EFFECTS OF RESISTANCE TRAINING, MODERATE INTENSITY, AND HIGH INTENSITY CYCLING ON INSULIN SENSITIVITY

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Abstract

Effects of Resistance Training, Moderate Intensity, and High Intensity Cycling on Insulin Sensitivity, Michael Braun, Hanover College, Hanover, Indiana.
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During carbohydrate digestion, insulin is needed to allow the uptake of glucose by muscle cells throughout the body. Studies have shown that exercise may improve glucose uptake for 24-72 hours, but information on how the exercise modality and intensity affects this phenomena is unclear. This study was designed to explore the possible benefits of two types of high intensity anaerobic exercise compared to moderate aerobic exercise. Specifically, this study was undertaken to determine how sprinting protocols and resistance training compare to steady state cardio in improve glucose uptake.

Methods: Six highly fit collegiate males, familiar with resistance training and intense exercise, completed separate bouts of continuous cycling, max effort cycling repeats, and resistance training each followed by an oral glucose tolerance test (OGTT). These provided a baseline to examine the extent each form of exercise improved insulin sensitivity. Work output was the same for continuous and high intensity exercise and as similar as possible for resistance training

Results and Discussion: Results demonstrated that all exercise condition promote glucose clearance when compared with no exercise. Though not statistically significant, results indicate that high intensity exercise (HIE) was the most effective, reducing the area under the curve on a one hour oral glucose tolerance test by 13.9% and reducing peak glucose by 15.5% This was followed by RT which reduced these values by 11.7% and 13.0% respectively. MIE appeared to produce moderate by not insignificant improvements reducing AUC by 6.5% and glucose peak by 6.1%. All of these exercise conditions may serve as beneficial components of a treatment regimen for individuals with type-2 diabetes or metabolic syndrome.

Chapter One

<u>Introduction</u>

In the United States alone, there are over 29 million people with diabetes and 86 million with pre-diabetes (5). This results in astronomical healthcare costs—hundreds of billions of dollars are spent each year treating the disease (12). With so much money spent one would expect a cure. Some magic pill that cures diabetes and gets rid of all it symptoms, but in fact we are nowhere near that. At best, medications only manage diabetes, and they have a plethora of side effects including—nausea, diarrhea, weight gain, and an increased risk of infections, fractures, and heart failure (17).

What if there was a magic pill and it didn't cost anything? It's been known since the London Busmen study conducted by Jeremy Morris in 1953 that those who engage in regular physical activity are at lower risk for cardiovascular disease, but as more research is conducted the greater the realization that the simple act of exercise has immense benefits on physiological systems. It reduces abdominal obesity, psychological stress, blood pressure, and triglycerides just to name a few. Studies have also shown exercise can have an effect on insulin sensitivity (4), and this benefit is not limited to those who have been exercising for long periods of time. As little as one session can improve postprandial insulin sensitivity (20.). However, little is known about the effect different exercise modalities and intensities have on these improvement.

Statement of the problem

The purpose of this study is to compare the effects of resistance training and different cycling intensities on post prandial insulin sensitivity

Significance of the study

Professional Significance:

With the high prevalence and cost to diabetes and pre-diabetes, understanding non-pharmaceutical treatment options is an important public health question. It is well established that low to moderate aerobic exercise can improve insulin sensitivity, but adherence to such program is quiet low (13). If other forms of exercise can be demonstrated to show similar improvements it can give individuals looking to manage their diabetes greater options.

It has previously been suggested that intense exercise does not improve insulin sensitivity more than moderate exercise (13). However, recent studies using exercise above the lactate threshold have suggested that exercise above the lactate threshold may result in greater improvements insulin sensitivity (20, 21.). This study aims to add to the body of evidence about the effects of highly intense exercise in order that decisive conclusions can be made.

The benefits of improving insulin sensitivity is not limited to those with diabetes. Insulin is an anabolic hormone and Glycogen is the major fuel source for both intense exercise and many athletic performances. Improving insulin sensitivity may improve recovery and athletic performance (2).

