Quantifying Differences in the "Fat Burning" Zone and the Aerobic Zone: Implications For Training

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Abstract

Carey, DG. Quantifying differences in the "fat burning" zone and the aerobic zone: implications for training. *J Strength Cond Res* 23(7): 2090–2095, 2009—The primary objective of this study was to examine the relationship of the "fat burning" and aerobic zones. Subjects consisted of 36 relatively fit runners (20 male, 16 female) who completed a maximal exercise test to exhaustion on a motor-driven treadmill. The lower and upper limit of the "fat burning" zone was visually assessed by examining each individual graph. Maximal fat oxidation (MFO) was determined to be that point during the test at which fat metabolism in fat calories per minute peaked. The lower limit of the aerobic zone was assessed as 50% of heart rate reserve, whereas the upper limit was set at anaerobic threshold. Although the lower and upper limits of the "fat burning" zone (67.6–87.1% maximal heart rate) were significantly lower ($p < 0.05$) than their counterparts in the aerobic zone (58.9–76.2%), the considerable overlap of the 2 zones would indicate that training for fat oxidation and training for aerobic fitness are not mutually exclusive and may be accomplished with the same training program. Furthermore, it was determined that this training program could simultaneously meet the requirements of the American College of Sports Medicine for both aerobic fitness and weight control. Maximal fat oxidation occurred at 54.2% maximal oxygen uptake ($\dot{V}O_2max$). However, the great variability in response between individuals would preclude the prediction of both the "fat burning" zone and MFO, indicating a need for measurement in the laboratory. If laboratory testing is not possible, the practitioner or subject can be reasonably confident MFO lies between 60.2% and 80.0% of the maximal heart rate.

Key Words respiratory exchange ratio, anaerobic threshold

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Introduction

The prevalence of overweight persons and obesity in the United States has been rising exponentially in recent years (15). This increase has been accompanied by a corresponding increase in chronic diseases such as coronary heart disease, diabetes, hypertension, osteoarthritis, and gall bladder disease (13). Public health guidelines have recommended dietary changes with increases in physical activity in an effort to slow or reverse this trend. With loss of body fat as a primary objective, exercise that optimizes metabolism of fat has been prescribed. In addition to weight control, improvement in fat oxidation has been associated with improvement in insulin sensitivity (11), which may be another mechanism by which exercise reduces the risk of diabetes. One only needs to go to an exercise equipment store to see guidelines for the "fat burning" zone (FBZ) on treadmills, cycle ergometers, rowers, ellipses, etc.

The respiratory exchange ratio (RER) is the ratio of carbon dioxide (CO2) produced to oxygen (O2) consumed and allows for the precise determination of percent carbohydrate and fat metabolized under both resting and exercise conditions. This determination may be made using the following stoichiometric equations:

Carbohydrate

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$$

Fat

$$C_{16}H_{32}O_2 + 23O_2 \rightarrow 16CO_2 + 16H_2O$$

For carbohydrate, the ratio of CO2 and O2 is 6 to 6, producing an RER of 1.0. For fat, the ratio of CO2 and O2 is 16 to 23, producing an RER of 0.70. During incremental exercise, lipolysis increases as a result of both the release of free fatty acids from adipocytes and the metabolism of intramuscular triglyceride stores (18). As intensity progresses from light to moderate, the percentage of calories metabolized as fat declines. However, total fat calories increases because the decline in percent fat calories is countered by an increase in total caloric expenditure. As intensity increases from moderate to severe, fat oxidation decreases because glycolytic flux, alterations in pH, redistribution of blood flow away from adipocytes, and enzymatic reactions all have an inhibitory effect on mobilization and metabolism of fat. The relative decline in fat metabolism coincides with an increase in carbohydrate metabolism to meet the caloric demands of exercise. At RER equal to and greater than 1.0, carbohydrate is supplying 100% of the energy demand.

