure was similar in men and women throughout the test and declined as exercise intensity was increased. Percent fat contribution in men and women was 62.8 ± 3.0 % and 57.7 ± 5.2 % in the first stage and was decreased to 18.0 ± 2.0 % and 20.6 ± 4.3 % in the last stage. However, due to the higher VO_{2max} of men (Table 1), the absolute oxygen consumption and thus energy expenditure was significantly higher in men compared to women (Table 2). The effect size in these comparisons was >1.3 (large). The higher oxygen uptake of men resulted in a higher absolute fat oxidation rate ($g·min^{-1}$) in the first four stages but not for the final exercise stage (main effect sex, $p < 0.01$; effect size 0.53; medium; sex vs. stage interaction, $p < 0.04$, Figure 1). PFO ($g·min^{-1}$) was higher in men compared to women (0.31 ± 0.02 vs. 0.20 ± 0.02 $g·min^{-1}$; $p < 0.01$, effect size: 1.16, large; Figure 1). The range for PFO was 0.16-0.54 $g·min^{-1}$ in men and 13-0.43 $g·min^{-1}$ in women. However, when PFO was expressed relative to Fat Free Mass (FFM),

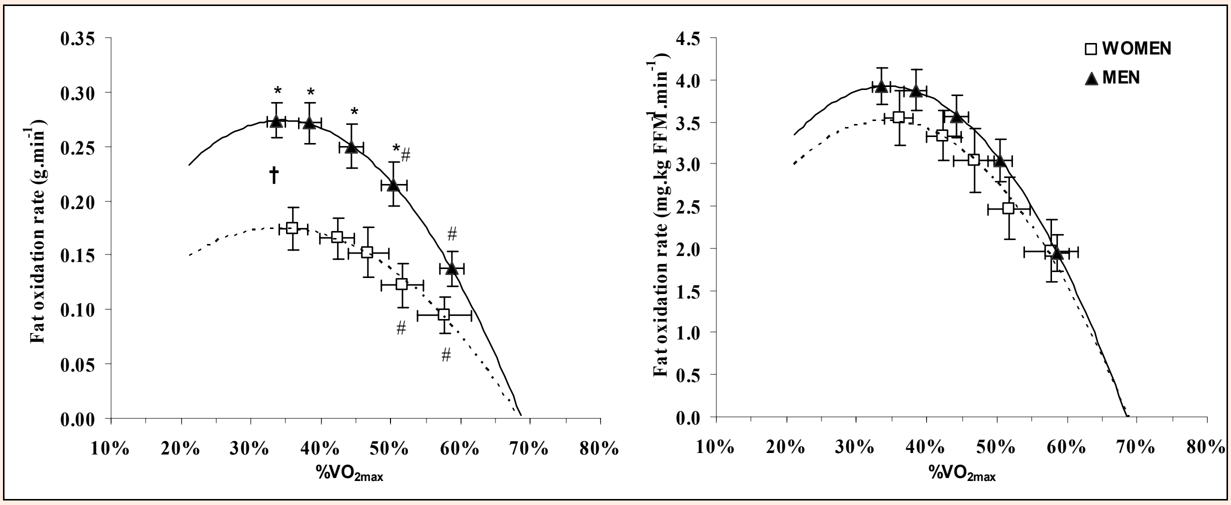

Figure 1. Fat oxidation rate, expressed in absolute ($g·min^{-1}$, left panel) and relative units ($mg·kg^{-1}·min^{-1}$ fat free mass, FFM, right panel), at each exercise intensity (%VO_{2max}). Values are mean±SE. Mean data are fitted using a quadratic polynomial (r^2>0.98 for all four curves).