Personal Significance:

This study also hold some personal significance. Working as a coach for adult fitness classes. I have met many people who don't enjoy long walks and jogs, but though they were the only way to stay healthy. This causes them to simply avoid exercise for a large portion of their life. It is only after they find an exercise they enjoy doing regularly that their health improves. I hope to show that the health benefits of exercise extend not only to long distance runners, but people who enjoy sprinting and resistance training as well. I feel that the most important aspect of exercise is not the type chosen, but that it is performed regularly.

Delimitations

Six fit college-age fit male subjects participated in this study. Each subject was tested in three exercise conditions and a baseline, leading to a total of 24 sessions. The three conditions were intense cycling preformed as intervals, moderate cycling, and free-weight resistance training.

Variables—The independent variable was the exercise modality and intensity, while the dependent variable was insulin sensitivity. Insulin sensitivity was inferred by the blood glucose peak and area under curve in the hour of the OGTT. Blood glucose was measured using a finger stick Accu-Check glucometer.

Controls—Since blood sugar and hormone levels vary throughout the day, subjects performed each of their trials at the same time. Sleep levels also effect insulin sensitivity (6) so subject were instructed to get at least 6 hours of sleep. The day of the trial were also instructed to abstain from physical and cease eating 3 hour prior to testing.

Limitations

- Insulin sensitivity could not be directly measured, it was therefore assumed that the changes in glucose uptake during the OGTT was representative of improved insulin action
- Time period—glucose disposal was only measured once post-prandially in the 2nd hour following exercise. Previous studies have found that the effects of a single exercise session last from 48-72 hours (19). It is possible that the different exercise modalities result in insulin sensitivity changes of different intensities and duration. These would require further studies
- External validity--due to low number of subject and single gender and age group. Further research is necessary to determine if the results extend to other populations

Assumptions

- The Accu-check glucometer produced reliable blood sugar readings
- Subjects gave their best effort on Wingate tests – volitional exhaustion.
- Subjects adhered to the pretest protocol

Hypotheses

Insulin sensitivity will increase:

1. After moderate exercise
2. After intense exercise
3. After resistance training

4. Moderate intensity exercise will increase postprandial insulin sensitivity significantly more than resistance training

High intensity exercise will increase postprandial insulin sensitivity significantly more than:

5. Moderate exercise
6. Resistance training

Definition of terms

- Fasted—nothing but water 3 hours pre-test
- Adequate rest—6+ hour (subject own control)
- Intense exercise—exercise performed above the lactate threshold

Chapter 2

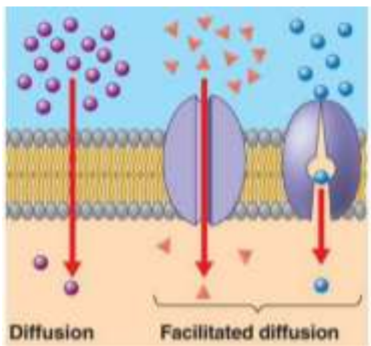
Background

Introduction

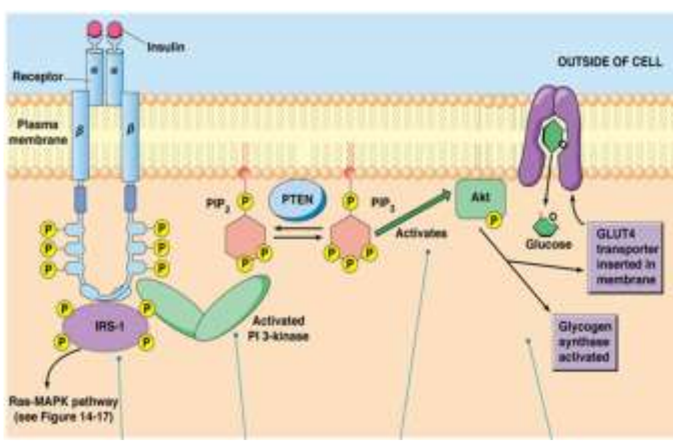
In order to examine the relationship between insulin sensitivity and the intensity and modality of exercise, one must first examine the piece. Namely—how does glucose enter the cell and what effect does insulin play on this process? How can this process go wrong? And finally how does exercise aid this process and why might different exercise produce different effects?