Several factors are known to modify the relative contributions of fat and carbohydrate to total oxidation, including training status, diet, and sex. Both longitudinal (9,11) and cross-sectional studies (7,14,16,19) have demonstrated greater fat oxidation at both the same absolute and relative exercise intensities for trained compared with untrained subjects. However, it has also been reported that only low-intensity, and not high-intensity, exercise will enhance fat oxidation (17). Acutely, ingestion of carbohydrate before exercise will facilitate carbohydrate oxidation and suppress fat oxidation (3). In addition, chronic dietary manipulation, such as adoption of a high-fat diet, will favor the oxidation of fat under both rest and exercise conditions (8). Finally, for any given absolute and relative exercise intensity, females have higher fat oxidation rates than males (19).

Several assumptions are made when determining the relative percent of fat and carbohydrate oxidation. When RER exceeds 1.0, metabolic CO2 from the bicarbonate pool is produced and will result in the overestimation of carbohydrate and underestimation of fat oxidation. In addition, although protein may contribute 10–15% of total energy expenditure during prolonged exercise, its effects are negligible during short-term incremental exercise (12) and will be excluded from consideration in this study. Other factors that may slightly alter the stoichiometry, such as gluconeogenesis, lipogenesis, and the glucose-alanine cycle, are probably inconsequential under normal conditions during short-term exercise and are also excluded from consideration.

Given that fat oxidation is a desirable objective, the inevitable question becomes "Should I exercise at a level that optimizes fat oxidation, or is total caloric expenditure the ultimate determinant of fat loss?" Surprisingly, this fundamental question has not been answered to date, probably because of the difficulty of precisely controlling caloric intake and expenditure. Those studies that have been completed generally have controlled for exercise dose, comparing high-intensity, short-duration exercise with low-intensity, long-duration exercise of equivalent caloric expenditure. However, nonexercise physical activity and caloric intake were not controlled, and no definitive conclusion could be reached.

Although optimal training intensity for fat loss is beyond the scope of this study, it does appear prudent to compare the FBZ with the aerobic zone (AZ). Can improvement in aerobic capacity and optimization of fat oxidation be attained simultaneously, or are these objectives distinctly different and require different intensities of training for their attainment?

The purpose of this study is to compare the FBZ and AZ in a group of competitive endurance athletes (runners). To the best of our knowledge, this is the first study to directly compare these 2 training zones in the same group of subjects.

Table 1. Physical characteristics and maximal oxygen test results.

	Age (yr)	Height (cm)	Weight (kg)	Resting HR	MaxHR	MaxHR (% prediction)	ATHR	$\dot{V}O_2$max (mL/kg/min)
Male (*n* = 20)	36.8 ± 1.8	180.6 ± 6.1	83.1 ± 11.0	54.5 ± 3.7	180.8 ± 9.7	99.0 ± 5.2	156.5 ± 13.2	54.5 ± 7.6
Female (*n* = 16)	35.9 ± 8.4	162.8 ± 10.2	60.0 ± 5.7	57.3 ± 4.1	176.4 ± 12.7	95.7 ± 5.4	155.1 ± 15.1	48.6 ± 8.5
Total (*n* = 36)	36.4 ± 8.1	172.7 ± 11.9	72.9 ± 14.6	55.5 ± 3.9	178.8 ± 11.1	97.5 ± 5.5	155.8 ± 13.9	51.9 ± 8.4

*ATHR = anaerobic threshold heart rate; MaxHR = maximum heart rate; $\dot{V}O_2$max = maximal oxygen uptake.

Methods

Experimental Approach to the Problem

Results of this study have implications for both the individual and health professional prescribing exercise. Because training for cardiovascular fitness and weight control are reasons often cited for beginning and maintaining an exercise program, it appears prudent to examine the relationship between these 2 objectives. Although access to metabolic measurement and assessment of FBZ and AZ is often limited, prescription of exercise by heart rate based on the outcome of this study may be of value to those individuals whose objectives include weight control or aerobic fitness.

