The Relationship Between Percent Body Fat and Fat Metabolism During Moderate Exercise

by

Minori Osako

A PROJECT

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It has previously been shown that the proportion of fat metabolized during aerobic exercise is higher in trained subjects, and there is conflicting evidence as to whether or not gender or age influence fat utilization during exercise. PURPOSE: The primary objective of this study was to investigate whether body composition influenced fat utilization during exercise, using data from a larger study. METHOD: 80 participants were separated into groups by gender, age and fitness level. The younger group age frame was 18 to 24 years old, and the older group consisted of 38-44 year olds. Their body composition was measured by Bod Pod prior to running on the treadmill for 35 minutes. The respiratory exchange ratio (RER) was recorded during their last 30 minutes of the run, below their ventilatory threshold. The Pearson Product Moment correlation was determined between body fat percentages and RER of the participants in 11 different groupings: male/female, trained male (TM)/ untrained male (UTM), trained female (TF)/ untrained female (UTF), older male (OM)/ younger male (YM), older female (OF)/ younger female (YF), and all subjects. RESULTS: None of the correlations between percent body fat and RER was statistically significant except for the correlation in the younger trained and untrained male group (R=0.5053). DISCUSSION: The major finding of this study was that there was no consistent relationship between body fat percentages and fat metabolism during exercise.

Key Words: Body, Fat, Composition, Metabolism, Exercise

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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Minori Osako, Author

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During exercise, the human body relies on fat and or carbohydrate as a source of energy. Carbohydrate, an organic compound that consists of carbon, hydrogen and oxygen, provide the body with rapidly available energy. It is written as $C_6H_{12}O_6$ in an equation, with an equal ratio of carbon to oxygen. When the body demands energy during exercise, glucagon, a hormone that stimulates glycogen breakdown, releases glucose into the bloodstream. This glucose mobilization provides the body with access to carbohydrate as an energy substrate. Fat on the other hand, has a higher ratio of carbon to oxygen, as evident in oleic acid, a type of fatty acid represented as $C_{18}H_{34}O_2$. Fat is stored in the adipose tissue and muscle in the form of triglyceride. When the body needs energy, triglyceride is broken in to three free fatty acids (FFA) and a glyceride backbone, and this FFA is used by the muscles for energy. How much the body depends on one source over the other is greatly influenced by the intensity and duration of the exercise. As the intensity of the exercise increases, the source of energy shifts towards carbohydrate. But with increase in duration, fat becomes the primary source of energy. This is reflected by the respiratory exchange ratio (RER), the ratio between the amount of carbon dioxide produced and oxygen consumed. When carbohydrate is the only source of energy, RER is 1. But when fat is the only source of energy, the RER is 0.7. When fat and carbohydrate are equally in use, the RER is 0.85. Numerous studies show that certain physiological factors, such as fitness levels, gender and age, can intensify one's reliance on fat and or carbohydrate, and this may be the result of hormonal differences.

Fitness Level

There are numerous past studies that have looked at the influence of training status on metabolism and energy expenditure. For instance, Bassami and his colleagues investigated the interrelations of exercise intensity and exercise duration for the same total energy expenditure on fat metabolism in trained and untrained elderly subjects (2007). When the subjects biked on a cycle ergometer for 30 minutes at 50, 60 and 70% VO_2 max, they found that trained individuals had a higher absolute peak oxidation level than the untrained, and achieved their peak rate at their 50% VO_2 max, as opposed to 60% VO_2 max for the untrained (Bassami et. al., 2007). Even within the trained group, highly trained individuals used more fat than moderately trained individuals, according to Achten and Jeukendrup (2004) who performed a follow up study on the Romijin et. al. (1993) research, which studied male cyclists exercising at 25%, 65% and 85% VO_2 max. The follow-up study consisted of a larger group of moderately and highly trained individuals and an exercise protocol that permitted them to investigate a larger number of exercise intensities with smaller increments. They found that at the same percent VO_2 max between the highly trained and moderately trained, the highly trained group had higher peak fat oxidation rates of 0.56 g/min, as well as higher absolute energy expenditure than the moderately trained cyclists at 0.48 g/min (Achten and Jeukendrup, 2004).