Glucose Uptake

An important step of carbohydrate digestion is taking glucose from the bloodstream into the muscle cells throughout the body. This is known as glucose uptake or glucose disposal. Due to the large size and polar nature of the glucose molecule, it cannot simply pass through a cell membrane on its own. Instead, its diffusion must be facilitated by a carrier protein.



The primary carrier protein used in glucose disposal is known as GLUT-4, but this protein isn't always embedded in the cell membrane. When uptake is not occurring GLUT-4 sits dormant within the cytoplasm of the cell. During this time glucose is unable to enter the cell and stays within the bloodstream. A high concentration of glucose in the bloodstream causes the pancreas to release a hormone known as insulin. This hormone travels through the bloodstream and membrane receptor on the outside of the cell. This begins a chain reaction resulting in the movement of GLUT-4 into the cell membrane. Once GLUT-4 is inserted into the cell membrane glucose can diffuse into the cell where it is stored as glycogen.



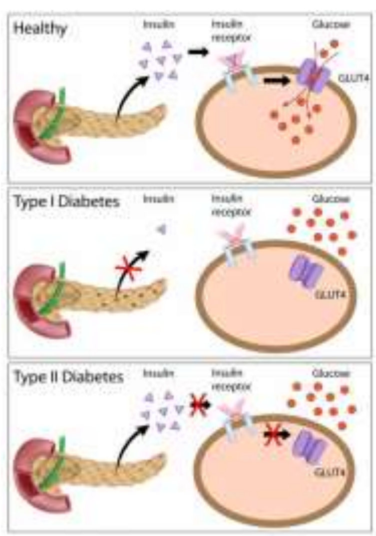
Summary: Glucose is taken up into a muscle cell by the carrier protein GLUT-4 which requires activation by the hormone insulin.

Diabetes

A disease characterized by the disruption of glucose disposal is diabetes. Diabetes effects 29.1 million people each year and 1 out of 4 of them don't even know they have it (5). With such a high prevalence, it is no wonder that diabetes is one of the largest health care cost in the United States. An estimate 1 out every 8 dollars can be directly attributed to diabetes (12).

There are two major forms of diabetes, known as type-1 and type-2. Type-1 diabetes, also known as juvenile onset, is characterized by the pancreas releasing little to no insulin. This cease in insulin production usually occurs before the age of 20 and the cause is unknown. However, it is known that immune system begins attacking the beta cells in the pancreas which are responsible for the production of insulin. Without insulin from the pancreas, nothing binds to the insulin receptor of the cell and the process of translocating GLUT-4 to the cell membrane cannot begin. This gives type-1 diabetics few treatment option and they must receive synthetic insulin. Type-1 diabetes is quite rare, accounting for only 5-10% of diabetes patients.

A much more prevalent form of diabetes is type-2, accounting for nearly 90-95% of all diabetes cases. In type-2 diabetes, instead of not releasing insulin, the muscle cells become insensitive to its actions. Insulin floats around the blood stream and it is either unable to bind to the muscle's insulin receptor or it does bind and the chain reaction moving GLUT-4 breaks down. In either case, GLUT-4 remains dormant in the cytoplasm of the muscle, and glucose is unable to enter the cell. Since blood glucose is still elevated, the pancreas works overtime releasing more and more insulin trying to fix the problem. However, this causes a lot of problems of its own, particularly to the circulatory system. The damaged circulatory system often results in common diabetes side effects, namely blindness, loss of sensation in peripheries, and even heart attack or stroke. Overtime, the overworking of pancreas can cause it to fail resulting in a dependence on synthetic insulin, like that seen in type-1 diabetes. Type-2 diabetes used to be known as adult onset diabetes, but, with obesity becoming more prevalent, cases of juveniles developing type-2 diabetes are increasingly common.