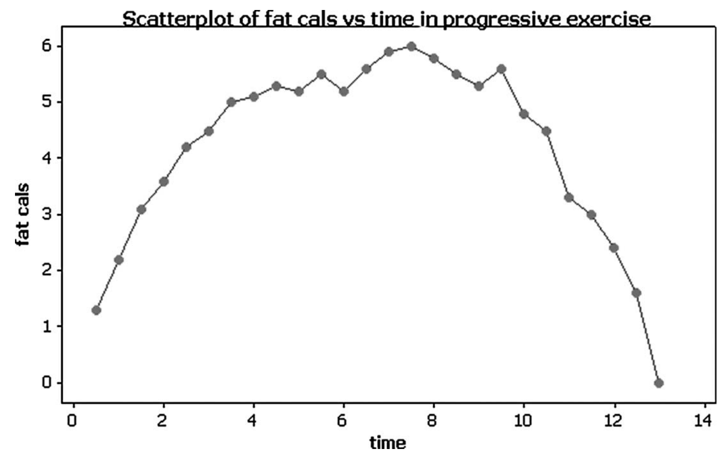

Figure 1. Example of fat calories burned during incremental exercise to fatigue.

Subjects

Table 1 contains the physical characteristics and maximal oxygen testing results in 36 runners (20 men, 16 women) who volunteered to participate. Males attained 127.9% of their predicted maximal oxygen uptake ($\dot{V}O_2max$), whereas females attained 140.5% of their predicted $\dot{V}O_2max$ (3), indicating that participants were highly fit. Subjects responded to an advertisement placed on a prominent website frequented by endurance athletes. Approval to conduct this research was granted by the Institutional Review Board of the University of St. Thomas. All subjects read and signed consent forms before testing. Results of this study on highly fit endurance athletes may or may not be applicable to individuals beginning or maintaining a moderate exercise program.

Procedures

All tests were conducted at either 7:30 or 9:00 AM. Subjects were instructed to avoid prolonged strenuous exercise 24 hours before testing and ingest nothing but water for 10 hours previous to the test. Weight was obtained to the nearest 0.5 kg. on a Seca balance scale (Seca Corporation, Hamburg, Germany). Resting and exercise heart rates were monitored with the Polar Vantage XL Monitor (Polar Electra, Woodbury, New York, NY, USA). Resting heart rate was obtained after 10 minutes in a quiet, recumbent position.

Exercise tests were performed on a Quinton 4000 motor-driven treadmill according to a modified Bruce protocol. Gas analysis was performed with the Medical Graphics VO2000 metabolic measurement system (Medical Graphics, St. Paul, MN, USA), which has been previously validated (6). Breath-by-breath analysis with 30-second averaging was used for all metabolic measurements. The system was calibrated before each test according to manufacturer specifications. All

Table 2. Comparison of aerobic and "fat burning" zone.

	Aerobic zone	"Fat burning" zone
Males ($n = 20$)		
Heart rate	121.9–156.5	104.5–134.4
Percent max heart rate	67.4–86.7	57.8–74.3
Fat cal/min	3.84–2.21*	3.70–4.28
Total cal/min	10.8–16.6	7.59–12.5
Females ($n = 16$) zone		
Heart rate	119.8–155.1	106.6–138.7
Percent max heart rate	67.9–87.9	60.4–78.6
Fat cal/min	2.20–1.02*	2.38–2.40
Total cal/min	7.03–11.1	5.55–9.64
Total ($n = 36$) zone		
Heart rate	120.9–155.8	105.4–136.3
Percent max heart rate	67.6–87.1	58.9–76.2
Fat cal/min	3.11–1.68*	3.11–3.45
Total cal/min	9.15–14.2	6.74–11.5

*Fat calories decrease at upper limit of aerobic zone.

subjects demonstrated at least 2 of the following criteria for attainment of maximal exercise: a) plateauing in oxygen consumption (no greater than 200 mL/min difference in oxygen consumption over the final 2 stages of the test), b) attainment of 95% of age-predicted maximal heart rate, c) attainment of RER of 1.1 or greater. Verbal encouragement was given toward the end of the test. Maximal oxygen consumption ($\dot{V}O_2$ max) was determined to be the highest $\dot{V}O_2$ attained during any 30 seconds (final stage). Anaerobic threshold (AT) was computer assessed by a macro designed to assess least squared error in breakpoint of the ventilatory equivalent for oxygen (VE/$\dot{V}O_2$) (20).