† main effect for sex, $p < 0.01$; * $p < 0.01$ from corresponding value for women; # $p < 0.01$ from fat oxidation value at the lowest exercise intensity for each sex.

the difference between men and women was not statistically significant (4.36 ± 0.23 vs. 3.99 ± 0.37 mg·kg FFM^{-1}·min^{-1}, respectively; Figure 1). The range for PFO per kg FFM was 2.3-7.1 mg·kg FFM^{-1}·min^{-1} in men and 1.8-7.2 mg·kg FFM^{-1}·min^{-1}in women. PFO occurred at similar exercise intensities for men and women, which corresponded to 40.1 ± 1.8% VO_{2max} and 60.0 ± 1.4% HR_{max} for men and 39.5 ± 2.3% VO_{2max} and 57.8 ± 1.4% HR_{max} for women. Figure 2 presents these parameters as box plots, showing the distribution of the data. The walking speed corresponding to PFO was 5.5 ± 0.2 and 5.0 ± 0.1 km·h^{-1} for men and women, respectively. The crossover point occurred at similar intensities for men (41.1 ± 1.5%VO_{2max}) and women (40.6 ± 2.8%VO_{2max}) and was not different from the peak fat oxidation point (Figure 3).

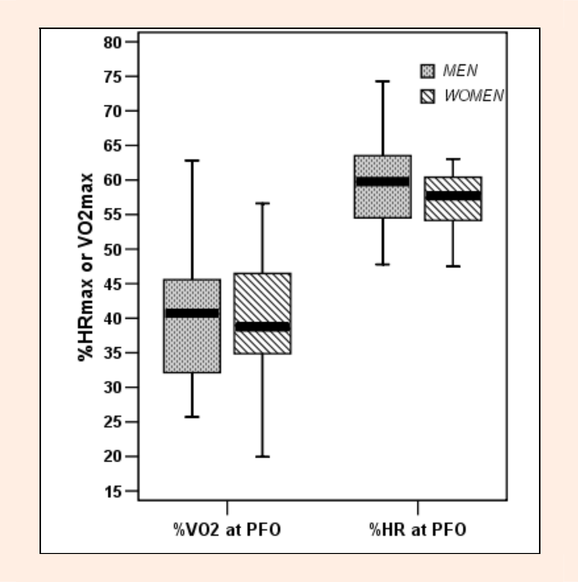

Figure 2. Box plots of relative exercise intensity that elicited peak fat oxidation rate in men and women, expressed as a percentage of maximal heart rate (%HR_{max}) and maximal oxygen uptake (%VO_{2max})

The results of the bivariate correlations between PFO in absolute terms and relative terms and their possible predictor variables are shown in Table 3. When PFO in absolute terms was the dependent variable in the regression analysis, the following predictor variables were included: sex, FFM, percent body fat, and VO_2max per kg body mass. When PFO relative to FFM was the dependent variable, the predictor variables entered into the model were: VO_{2max} per kg body mass and VO_{2max} per kg FFM. Regression analysis showed that sex, FFM and VO_{2max} were significant predictors of PFO in g·min^{-1} (adjusted R^2 = 0.48, p = 0.01), while only a small part of the variance in PFO per Kg FFM was explained by VO_{2max} per kg FFM (adjusted R^2 = 0.12, $p < 0.05$).

Discussion

The main finding of the present study was that PFO in overweight and sedentary men and women was observed at a low exercise intensity (~40 % VO_{2max}). Furthermore, although absolute PFO rate (g·min^{-1}) was 50% higher in men compared to women this difference disappeared when PFO rate was expressed relative to FFM (Figure 1). The present study is one of the few that used walking, instead of cycling, at a range of speeds commonly used for exercise in this type of locomotion (Rotstein et al., 2005). An important practical information from the results is the treadmill speed corresponding to PFO (5.0-5.5 km·h^{-1}) was similar to the self-selected speed of walking (Browning and Kram, 2005; Minetti et al., 2003). Thus the present study has shown that this speed is not only convenient for walking for overweight individuals (Browning and Kram, 2005), but also maximizes the contribution of fat metabolism to energy expenditure. It is interesting to note that walking may be preferable compared to cycling because it enables to attain the target energy expenditure at lower heart rate, blood lactate concentration and subjective perception of effort (Lafortuna