Summary: Diabetes disturbs glucose uptake by preventing either insulin release (type 1) or the movement of GLUT-4 to the cell membrane (type 2).

The Effects of Moderate Exercise

Not all is lost for type-2 diabetics, while type-1 diabetics must rely on synthetic insulin, type-2 diabetes can be treated through lifestyle change. Many drugs exist to treat type-2 diabetes. However previous studies have shown exercise to be equally, it not more, effective in promoting insulin sensitivity. After a single bout of moderate exercise glucose uptake is increased for 48 to 72 hours by at least 40% (19). This occurs because exercise increases the number GLUT-4 carrier proteins and their ability to translocate (11), which in turn results in an increase in the responsiveness of the muscle cell to insulin. This results in greater glucose uptake. This is desirable for the cell because skeletal muscle relies on intramuscular glycogen stores as a source of energy during exercise, and the only way these stores can be replenished is through the uptake of new glucose molecules (25). These benefits increase if moderate exercise is continued over the course of weeks or months. Simply walking 12 miles a week can improve insulin sensitivity by 85% (13).

The effect of moderate exercise on life-style induced diseases such as heart disease, diabetes, and metabolic syndrome cannot be over-stated. It's main effect is the burning of excess calories which reduces abdominal adiposity. This reduced adiposity increases insulin sensitivity (4, 13, 20), thereby raising HDL since the body can use glucose properly and no longer relies on the glycerol. The increased HDL levels and insulin sensitivity reduce SNS activity and retention of H_2O, which in turn lowers blood pressure. Moderate exercise has some key advantages over vigorous exercise including that it can be done right after a meal resulting in increased calorie burning. Moderate exercise can also be accomplished by anyone regardless of fitness.

Summary: Moderate exercise results in many health improvements, including improving insulin sensitivity in as little as a single session.

Intense Exercise

Vigorous exercise has been shown to have all the health benefits of moderate exercise plus direct effects on raising HDL (23), reducing psychological stress, and reducing blood pressure. Psychological stress was improved through metabolism of catecholamines and the release of endorphins. Blood pressure is directly reduced thought the production of nitric oxide, which increases the endothelial linings ability to vasodilate. Vigorous exercise can definitely promote health to an even greater degree than moderate exercise provided that a person is willing to complete it regularly.

One area that vigorous exercise has been thought to be superior to moderate is insulin sensitivity. Early studies comparing the effects of moderate versus intense exercise have concluded that increasing intensity does not result in greater insulin sensitivity benefits (13). However, many of these early works used intense exercise that still fell below the lactate threshold. When exercise rises above the lactate threshold the body is in a fundamental different state than in moderate exercise. Unlike moderate exercise, insulin secretion decrease minimally, if at all. Glucose become the exclusive muscle fuel resulting in a rise in glucose utilization by 3 to 4-fold and a rise utilization by 7 to 8 fold. That's not even to mention the stress responses including a 14 to 18 fold rise in plasma catecholamine and a rise in hormone levels including epinephrine, norepinephrine, and growth hormone (20). Due to its fundamental differences, exercise above the lactate threshold (LT) must be looked at differently than exercise below the LT. Recent studies using exercise above the LT have suggested that this type of exercise may in fact result in greater improvements insulin sensitivity (20, 21). This study aims to add to the body of evidence about the effects of highly intense exercise in order that decisive conclusions can be made.

Summary: Vigorous exercise has all the health promoting properties of moderate exercise and more. While greater intensity may not improve insulin sensitivity below the lactate threshold, exercise above the LT deserves a subsequent examination due to it physiological differences. Early findings suggest that exercise above the LT may result in greater improvements in insulin sensitivity.