The AZ was determined by using the American College of Sports Medicine (ACSM) formula (5) for minimal exercise intensity for eliciting an aerobic training response (50% of heart rate reserve) for the lower limit and the anaerobic threshold heart rate for the upper limit. Fat burning zone was assessed by visual inspection of the time/fat calorie graph. Although individual graphs varied somewhat in appearance, most resembled Figure 1. There was a relatively steep climb in fat calories early in the exercise test, followed by a flattening or gradual increase, and ending in a steep decrease in fat calories. Maximal fat oxidation (MFO) was determined to be the highest level of fat oxidation achieved during the test. Fat calories were calculated by multiplying percent fat oxidation by total calories for any given 30-second period. Aerobic fat calories were determined by multiplying the percent fat oxidation and total calories for both the lower and upper limit for the AZ.

Statistical Analyses

All values are expressed as mean and *SD* unless otherwise designated. Paired *t*-tests were used to assess differences with alpha set at 0.05. Pearson correlation coefficients were used to examine relationships between variables.

Results

Table 2 is a comparison of measurements for FBZ and AZ. For both the lower and upper limits, AZ consisted of significantly ($p < 0.05$) higher absolute and relative heart rate (% max heart rate) for men, women, and total, when compared with FBZ. Similarly, both lower and upper limits of total calories per minute were significantly ($p < 0.05$) greater for AZ versus FBZ for men, women, and total.

In contrast, although there was no significant difference ($p > 0.05$) for fat calories/minute at the lower limits for AZ and FBZ for all 3 groups, the upper limits of FBZ resulted in significantly greater fat calories/minute than AZ for all 3 groups. The maximal rate of fat oxidation (MOF) (not reported in table) was significantly greater ($p < 0.05$) than either the lower or upper limit of fat calories per minute in the FBZ for all 3 groups. However, there was no significant difference in fat calories per minute for the upper and lower limits of FBZ for all 3 groups. This would indicate that, within FBZ, there is a single intensity at which fat oxidation peaks that would represent an optimal intensity for fat oxidation (Figure 1). To assess the relationship of aerobic fitness to fat oxidation, $\dot{V}O_2$max was compared with MFO and MFO as a percent $\dot{V}O_2$max (Table 3).

No significant relationship ($p > 0.05$) was observed for either men or women, indicating that higher rates of fat oxidation were not more common in more fit subjects. However, combining the data for men and women resulted

Table 3. Correlation coefficients and *p* values comparing maximal oxygen uptake ($\dot{V}O_2$max) with measurements of fat oxidation.

	Peak fat oxidation oxidation (cal/min)	Peak fat (% $\dot{V}O_2$max)
Males (*n* = 20)	0.003	−0.347
	0.98	0.134
Females (*n* = 16)	0.360	−0.290
	0.171	0.275
Total (*n* = 36)	0.319	−0.324
	0.058	0.054

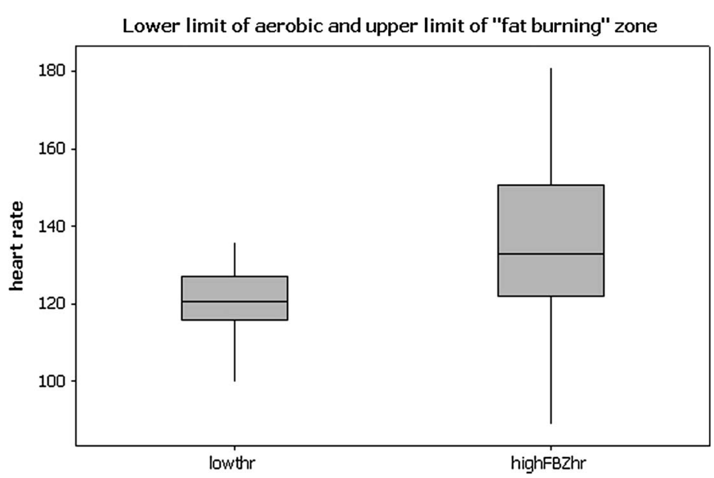

Figure 2. Boxplots comparing lower limit of target heart rate zone to upper limit of fat-burning zone.

