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Review

A role for high intensity exercise on energy balance and weight control

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GR Hunter[1], RL Weinsier[2], MM Bamman[3] and DE Larson[4]

[1]*Exercise Physiology Laboratory,* [2]*Department of Human Studies,* [3]*Division of Physiology and Metabolism,* [4]*Department of Nutrition Sciences, University of Alabama at Birmingham, Birmingham, AL 35294-1250, USA*

The objective of this commentary is to remark on the impact, exercise intensity has on energy expenditure and its potential for body weight control. Exercise intensity can favorably impact on energy expenditure in a number of ways. First, exercise-associated energy expenditure is increased by decreasing exercise efficiency and increasing work rate. Second, resistance training that increases muscle mass, in turn increases resting energy expenditure. Third, aerobic exercise $>70\%$ VO_2max, increases resting energy expenditure separate from any change in muscle mass. High-intensity exercise training has the added benefit of improving fitness, thus making low-intensity exercise less difficult and more easily tolerated. Although continuous intense exercise is difficult to maintain for extended periods of time, intense interval exercise can be easily endured and may be an important adjunct to lifestyle modifications for body weight control.

Keywords: energy expenditure; exercise intensity; exercise efficiency

Introduction

US trends survey data show diverging trends in energy intake (falling) and obesity prevalence (rising) suggesting that there must be a dramatic decrease in total energy expenditure in this country since the 1970s.[1] Recent survey data from the UK shows similar diverging patterns of energy intake and prevalence of obesity, indicating the decrease in total energy expenditure is not confined to the US.[2] It seems prudent to explore ways to increase total energy expenditure. Physical activity related energy expenditure is the component of total energy expenditure that is most variable and has the greatest potential for increasing total energy expenditure. It is also the component of energy expenditure that is most likely responsible for the recent decrease in total energy expenditure. Recent efforts for increasing physical activity have focused on low intensity exercise.[3] However, high intensity exercise may add components to exercise programs that cannot be achieved by low intensity exercise alone. Indeed, it has been recently shown that high intensity exercise training is associated with markedly greater decreases in subcutaneous skinfolds than low intensity exercise training, even though over twice as much energy was expended in the longer duration low intensity exercise.[4] This commentary is an effort to summarize some of the advantages of high intensity exercise on total daily energy expenditure (EE) and discuss it's possible role in weight control.

Energy expenditure during work: function of total work completed and efficiency of doing that work

The factor that probably has the greatest impact on EE is volume of work, which is a function of duration and intensity of exercise. An individual will expend more energy while walking five miles than while walking two and a half miles or will expend more energy while bench pressing 100 pounds 20 times than while bench pressing 100 pounds 10 times. In fact, the EE-to-work relationship for any task is approximately linear, as long as the task is performed at the same intensity. Regression equations have been developed to estimate EE for activities such as walking, running, bicycling, climbing stairs and weight training. However, a number of factors may influence how efficiently work can be performed, making the standard error around these estimates as high as 25%.

One factor that affects exercise efficiency is intensity of the exercise. A negative relationship between exercise intensity and efficiency has been shown in a number of activities including stationary cycling,[5–7] walking[8] and various weight training exercises.[9–11] The variation in magnitude of efficiency can be quite large, decreasing more than 300% over the spectrum of exercise intensities. For example, it has been found that 22% more energy is required to perform the same amount of bicycle work at a high intensity than at a low intensity,[7] and that

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Correspondence: Dr GR Hunter, Room 205 Education Boulevard, University of Alabama at Birmingham, 901 South 13th Street, Birmingham, AL 35294-1250, USA.
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three times as much energy is required to perform one bench press at 80% of one's maximum compared to four bench presses at 20% of maximum.[9]

Although it is unknown what causes the inverse relationship between efficiency and exercise intensity, several factors have been hypothesized as potential contributors. Included in this list is increased dependence on inefficient fast twitch muscle fibers,[12] increased recruitment of stabilising muscles,[9] and increased work of the heart and respiratory muscles[9] as exercise intensity increases. Other factors that may contribute are use of energy to remove lactate through gluconeogenesis, change in the myosin ATPase activity to cross-bridge sweep ratio and sympathetic nervous system activity.

Running is the one activity that typically is not associated with reduced efficiency as runing speed (intensity) increases. This may be the result of an increased use of elastic energy as running speed increases, counteracting a decrease in muscle efficiency. As the runner increases velocity, the muscle is stretched with greater velocity each time his/her foot contacts the ground. Because of the greater landing velocity, the velocity of the eccentric muscle action is greater and more myosin cross-bridges are stretched and remain bound as the eccentric muscle breaking action stops the descent and muscle stretch. These stretched myosin cross-bridges, may add elastic energy to the concentric muscle action furnishing more force for the forward and upward propulsion.[13] The elastic energy furnished by the stretched myosin cross-bridges will not, of course, cost the muscle any expenditure of adenosine triphosphate (ATP), thus reducing the total energy needed to do the task.