These studies suggest that higher fitness level is correlated with greater fat oxidation, although differences in growth hormone and catecholamine production could be the reason behind it. In a study by Bunt and his colleagues, they found that runners produced more growth hormone with prolonged exercise than the non runners during a 60 minute exercise at 60% VO_2 max (Bunt et. al., 1986). As mentioned before, fat is the preferred source of energy during prolonged exercise. Hence, during this test, runners and non runners were both utilizing more FFA than carbohydrate. Even though both groups produced five to six times the amount of growth hormone produced at rest, the data showed higher growth hormone production in the runners than non runners. Since growth hormone increases FFA mobilization while reducing glucose uptake by the tissue, the results from this study suggests that runners were burning more fat. Finally, a study was done by Dela and his colleagues to investigate catecholamine levels in trained and untrained (UT) individuals (Dela et. al., 1992). These men had similar height, weight and age, with the only significant difference being that trained individuals had lower body fat percentages and higher VO_2 max (7±1% vs. 15±2% and 76±2 vs. 48 ±1 VO_2 max). This study found that within the 24 hours of their observation, the trained individuals produced more catecholamine than the UT. During the day, when the production level during exercise was ignored, the trained individuals still produced more catecholamine. Even during sleep, trained individuals had higher catecholamine levels (Dela, 2001). These hormones favor the mobilization of FFA from the adipose tissue, while maintaining plasma glucose by mobilizing glucose from the liver, simultaneously. In addition, when the sympathetic nervous system releases catecholamine, they also act to speed up lipolysis. Hence, as the production of catecholamine increases during exercise, the body is mobilizing and breaking down more fat at a faster rate than carbohydrate. This could imply that lipolysis occurs more readily and rapidly in trained individuals than UT, which could contribute to why trained individuals have lower body fat percentages.

Gender

Another factor that is thought to have an impact on fat metabolism is gender. Venables et. al. (2005) studied fat oxidation rates in 300 volunteers, 157 men and 143 women. Their compelling findings revealed that women had higher maximal fat oxidation than men did, at 8.18 mg/kgFFM/min and 7.14 mg/kgFFM/min, respectively. The women in this study reached their peak fat oxidation rate at a higher intensity than men, at 52% VO2 max compared to 45% VO_2 max for the men (Venables et. al., 2005).

The differences in fat oxidation level between genders can be justified by the abundance of 17-beta-estradiol, a type of sex hormone that is predominantly present in females. A study by Tarnopolsky investigated why women, who have higher body fat percentages than males, have higher fat oxidation level (Tarnopolsky, 2008). He found that at the same relative VO_2 intensity, women had lower RER than men, meaning they were more dependent on fat than carbohydrate. Because they were mobilizing more fat, their fat oxidation levels were higher. Tarnopolsky suggested that this is due to the hormone called, 17-beta-estradiol, which is more abundant in women. When this hormone was administered to men, they showed an induced lipolysis. In contrast, he injected menopausal women with testosterone, and these women showed attenuated lipolysis. Therefore, the differences in fat oxidation between men and women may be attributed to the sex hormones, testosterone in men, which lowers lipolysis, and 17-beta-estradiol in women, which induces lipolysis (Tarnopolsky, 2008).

Age

Although not all studies are in agreement, previous studies have investigated the impact of age on fat and carbohydrate metabolism. For instance, a study by Hagberg and his colleagues found that younger trained and untrained males had higher absolute energy expenditure and higher fat oxidation rates at their 50% VO_2 than the older trained and untrained males at their 50% VO_2 (Hagberg, 1988). The differences in fat oxidation rates between the two groups may be due to the idea that aging depresses catecholamine levels. A study by Kohrt and his colleagues (1993) investigated the catecholamine responses to exercise in 24 younger subjects around 25 years of age, and 106 older subjects around 64 years old. The subjects ran on the treadmill for 15 minutes at about 78% VO_2 max. They found that at the same relative intensity as the younger group, catecholamine response to exercise was attenuated in the older group. Kohrt proposed that since the absolute workload for the older group was lower, the blunted catecholamine response in older subjects is most likely attributable to a smaller muscle mass being activated during exercise (Kohrt et. al., 1993).

Dr. Onsiri's Study

A study done by Dr. Sombat Onsiri in 2012 at Oregon State University investigated whether males and females of varying age and fitness levels metabolized fat and carbohydrate differently during moderate intensity exercise. In his study, he had 80 participants run on the treadmill for 35 minutes just below their ventilatory threshold, and their average RER was recorded. The 80 participants were categorized by gender, age, and fitness levels, and grouped into one of eight groupings; younger males trained, younger females trained, younger males untrained, younger females untrained, older males trained, older females trained, older males untrained and older females untrained. Every participant's body fat percentages were collected using air displacement plethysmography (Bod Pod). The last 30 minutes of the 35-minute run were analyzed. As the participants ran, their oxygen consumption and carbon dioxide production were measured, which was used to calculate the respiratory exchange ratio. The major finding of his study was that untrained females utilized proportionately more fat (RER=0.860±.027) than untrained males (RER=0.870±.032), but the difference between the trained males and females (RER=0.847±0.32 vs RER=0.840±0.31, respectively) was not statistically significant (See Table 1). He also found that a 20-year age difference did not make a significant difference in fat metabolism during exercise. His data showed that the trained individuals had lower RER than untrained, which means more fat utilization than carbohydrate, and this concurs with Bunt et. al.(1986) study. His findings on females with lower RER than males is in partial agreement with Veneable et. al. (2005) findings as well. In terms of age difference, younger trained and untrained males had lower RER than older trained and untrained males. This was the case for females as well, and therefore supports Hagberg's (1988) findings.