in correlation coefficients of borderline significance (p = 0.058) for MFO in calories per minute and $\dot{V}O_2$max. This would indicate a tendency for MFO in calories per minute to be related to aerobic fitness. The disparity of results between men and women separately compared with results as a group may reflect the greater heterogeneity of the group for $\dot{V}O_2$max. In addition, the increase in number of subjects increased the power to detect a relationship. Maximal rate of fat oxidation occurred at 53.2%, 55.4%, and 54.2% $\dot{V}O_2$max for men, women, and total, respectively.

A comparison of MFO for males (5.95 ± 1.67 cal/min) and females (4.07 ± 1.91 cal/min) resulted in a significantly greater MFO for males (t = 3.09, p = 0.004). However, differences in MFO as percent $\dot{V}O_2$max for males (53.2 ± 0.16) and females (55.4 ± 0.14) were not significant (t = 0.44, p = 0.663).

Although significant differences for both the lower limit for FBZ (105.4 bpm) and AZ (120.9 bpm) ($p < 0.001$), as well as the upper limit for FBZ (136.3 bpm) and AZ (155.8 bpm) ($p < 0.001$), were found, there was considerable overlap between the 2 zones (Figure 2).

Finally, when expressed as a percent maximal heart rate, there was a large interindividual variability in FBZ heart rate for both the lower limit of the FBZ (58.9 ± 9.3%) and the upper limit of the FBZ (76.0 ± 12.5%). However, for MFO, 32 of the 36 subjects (89.0%) fell in a range of 60.2–80.0% of maximal heart rate.

Discussion

To the best of our knowledge, this is the first study to directly compare FBZ with AZ in the same group of subjects. Although these findings would indicate a significantly greater exercise intensity for improving fitness, when measured both by percent of maximum heart rate and caloric expenditure compared with FBZ there is considerable overlap of these 2 zones (Figure 2). For example, the upper limit of exercise intensity for FBZ (80.0% max heart rate) is mid-range for the AZ (67.6–87.1% max heart rate). In addition, the upper limit for calories per minute (11.5) for FBZ is mid-range for AZ (9.15–-14.2 cal /min). The upper limit of fat calories per minute for FBZ (3.45) was not significantly different (t = 1.23, p = 0.225) from the lower limit of AZ (3.11). The biggest discrepancy between the 2 zones occurs when comparing fat calories expended at the upper limit of FBZ (3.45 fat cal/min) with the upper limit of AZ (1.68 fat cal/min). If the objective is metabolism of fat calories, training at the upper limits of AZ should not be recommended. If total caloric expenditure is the objective, the upper limits of AZ will be the most efficient. In addition to more calories being expended during exercise, caloric expenditure during recovery from high-intensity exercise is greater than recovery caloric expenditure from low-intensity exercise because of the additional energy requirement of ventilation, restoration of adenosine triphosphate phosphocreatine, replenishment of glycogen stores, and body temperature elevation. Also, prolonged exercise at high intensity, as in marathon running, has shown a gradual decrease in carbohydrate oxidation and gradual increase in fat oxidation as glycogen stores become depleted. If fat calories, and not total calories, were a better predictor of weight control, we would expect endurance athletes, who spend a rather large volume of training above FBZ, to have weight control problems. This is clearly not the case.

The ACSM (5) has established guidelines for training intensity at 70–85% maximal heart rate, corresponding to 50–70% $\dot{V}O_2$max. The upper, but not lower, limits of FBZ attain these guidelines. These results would appear to indicate that individuals may choose to train in FBZ and still obtain improvement in aerobic fitness and $\dot{V}O_2$max, provided they are in the upper end of FBZ.