Resistance Training

Little research has been done on resistance trainings effects on insulin, but initial findings have shown 6 months of resistance training (RT) to be as effective as a 6 month walking program at improving glucose disposal in elderly subjects (8). Like highly intense exercise, RT uses glycogen as the primary fuel source and it utilizes a greater muscle mass indicating that recovery may require large amounts of glucose uptake. However, glycogen demands of RT are not as high as one might expect (7) and RT damages muscle tissue possibly interfering with insulin action.

Although, not normally discussed resistance training also has health benefits. The amount of muscle mass is one of the greatest indicators of longevity in the elderly (22). Strength is positively correlated with increased the daily activity due because moving your body around is easier when you are used moving with an external load in moves such as squats and deadlifts. Strength also prevents fall risk in the elderly.

Summary: Strength is known to have health benefits, but little is known about the effect of resistance training on insulin sensitivity.

Research support of hypotheses

This section will discuss the current literature related to the 6 hypotheses. 10 source were included relating to insulin sensitivity and either moderate, intense, and/or resistance exercises. All source were found to support the hypotheses.

Hypothesis 1—Insulin sensitivity will increase after moderate exercise:

Supportive research:

1) Boulé, N. G., Haddad, E., Kenny, G. P., Wells, G. A., & Sigal, R. J. (2001). Effects of Exercise on Glycemic Control and Body Mass in Type 2 Diabetes Mellitus. Jama, 286(10), 1218. doi:10.1001/jama.286.10.1218
2) Houmard, J. A., & E. (2004). Effect of the volume and intensity of exercise training on insulin sensitivity. Journal of Applied Physiology. Retrieved November 4, 2016, from http://jap.physiology.org/content/96/1/101
3) Rynders, C. A., Weltman, J. Y., Jiang, B., Breton, M., Patrie, J., Barrett, E. J., & Weltman, A. (2014). Effects of Exercise Intensity on Postprandial Improvement in

Glucose Disposal and Insulin Sensitivity in Prediabetic Adults. The Journal of Clinical Endocrinology & Metabolism, 99(1), 220-228. doi:10.1210/jc.2013-2687

The first item of supportive research is a 2001 review article published in JAMA. This provided a meta-analysis of 12 randomized control trials including 251 diabetic men and women. These subjects partook in moderate exercise programs, consisting mainly of walking, for greater than 8 weeks. Studies including drug and/or diet cointerventions were excluded. At the end of the exercise programs average blood HbA1c concentration in blood decreased .66% ($P<.001$).

HbA1c is a type of hemoglobin which include bound glucose. The life span of a red blood cell is about 6-8 weeks. Therefore, the percentage of hemoglobin that is bound to glucose serves as an indicator of the blood glucose levels for the last 6-8 weeks. While .66% seems like a small change, normal HbA1c levels only range from 4-6% and a .66% improvement indicates a substantial change.

The second item examined the effects of different exercise duration and intensities on insulin sensitivity as measured by intravenous glucose tolerance test. The 154 obese male and female subject completed 6 months of training and were divide into three groups:

1) low-volume/moderate-intensity group [∼12 miles walking/week at 40–55% peak O2 consumption ($\dot{V}o2$ peak)],
2) low-volume/high-intensity group (∼12 miles jogging/week at 65–80% $\dot{V}o2$ peak),
3) high-volume/high-intensity group (∼20 miles jogging/week at 65–80% $\dot{V}o2$ peak).

This study saw an 85% improvement in insulin sensitivity in both groups 1 and 3 with only a 40% improvement in group 2. Because both group 1 and 3 exercised for approximately 170 minutes, (compared to the 115 minutes of group 2) it was concluded that it was exercise duration that effect insulin sensitivity. This study provided the initial evidence that exercise induced improvements in insulin sensitivity could be assessed by glucose tolerance and provided the operational definition of >80% VO2 as intense exercise.

The third and final piece of evidence was a 2014 study that assessed the effects of a single bout of exercise on insulin sensitivity. It was found that after a single bout of moderate exercise (200 kcal of cycling at the lactate threshold) improved insulin sensitivity by 51%. Because this study used a single effort of cycle ergometry, and assessed insulin sensitivity through OGTT. It provided the best evidence for the current study.