Table 1. Characteristics of the subjects in Onsiri's study.

			Younger						**Older**		
	Trained			**UT**			**Trained**			**UT**	
	M	**F**		**M**	**F**		**M**	**F**		**M**	**F**
Age	21.0 ±1.2	20.6 ± 1.5		22.6 ± 1.3	21.1± 2.2		41.0±2.1	40.0 ± 2.3		40.0± 1.9	39.4 ±1.3
Height (cm)	174.9 ± 8.9	163.8±7.3		174.1±6.1	163.±4.5		180.3±5.6	163.8±2.8		180±5.6	162.1±5.8
Weight (kg)	69.8±8.7	62.5±8.0		77.8±12.4	55.5±7.0		82.7±13.0	58.9±7.2		81.1±14.0	62.1±7.3
%BF	11.8±6.4[abc]	22.5±8.8[bc]		21.7±6.9[ab]	24.9±4.6[b]		20.6±7.7[ac]	21.4±4.5[c]		23.7±7.2[a]	26.8±7.5
RER	0.840±.008	.837±.001		.890±.009[a]	.874±.023		.847±.032	.840±.031		.893±.012	.870±.081

[a] Male subjects are significantly different from female subjects.
[b] Younger subjects are significantly different from older subjects.
[c] Trained subjects are significantly different from untrained subjects.

Purpose

With all these factors playing a role in fat metabolism, the question of interest became whether other factors, such as body composition influenced fat metabolism. No studies have been performed investigating the relationship. Could body composition, a measurement of fat percentage in comparison to lean mass, place certain individuals at better utilizing fat than others? The primary objective of this investigation was to compare the body fat percentages of males and females varying in age and training status to their fat use during exercise.

Body Composition

One process of measuring body composition is called densitometry because it determines body density. There are numerous techniques that measure body density, but one of the most fundamental, well known methods is hydrostatic weighing. Hydrostatic weighing is based on the application of Archimedes' principle. Archimedes' principle states that a submerged object will displace its own volume. Measuring body volume, which serves as the denominator in the body density equation, will ultimately help calculate the body composition. In hydrostatic weighing, the subject gets submerged underwater, and experiences an upward buoyant force equal to the weight of the water displaced. The buoyant force equals the subject's weight in air minus the weight in water, and this equals the weight of the water displaced. Dividing the weight of the water displaced by the density of water determines the volume of water displaced. The density of the water is 1Kg/L, but this can vary depending on the temperature of the water. Thus, body volume is determined, but within this volume is a residual volume of air in the lungs, which must be accounted for and subtracted from total body volume. Body volume corrected for residual lung volume becomes the denominator in determining body density, while the numerator is the body mass. The Siri equation is used to convert the body density value to a percent body fat. The equation is based upon a two compartment model of body composition, where the density of fat is assumed to be 0.9Kg/L and the density of the fat free mass (FFM) is 1.1 Kg/L. As the body density gets closer to 1.1 Kg/L, this indicates that the subject is more dense, implicating that the majority of the body consists of lean muscle. However, these assumptions set limitations to the two compartment model, due to the variability in hydration level and mineral composition among different subjects.

The limitation can be reduced by measuring total body water and body mineral content, which when quantified in addition to determination of body density, theoretically provides the most accurate determination of body composition.

Bod Pod

Hydrostatic weighing is time consuming and laborious. The method can also be uncomfortable and difficult for some subjects as it requires them to be underwater with maximum air exhalation. Therefore, as an alternative, air displacement plethysmography, also known as Bod Pod was created. This fiberglass egg-shaped chamber uses air instead of water displacement to measure body volume. The entire unit consists of the dual chambered plethysmograph, electronic weight scale, and computer software. The Body Pod uses the pressure-volume relationship to derive body volume within the closed Bod Pod chamber. The method is based on Boyle's law ($P_1/P_2=V_2/V_1$), and measures the change in pressure in the closed chamber once the subject is inside. The molded seat inside the chamber separates the front and the rear, and within this wall separation, a movable diaphragm oscillates under computer control. This oscillation produces pressure fluctuations, which ultimately captures how much volume the subject is taking up inside the front chamber (McCrory et. al., 1995). In order to be as accurate as possible when collecting measurements, there are certain protocols that a subject must follow. The subject must be in tight-fitting clothes and wear a swim cap because hair or loose-fitting clothes could create more volume. Generally, the subject cannot have consumed food or exercised at least 2 hours prior to testing to avoid body temperature change. Body temperature change must be avoided because Boyle's law assumes isothermal conditions exist, meaning that air temperature remains the same even though the volume changes. Warm air around the skin post-exercise will behave differently under the pressure-volume relationship.