For weight control, ACSM recommends an energy expenditure of 2,000 kcals per week (5). Because this represents "dose" of exercise, individuals may wish to attain this goal by any combination of frequency, intensity, and duration. Let us assume an individual exercises 5 times per week. If he/she is training at the upper limit of FBZ (11.5 cal/min), it would take 34.8 minutes of exercise per session to achieve this goal. If he/she is training at the upper limit of AZ (14.2 cal/min), it would take 28.2 minutes to achieve this goal. The small difference in time (6.6 min) would appear to indicate ACSM guidelines for weight loss can be met by training in the upper limits of either FBZ or AZ. However, our subjects were highly fit and expended a high rate of calories per minute. Subjects of poor to moderate fitness may expend only 50–60% of this caloric expenditure and may expect to invest 50–60% more time in attaining these goals.

Our finding that MFO occurred at 54.2% $\dot{V}O_2$max is comparable with others who have found MFO percent $\dot{V}O_2$max at 57.0% (18), 56.0% (16), 64.0% (2), and 62.5% (1). However, our results have been significantly greater than some (40.8%) (10) but also significantly less than others (75.0%) (7). It would appear that much of the variability in MFO cannot currently be explained, even in a homogeneous group of subjects such as participated in this study.

It has been stated that MFO correlates with AT (7) and is predictive of AT (4). Others (10,19), however, have found AT to occur at significantly greater exercise intensity than MFO. Our AT (74.1 ± 9.1% $\dot{V}O_2$max) was significantly greater than MFO (54.2 ± 15.3% $\dot{V}O_2$max) and supports the latter findings. In fact, 20 of our 36 (55.6%) subjects were oxidizing 100% carbohydrate and no fat at AT.

A final comment on fat oxidation and its relationship to aerobic training is warranted. In his review of fat oxidation, Jeukendrup and Wallis (12) commented that "66% of the variance could not be accounted for. Dietary factors are likely to explain some of the remaining variance, but there is still a large part of the variance unexplained and this is likely to be genetically determined." Others have supported this. Venables et al. (19) found that only 12% of the variance in MFO could be explained by physical activity, $\dot{V}O_2$max, and sex. Our results support this statement. For example, although the lower range of the FBZ was 3.11 fat calories per minute, the *SD* of 1.72 fat calories per minute is a deviation of 55.3%. Likewise, although MFO was 54.2% $\dot{V}O_2$max, the *SD* of 15.3% represents a variability of 27.7%. The implications of these results are that, although mean values give an indication of a group response, determination of fat oxidation in the individual is best assessed in the laboratory. However, because 32 of 36 subjects fell in a range of 60.2–80.0% of maximal heart rate for MFO, we can be 90% confident in telling the individual that maintaining an exercise heart rate in this range will optimize fat metabolism.

In addition to intersubject variability, intrasubject variability will tell us how reliable a single measurement will be. To the best of my knowledge, the only authors to address this question are Achten and Jeukendrup (2), who obtained a coefficient of variability of 9.0%, indicating a modest reliability for MFO. Further research is needed to address this important question.

Practical Applications

From the results of this study, the following conclusions/recommendations are warranted:

1. Although the lower and upper limits of FBZ were significantly less than their counterparts of AZ, the considerable overlap in the 2 zones would indicate that one could attain both optimal "fat burning" and improved aerobic fitness with the same training program.
2. Training at the upper limits of FBZ and lower limits of AZ meet guidelines established by the ACSM for both improved fitness and weight control.
3. Training at AT is not optimal for fat oxidation but is optimal for total caloric expenditure.
4. A large variability in response would indicate that prediction of the upper and lower limits of the FBZ for the individual is difficult. It is recommended that the FBZ be individually determined. When this is not possible, the individual may be 90% confident that their MFO occurs from 60.2–80.0% of maximal heart rate.

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