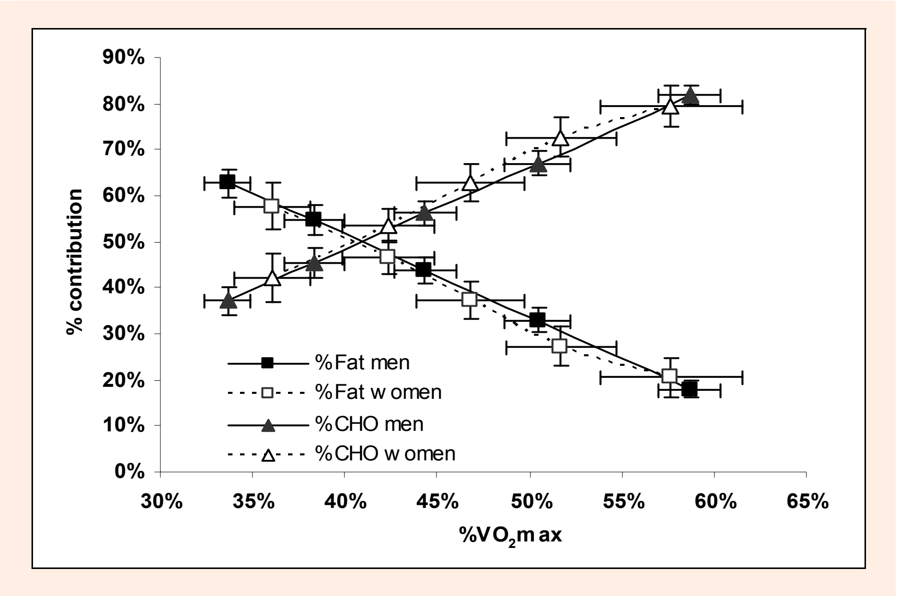

Figure 3. Percent Fat and carbohydrate (CHO) contribution to the energy expenditure at each stage of the treadmill test for men and women, and peak fat oxidation rates (as %fat), plotted against the relative exercise intensity (%VO_2max). Values are mean± SE.

Table 3. **Correlation coefficients (r) between peak fat oxidation (PFO) rate in absolute units ($g.min^{-1}$) and relative to fat free mass (FFM) and the following variables: body mass index (BMI), FFM, percent body fat, waist-to-hip ratio, VO_2max per kg body mass ($ml·Kg^{-1}·min^{-1}$) and VO_2max per kg FFM ($ml·Kg\ FFM^{-1}·min^{-1}$).**

	BMI ($kg·m^{-2}$)	Waist-to-hip ratio	FFM (kg)	Body fat (%)	VO_2max ($ml·Kg^{-1}·min^{-1}$)	VO_2max ($ml·Kg\ FFM^{-1}·min^{-1}$)
PFO ($g·min^{-1}$)	.47 **	.51 **	.66 **	-.38 **	.42 **	.30 *
PFO ($mg·kg\ FFM^{-1}·min^{-1}$)	.17ns	.15 ns	.19 ns	-.11 ns	.37 **	.37 **

** $p < 0.01$; * $p < 0.05$, ns: not significant $p > 0.05$.

et al., 2008; Miles et al., 1980).

The exercise intensity corresponding to PFO in the present study was considerably lower than the 62% VO_2max reported for moderately trained athletes (Achten et al., 2003). Comparison among studies with individuals of different body composition and fitness level indicates that an increased body fat and inactivity are associated with lower exercise intensity corresponding to PFO. For example the average intensity at PFO was 48% VO_{2max} in a large heterogeneous population group with body fat around 20-25% (Venables et al., 2005), while exercise intensity corresponding PFO during cycling was as low as 30.5% in a group of inactive obese individuals (Perez-Martin et al., 2001). The relatively low exercise intensity at which fat oxidation is maximized in overweight individuals raises a practical issue regarding exercise prescription in this population. If the goal is weight loss, an exercise intensity of around 50-60% VO_{2max}, which is higher than that corresponding to PFO, is commonly prescribed to increase the rate of energy expenditure (Jakicic et al., 2001). Although the magnitude of cardiorespiratory adaptations to exercise depends on relative intensity, the rate of weight loss seems to be dependent only on the total energy expenditure (Jakicic et al., 2001).The advantage of using a higher relative intensity is that target energy expenditure can be achieved in less time. For example, a target energy expenditure of 300 kcal per exercise session would be attained in about 30 and 50 min in the men and women of the present study at an intensity of ~60% VO_{2max} (Table 2). If the exercise intensity is set at that corresponding to PFO (40% VO_{2max}), the same energy expenditure would be attained in a longer time (50 and 70 min, respectively). However, the possible superiority of training at an intensity corresponding to PFO is that it causes adaptations that also promote health, such as increased fat oxidation during exercise and improved insulin sensitivity, that do not occur when higher training intensities are used (Van Aggel-Leijssen et al., 2002 Venables and Jeukendrup, 2008).