Another factor that can affect muscle efficiency is the range of motion over which a muscle contracts during an activity. It is possible that muscle efficiency varies across the range of muscle lengths. For example, over twice as much energy is needed to do identical amounts of knee flexion work when the hip is extended as compared to when the hip is flexed.[10] The prime movers in knee flexion are all two-joint muscles that cross both the hip and knee. Therefore, the knee flexors are all in a more lengthened position when the hip is flexed, compared to when the hip is extended. Lower normalized electromyography (Ref. 14 and unpublished observations from this lab) indicates that the muscle is not working as hard when the hip is extended. This finding is consistent with the hypothesis that stretched muscle is better able to use series elastic energy from the soft tissue of the stretched muscle. In any event, joint positions may affect the amount of energy needed to perform work.

In summary, a high volume of work performed at high intensity will be most effective in increasing EE during exercise. Since high intensity and high volume work can be very fatiguing, interval work (that is, high intensity work interspersed with low intensity work) is one way to combine relatively high intensities with large volumes. Improvements in fitness that accompany properly prescribed high intensity work, will increase the volume of work that can be accomplished at any relative intensity.

Exercise-induced increase in resting energy expenditure (REE)

A number of studies have shown that REE is increased by 5–15% for 24–48 h as a consequence of aerobic exercise of at least 70% of VO_2max, but not increased following aerobic exercise at lower intensities.[7,15–17] In addition, a number of studies have shown that athletes (who presumably will be involved in high intensity exercise) have approximately 5–20% higher REE than sedentary controls, even after adjusting for fat free mass (FFM).[18–25] It is unknown whether the increase in REE is due to an acute effect (that may increase EE for only 24–48 h after exercise) or due to a more long lasting training effect. From a practical standpoint, it probably makes little difference. REE is increased following exercise and will stay increased as long as exercise is repeated within 24–48 h.

Several hypotheses exist for explaining this exercise-induced increase in REE. One is exercise-induced increases in muscle mass. Increases in muscle mass will occur only minimally, if at all, consequent to aerobic training and will certainly not occur following one bout of exercise. Although increases in muscle mass may contribute to increases in REE following long-term high-intensity exercise, other factors must also play a role in increasing REE.

Increased appearance of serum norepinephrine following aerobic exercise,[15,26–28] indicates that the sympathetic nervous system may be involved in increased EE following exercise. Elevated levels of norepinephrine probably play an important role in increasing EE early in recovery from exercise, but normally return to pre-exercise levels within a few hours.[26] However, elevations of serum norepinephrine[15,28] have been found up to 24 h following high intensity aerobic exercise[15,28] and older athletes have been shown to have higher muscle sympathetic nerve activity than older non-athletes.[29] Thus it is possible that sympathetic tone may be partially responsible for exercise-induced increases in REE. It is important to point out, that consistent with the hypothesis, elevations in REE only occur following high intensity aerobic exercise; sympathetic tone is elevated for less than 2 h following low-to-moderate intensity exercise.

Toth and Poehlman[30] hypothesize that 'energy flux', that is, increased energy intake and expenditure in response to exercise, may be responsible for the increase in exercise-induced REE. When exercise training is combined with increased food intake to maintain caloric balance, a high flux energy balance state occurs and it is the increased 'energy flux' that increases EE. Recent research by Burke *et al*[31] and Goran *et al*,[32] suggest that high-energy flux may act as a stimulus to increased REE. However, the high energy flux hypothesis, does not account for the greater increases in REE found following high-intensity *vs* low-intensity aerobic exercise, when diet intake is controlled.[7] Although it is certainly possible that high energy flux may contribute to the increase in REE following high intensity exercise, other factors appear to be contributing to the elevation as well.

Lipid oxidation rates increase to a greater extent following high-intensity exercise,[7,33] while post-exercise glycogen synthesis is increased, replacing the glycogen consumed during exercise.[34] Greater increases in the activity of a marker of beta-oxidation (muscle 3-hydroxyacyl coenzyme A dehydrogenase enzyme activity) following high-intensity training, than low-intensity training, are supportive of the hypothesis that high intensity exercise elevates resting lipid metabolism more than low intensity exercise.[4] It is a logical hypothesis that the increase in lipid oxidation following high-intensity exercise may be at least partly the result of increased glycogen storage. Increased lipid oxidation should also be associated with an increase in turnover of the triglyceride-free fatty acid cycle. Recently it has been found that the rate of appearance of glycerol and free fatty acids is increased in athletes, compared to untrained controls.[35] Of course, increased sympathetic tone should also act to increase this cycle and its energy requirements.