BP and HW Reliability

With these two methods of measuring body composition, reliability and validity become sources of concern. Numerous previous studies show that the Bod Pod and hydrostatic weighing provide similar results. A study by McCrory and her colleagues from 1995 claim that there is an excellent agreement between the Bod Pod and hydrostatic weighing, with the mean difference between the two methods of -0.3±0.2% BF. These two techniques also have great reliability, as there were no significant differences between the first and second trials in body fat percentage testings. Even a more recent study from 2005, by Ginde and his colleagues state there was a strong correlation between percent body fat and body density derived from the air displacement plethysmography (ADP) and hydrostatic weighing. The correlations were 0.94 for body fat and body density (Ginde et. al., 2005). However, confounding articles argue otherwise. A study by Wagner and his colleagues from 2000 stated that in comparison to hydrostatic weighing, the Bod Pod overestimated body volume and it underestimated body density, which lead to overestimation of percent body fat, although the correlation difference between the two methods came out to be less than 0.001. While some differences exist between the two methods, the majority of researchers seem to agree that the Bod Pod and hydrostatic weighing produce results that are in close agreement with each other.

Method

From the data collected by Dr. Onsiri, an extended analysis was performed. Since RER is a good indication of fat metabolism, this value was correlated with percent body fat in various groups. The correlation was calculated in 11 different groupings: male/female, trained male (TM)/ untrained male (UTM), trained female (TF)/ untrained female (UTF), older male (OM)/ younger male (YM), older female (OF)/ younger female (YF), and all subjects.

Results

After calculating the correlation, the results showed no consistent relationship between body fat percentage and RER. The correlation for the entire group came out to be 0.1717, which was statistically insignificant. The trained group, regardless of the gender, was the only group to show a negative correlation, though not statistically significant. All groups besides the trained group, showed positive correlation, with the highest R value in the younger male category. When the correlation values were compared to the acceptable R values with $p<0.05$, only the younger males category proved to be statistically significant at R=0.5053.

The correlation between RER and percent body fat in various groupings. *$p<0.05$.

	Male	**Female**	**All (n=80)**
All (n=40)	0.2666	0.2246	0.1717
Trained (n=20)	-0.3212	-0.1309	
Untrained (n=20)	0.3074	0.2367	
Young (n=20)	0.5053*	0.1304	
Old (n=20)	0.0175	0.3093	

Discussion

There was not a consistent relationship between body fat percentage and fat metabolism in all the groups, except for the younger male group, which turned out to be statistically significant. Their R value of 0.5053 suggests that younger males with greater body fat percentages are more likely to use carbohydrate than fat during exercise. A greater understanding of this R value can be gained when referring back to the characteristics of the subjects. The younger males group consisted of trained and untrained individuals. In this group, their fitness level appeared to have a great influence on their body fat percentages and RER values (See Table 1). The trained younger males had much lower body fat percentages, as well as lower RER than the untrained (11.8% and RER of 0.84 vs 21.7% and RER of 0.89, respectively). The differences in body fat percentages and RER between untrained and trained younger males allowed for two different clusters, which contributed to a high correlation between the two factors. Even in this statistically significant group, the fitness factor was well reflected by their body composition, which ultimately had a positive impact on the correlation. In contrast, the correlation for the younger females was only 0.1304. The differences in body fat percentages and RER values between the trained and untrained younger females were not as significant as the younger male group. The untrained younger females only had about two percent more body fat percentage than trained, and when there was not a drastic body fat percentage difference, the correlation remained low. The lowest correlation of 0.0175 was calculated in the older male group. Similar to the younger females, this group did not show much variance in body fat percentages between trained and untrained individuals, while there was a noticeable difference in RER values. The difference in RER values of trained and untrained older males was just as great as that found with the younger males, despite no differences in body fat percentage. Furthermore, the body fat percentage of the older trained male was statistically different from that of the younger trained males, at about 11% difference, although their RER values did not significantly differ. This suggests that body fat percentage does not seem to be an influencing factor in fat metabolism. Older individuals can metabolize fat just as well as younger trained individuals, regardless of body composition, as long as they keep training.

Conclusion

The finding of this study is that there is no consistent relationship between body composition and fat metabolism during exercise. Once the subjects are placed into different groupings, the highest correlation is seen in the younger male group, but even this correlation is not a strong correlation. The lack of significant relationship between the two factors may suggest that percent body fat is not a factor that influences fat metabolism during exercise, but rather, fitness level and gender have greater contributions. An individual who is high in body fat percentage should not assume that he/she will have an easier or a harder time losing fat, because body fat percentage has demonstrated no relationship with fat oxidation rate in this study.

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