As shown in Figure 2, there was a fair amount of inter-individual variation in both rate and exercise intensity of PFO. However, the variability of PFO in the present study was less than that found in normal weight individuals. Venables et al. (2005) reported a range for PFO rate between 0.18 and 1.01 $g·min^{-1}$, while the values in the present study ranged from 0.16 to 0.54 $g·min^{-1}$ in men and from 0.13 to 0.43 $g·min^{-1}$ in women. Furthermore, the exercise intensity corresponding to PFO in the study of Venables et al. (2005) ranged from 25 to 77% VO_{2max} or 41 to 91% HR_{max}, while in the present study it ranged from 20-63% VO_{2max} or 48-74% HR_{max} (Figure 2). It is interesting to note that the middle two quartiles of the relative intensity corresponding to PFO were between 33 and 45% VO_{2max} or 54-63% HR_{max}. The relatively lower range of values in the present study may be because the population was more homogeneous (i.e. overweight and sedentary individuals), compared with that in Venables et al. (2005) who included participants with VO_{2max} ranging from 20.9 to 82.4 $ml·Kg^{-1}·min^{-1}$. However, the fact that there is considerable inter-individual variability even among persons with similar characteristics (e.g. overweight and sedentary) as in the present study, suggests that individual testing is required to prescribe exercise at an intensity corresponding to PFO.

The results of the regression analysis concerning predictors of PFO in absolute terms are in agreement with similar analyses in normal-weight adults (Venables et al., 2005), with gender, FFM and VO_2max explaining almost half of the variance. However, when PFO was scaled per Kg FFM, aerobic fitness (VO_{2max}) was the only significant predictor explaining ~12% of the variance in PFO. Thus, the low VO_{2max} of the participants in the present study may suggest that inactivity reduces not only VO_{2max} but also the ability of muscle to use fat (Horowitz, 2001). On the other hand, obesity is also associated with a reduced reliance on fat oxidation during exercise due to large reductions in palmitate oxidation and muscle mitochondrial enzyme activity (Hulver et al., 2003; Kim et al., 2000). Whether the reduced fat oxidation in obese individuals is a result of decreased physical activity and/or metabolic disturbances due to obesity remains to be elucidated. Unfortunately, the relative contribution of adiposity and inactivity can not be explored with the present research design and this is constitutes a limitation of the present study. This would have been achieved by including a group of normal weight, sedentary adults or, alternatively, by including a group of overweight but active individuals of the same age. However, the lower intensity corresponding to PFO in the present study is possibly a result of an interaction between inactivity and obesity. For example, intramuscular triglycerides that may be increased in obesity are often associated with reduced insulin sensitivity (Moro et al., 2008) and may explain part of the variance of PFO rate (Deriaz et al., 2001). Nevertheless, an increased intramuscular triglyceride concentration must be accompanied by reduced oxidative capacity in order to have these detrimental effects on metabolism (Deriaz et al., 2001). The possible metabolic consequences of increased body fat and inactivity are also evident in the present study, where PFO per kg fat free mass was almost half compared with data from individuals with normal weight (~4.0 vs. 7.8 $mg·kg\ FFM^{-1}·min^{-1}$; Venables et al., 2005). Since FFM was almost identical in a large sample of the general population (Venables et al., 2005) and in our study (Table 1), the absolute PFO rate ($g \cdot min^{-1}$) was also half in our overweight participants. Based on this observation, the determination of PFO may be used as a complementary diagnostic tool for assessing metabolic fitness in overweight and obese individuals, as also suggested by Nordby et al. (2006).