Hypothesis 2—Insulin sensitivity will increase after intense exercise

Supportive research:

1) Barbraj. (2009). Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. BMC Endocrine Disorder. Retrieved November 4, 2016, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2640399/.
2) Little, J. P., Gillen, J. B., Percival, M. E., Safdar, A., Tarnopolsky, M. A., Punthakee, Z. Gibala, M. J. (2011). Low-volume high-intensity interval training reduces hyperglycemia and increases muscle mitochondrial capacity in patients with type 2 diabetes. Journal of Applied Physiology, 111(6), 1554-1560. doi:10.1152/japplphysiol.00921.2011
3) Adams, P. (2013). The impact of brief high-intensity exercise on blood glucose levels. Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy, 113. doi:10.2147/dmso.s29222

The first item of supportive evidence took 16 healthy lightly active males through a baseline OGTT. After the baseline was completed, the subjects participated in a 2 week exercise program consisting of six sessions of cycling interval exercise. Each exercise sessions was compose of 4-6 intervals of the Wingate test (30 seconds max effort with a resistance of 7.5% of body weight) with 4 minutes rest between intervals. Two or three days after the 6 session, a second OGTT was performed. Plasma glucose AUC and insulin AUC were reduced by 12% and 38% respectively. This was assessed to be an 18% improvement in insulin sensitivity.

The second item want to see if similar result could be produced in diabetes. 8 diabetic men complete 2 days/week of cycle interval training for two weeks. Due to lack of activity of the subjects, researchers felt that they couldn't produce maximal exertion during the standard Wingate test therefore the test was modified to 10 bouts of 60 second of cycling with 60 seconds of rest between bouts. At the end of 2 weeks the subjects had increased GLUT4 concentration by 369%, reduced average 24hr glucose concentration by 13%, and reduced postprandial glucose AUC by 30%. Furthermore, the subjects reported an average enjoyment ranking of 7.9 on scale of 1-9. This indicates that high intensity exercise could provide an alternative treatment option to individuals who do not enjoy moderate exercise.

The third and final item is a review article consisting of six studies that included 7.5-20 min/week of highly intense exercise (>80% of VO2peak). It was found that short duration highly intense exercise improved postprandial insulin sensitivity to a similar degree as 150 min of moderate exercise. This statement remained true regardless if the subjects were male or female or diagnosed with type-1 or type-2 diabetes.

Hypothesis 3--Insulin sensitivity will increase after resistance training

Supportive research:

1) Ferrara, C. M., Goldberg, A. P., Ortmeyer, H. K., & Ryan, A. S. (2006). Effects of Aerobic and Resistive Exercise Training on Glucose Disposal and Skeletal Muscle Metabolism in Older Men. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 61(5), 480-487. doi:10.1093/gerona/61.5.480
2) Frank, P., Andersson, E., Pontén, M., Ekblom, B., Ekblom, M., & Sahlin, K. (2015). Strength training improves muscle aerobic capacity and glucose tolerance in elderly. Scand J Med Sci Sports Scandinavian Journal of Medicine & Science in Sports, 26(7), 764-773. doi:10.1111/sms.12537

The first item of research that supports hypothesis 3 is a study in which 39 elderly men (average age 63) undertook 6 months of either 3 days/week resistance training or 3 days/week of walking at 75% of HRR. The resistance training protocol consisted of 8 machine exercises namely: the leg press, chest press, leg curl, latissimus pull down, leg extension, and military press. Participants alternated the upper and lower body exercises to minimize fatigue performing one set on upper body exercises and two sets on lower body exercises. The resistance was set at 80% of the 1 repetition maximum (1 RM), with the participant performing 8–12 repetitions per set. When participants reached 12 repetitions, the amount of resistance was increased by 5% at the next exercise session. At the end of 6 months an OGTT was performed and glucose disposal improved by average of 13%.