Following exercise, increased protein turnover may also contribute to elevated energy expenditure. High-intensity exercise may possibly cause greater increases in protein turnover than low-intensity exercise, resulting in greater post-exercise expenditure of energy. Increased EE induced by protein turnover, may also increase the need for endogeneous lipid, leading to elevated lipid oxidation.

Whatever the causes, it appears that REE can be increased for at least 24–48 h after high-intensity exercise. However, little if any long-lasting increase occurs following low intensity exercise. This increase following high intensity exercise can be sizeable (100 to >200 kcal/d) and quantitatively may impact on energy balance.

Exercise that increases FFM can have an additional effect on EE. Intensity of exercise needs to be high to increase FFM. In fact, little or no increases in muscle mass are normally found with aerobic training, either low- or high-intensity. Increases in FFM can occur with a relatively small investment in training time, however, with resistance training. These increases in FFM are associated with increases in REE. We have previously found that competitive body builders have seated REEs that are 31% higher and walking EEs that are 32% higher than would be expected for young men and women of similar body weights (unpublished results). These body builders had elevated FFMs.[36] Less extreme increases in REE have been reported for weight trainers when compared to controls (5–16% increase).[33,37–39] In addition, a number of studies have shown that weight training results in increases in REE and muscle cross-sectional area.[33,40,41] Although increases in REE following weight training programs are normally associated with increases in FFM, some studies suggest that increases in at least a portion of the REE are independent of increases in FFM.[33,40] As with high-intensity aerobic exercise, the causes of any increases in REE, independent of increases in FFM, are not known.

Other benefits of high-intensity exercise on energy balance

Another potential benefit of high-intensity exercise is on appetite. It appears that exercise will suppress appetite immediately after exercise but that it has little effect on long term eating behavior.[42] Recent research indicates that high-intensity exercise promotes a greater negative energy balance than low-intensity exercise by increasing the difference between EE and food intake.[43]

High-intensity exercise is very effective in increasing fitness and thus allowing individuals to expend more energy while doing low-intensity exercise of the same relative intensity. It is well accepted that physiological changes induced by training are dependent on the intensity of the workload. These physiological changes will reduce the physiological effort that is needed to perform any submaximal task. We have previously shown that older women have reduced cardiovascular[44] and muscular stress[45] while performing activities such as carrying a box of groceries or standing on a chair following 16 weeks of strength training. High-intensity aerobic exercise training increases aerobic fitness more than low intensity exercise.[46] These decreases in aerobic fitness will be associated with decreased perceived exertion, heart rate and ventilation rate while walking at submaximal speeds.[47] Training-induced increases in fitness will thus allow individuals to exercise at greater absolute intensities while experiencing the same relative intensity. For example, an individual exercising at 50% VO_2max with a max VO_2 of 4 l/min will burn 10 kcal/min, while an individual exercising at 50% VO_2 with a VO_2max of 3 l/min will burn only 7.5 kcal/min. In both cases, the individuals are exercising at the same low relative intensity (50% VO_2max) but the more fit individual (the one with the higher VO_2max) is burning 33% more energy each minute of exercise.

Effects of exercise intensity on weight control

Although it can be demonstrated that total EE, and possibly even energy intake, may be favorably affected by intense exercise, several methodological problems have made it difficult to accurately determine the effect of exercise intensity on weight control. Measurement error for self-reported activity, failure in adjusting for statistical confounders, inadequate time frame in longitudinal studies and small sample size in intervention studies, have all presented problems. Nevertheless, several cross-sectional studies have shown that exercise intensity is inversely related to rates of obesity[48–51] as well as lower waist to hip ratio (WHR).[51] In addition, exercise intensity was independently and negatively related to weight gain over a two year follow-up.[49] We are aware of few intervention studies that have compared low *vs* high-intensity exercise. Grediagin *et al*[52] compared 50% *vs* 80% VO_2max exercise and found no difference in fat loss between the two intensities. However, Lennon *et al*[53] found that males participating in high-intensity exercise lost more fat than males participating in low intensity exercise. The duration of the training program was short (only 12 weeks) and the sample size small in both of these interventions.

Conclusions

Some people do not like high-intensity exercise, in some cases because of low fitness.[54] In addition, at least in the elderly, free living activity related EE may decrease in older adults that participate in high-intensity training programs,[33,55] thus negating at least partially the EE advantages gained from the high-intensity exercise. It might be that the best exercise programs should include a combination of low- and high-intensity exercise. The low-intensity exercise, if the more preferred, may be done more frequently and will be the exercise in which the majority of energy is expended. However, some minimum amount of high-intensity exercise may be needed to elevate exercise related EE and REE, and to improve fitness and thus exercise tolerance. We do not know what combination of low- and high-intensity exercise is ideal for people who are resistant to exercise. However, development of training programs that will more effectively increase metabolic rates may play an important role in stemming the increase in the prevalence of obesity.

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