The crossover concept has been proposed to quantify substrate utilisation during exercise (Brooks and Mercier, 1994). The low crossover point found in the present study (41% VO_{2max}, Figure 3), was almost identical with the intensity corresponding to PFO rate. Perez-Martin et al., (2001) reported an even lower crossover point (33% of maximal aerobic work) in more obese individuals, suggesting that this may be a characteristic of the overweight and/or obese state. An early sympathetic system stimulation (Brooks and Mercier, 1994) as well as reduced oxidative capacity, fat mobilization and transport into the mitochondria (Kim et al., 2000) may explain the shift of the crossover point to the left in overweight and obese individuals.

An important practical point that should be considered when prescribing exercise intensity based on heart rate in obese individuals, is that the relationship between %HRmax and %VO_{2max} is different from that reported for healthy adults (Byrne and Hills, 2002). In the present study the %HRmax corresponding to PFO (i.e. 40% VO_{2max}) was approximately 60%HRmax, which is 5-6 percentage points higher than that expected from normal-weight individuals (Byrne and Hills, 2002). It is noteworthy that 61%HRmax corresponded to 48%VO_{2max} in a large sample of normal-weight individuals (Venables et al., 2005). These discrepancies should be taken into account to optimize exercise intensity using heart rate in obese individuals.

Although PFO in absolute units ($g \cdot min^{-1}$) was higher in men, this difference disappeared when fat oxidation was scaled for FFM (Figure 1). The fact that PFO per kg FFM was not higher in women compared to men is not a common finding and is contrary to the majority of studies that show a higher contribution of lipids in women during exercise (Tarnopolsky, 2008; Venables et al., 2005). There are several factors affecting fat oxidation sex dimorphism, including levels of hormones such as progesterone, estradiol and catecholamines (Horton et al., 1998; Tarnopolsky, 2008). Horton et al. (1998) examined gender-based differences in fuel metabolism in response to low intensity (40% VO_{2max}) prolonged exercise and found different catecholamine and estradiol responses in healthy normal-weight men and women. Unfortunately, these hormones were not measured in the present study, and thus the possible influence of obesity on the hormonal responses to exercise in men and women can not be ascertained. However, a possible explanation for the similar fat oxidation per kg FFM in men and women in the present study may be provided by comparing the aerobic fitness of the two groups. Previous studies have shown that total fat oxidation during submaximal exercise is the same in males and females, when they are matched for VO_{2max} per kg FFM (Mittendorfer et al., 2002). Thus, the fact that there was no difference in VO_{2max} per kg FFM between males and females (Table 1), may partly explain the similar PFO per kg FFM in the two sexes.

Conclusion

PFO rate and the corresponding relative exercise intensity in male and female overweight and sedentary individuals were lower compared to those reported for leaner and/or physically active persons. Although the absolute values of PFO rate were 50% greater in men than women, the differences disappeared when PFO rate was expressed per kg FFM. The low fat oxidation rate and the early turn of metabolism to carbohydrate as energy substrate may suggest that overweight persons may have an impaired fat metabolism due to decreased physical activity and/or metabolic disturbances due to excess fat accumulation. The fact that PFO is attained at a moderate walking speed, that is similar to the reported preferred speed of walking for obese individuals, suggests that it may be prescribed as a convenient way to improve health in this population.

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Key points

- Peak fat oxidation rate scaled per kg fat-free mass and the corresponding relative exercise intensity are similar in male and female overweight and sedentary individuals, but lower compared to those reported for leaner and/or physically active persons.
- Walking at a moderate speed (5.0-5.5 km.h^{-1}) may be used as a convenient way to exercise at an intensity eliciting peak fat oxidation in overweight individuals.
- The relationship between %HRmax and %VO$_{2max}$ in overweight individuals is different from that reported for normal-weight adults and should be taken into account to optimize exercise intensity using heart rate in obese individuals.
- Due to the low intensity corresponding to peak fat oxidation in overweight and sedentary persons and the inter-individual differences, exercise intensity for health benefits should be prescribed following individual testing.

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