The second item consisted of similar resistance training program lasting 8 weeks. In addition to the shorter duration, the subject pool was expanded to include both elderly men and post-menopausal women. Both genders improved glucose disposal by 21%.

Hypothesis 4– Moderate intensity exercise will increase postprandial insulin sensitivity significantly more than resistance training

Supportive research

1) Ferrara, C. M., Goldberg, A. P., Ortmeyer, H. K., & Ryan, A. S. (2006). Effects of Aerobic and Resistive Exercise Training on Glucose Disposal and Skeletal Muscle Metabolism in Older Men. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 61(5), 480-487. doi:10.1093/gerona/61.5.480

The Ferrara et al. article discussed for hypothesis 3 compared the results of their resistance training program to a 6 months program of 3 days/week walking at 75% of HRR. They found that neither program had effect on fasting glucose or insulin level, but while resistance training improved postprandial glucose disposal by 13%, moderate intensity exercise improved glucose disposal by 23%

This single study appears to be the only direct comparison of the 2 modalities. Its results seem consistent with the other studies. Studies that looked at resistance training saw relatively modest improvements in insulin sensitivity (8, 9, 14) compared to the results seen with moderate exercise interventions (4, 13, 20)

Hypothesis 5—Intense exercise will increase insulin sensitivity significantly more than moderate exercise

Supportive research:

1) Sandvei, M., Jeppesen, P. B., Støen, L., Litleskare, S., Johansen, E., Stensrud, T.,. Jensen, J. (2012). Sprint interval running increases insulin sensitivity in young healthy subjects. Archives of Physiology and Biochemistry, 118(3), 139-147. doi:10.3109/13813455.2012.677454
2) Rynders, C. A., Weltman, J. Y., Jiang, B., Breton, M., Patrie, J., Barrett, E. J., & Weltman, A. (2014). Effects of Exercise Intensity on Postprandial Improvement in Glucose Disposal and Insulin Sensitivity in Prediabetic Adults. The Journal of Clinical Endocrinology & Metabolism, 99(1), 220-228. doi:10.1210/jc.2013-2687

The first item of supportive literature for hypothesis 5 split 23 healthy male and female subjects into two groups. Both groups exercised 3 days/week for week, but their intensity varied. The exercise sessions for the first group consisted of 30-60min of continuous moderate intensity running at 70-80% maximum heart rate, while the second group completed 5-10 repetitions of 30 seconds max effort running intervals with 3 min rest between sprints. At the end of 8 weeks of training, both groups significantly reduced fasting glucose levels. However, the moderate intensity group did not change their postprandial glucose response while the max effort group significantly lowered both glucose AUC and glucose concentration at 120 minute mark.

The second study took 18 prediabetic male and female through 3 randomly ordered protocols. The 3 protocols were a control, which consisted of 1 hour of sitting; moderate intensity exercise, which consisted of 200 kcal of cycling at the lactate threshold; and high intensity exercise, which consisted of 200 kcals of cycling performed at 70% of the difference between VO2peak. After each protocol, the subject was given 60 minutes to recover and then a 3 hour OGTT was performed. During the OGTT, blood was drawn at 5 minute intervals during the 1st hour and at 10 minute intervals in the second and third hour. It was found that moderate intensity exercise increased insulin sensitivity by 51% and high intensity increase insulin sensitivity by 85%

Hypothesis 6—Intense exercise will increase insulin sensitivity significantly more than resistance training

Supportive research:

1) Ferrara, C. M., Goldberg, A. P., Ortmeyer, H. K., & Ryan, A. S. (2006). Effects of Aerobic and Resistive Exercise Training on Glucose Disposal and Skeletal Muscle Metabolism in Older Men. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 61(5), 480-487. doi:10.1093/gerona/61.5.480
2) Essen-Gustavsson, B., & Tesch, P. A. (1990). Glycogen and triglyceride utilization in relation to muscle metabolic characteristics in men performing heavy-resistance exercise. European Journal of Applied Physiology and Occupational Physiology, 61(1-2), 5-10. doi:10.1007/bf00236686

No known comparison of these modalities has ever been done. However, the first item of supportive research found that resistance training results in lower improvement in insulin sensitivity compared to moderate exercise. Since moderate exercise has been shown in research to produce smaller improvements in insulin sensitivity than exercise above 80% of VO2max (20 and 21). Furthermore, even though a resistance training program would utilize a larger muscle mass than cycling and both forms of exercise use glycogen as the primary source of fuel the second item of supportive found that resistance training generally uses modest amounts of glycogen. This low glycogen demand is likely not enough to support a sensitizing effect on insulin. Furthermore, damage to muscular tissue may affect the ability of muscle cells to uptake glucose during the rebuilding stage of resistance training (24-72 hours).

Summary:

Glucose disposal is the uptake of blood glucose into the cell where it is stored as muscle glycogen. This processes relies on proper function of insulin and GLUT4. Moderate, intense, and resistance training exercises have all been shown to increase the ability of the body to uptake blood glucose. Intense exercise has been shown to increase insulin sensitivity the most of the three exercise modalities followed by moderate exercise and finally resistance training. Intense exercise is believed to promote the greatest increases in insulin sensitivity due to its massive increases in GLUT4 concentration (15) and its reliance on glucose as a fuel source. Resistance training results in the smallest improvements in insulin sensitivity due to its low glycogen demand (7) and possible damage to muscle tissues.

Chapter Three – Methodology

Protocol

Each participant went through four separate exercise conditions followed by an oral glucose tolerance test (OGTT) in order to determine the immediate effects the exercise had on postprandial glucose disposal. The four conditions were as follows—high intensity exercise, moderate intensity exercise, resistance training, and a non-exercise control. After each condition, subjects were given one hour to recover before the OGTT. In order to prevent residual effects from previous trials each testing session was administered a minimum of three days apart. The trials were also administered in a random order to prevent the possible of any ordering effect. The only exception to the randomized order was the moderate exercise trial had to fall sometime after intense exercise trial—as its duration relied on the total work output of Wingate intervals.

Procedures

Subjects:

Eight males were selected to participate in the study. All participants were Hanover College students between 19 and 22 years old. Each subjects was familiar with both highly intense exercise and resistance training either through participation in collegiate sports or their own dedication to weight lifting and exercise. It was important for the subjects to be regular exercisers (minimum three days a week) in order for them to be capable of completing both exhausting resistance exercise and maximum effort cycling intervals

Pre-test Protocol:

- Each subject was asked to refrain from any exercise for at least six hours prior to testing. This was to ensure maximal effort could be given during trials and to minimize the effects of the subjects normal exercise/practice routine on insulin sensitivity
- Subjects were asked to refrain from eating at least three hours prior to testing. This was in effort to standardize fasting blood glucose. Normally fasting is defined as twelve hours for an OGGT. However, a true fast would've impaired the ability of the subject to perform maximal effort exercise. Therefore, fasting was operational defined as three hours
- Each subject was asked to get a full night of sleep the night prior to each trial they participated in. This was discussed to be at least six hours of sleep. This was to ensure the subject had energy to perform maximal effort exercise. This request was also based on previous research that as little as one night of sleep deprivation could negatively affect insulin sensitivity (6).
- All trials for an individual subject were performed at the same time of day. This was done because insulin sensitivity is known to fluctuate throughout the day (9). Since different groups were not compared during the study, times could vary from subject to subject, but it was important that an individual showed at his testing time so that he could serve as his own control.
- If any of these criteria were not met testing was rescheduled for a different day.

High Intensity Exercise

In order to ensure that the exercise was above the anaerobic threshold without requiring a VO_{2max} test repeat Wingate test were used.

Wingate repeats protocol:

Instruments:

- Exercise Physiology lab
- Body weight scale
- Polar heart rate monitor
- Stop watch
- Monark Cycle ergometer with 1 kg basket and computer readout
- Cycle ergometer weights

Testing Procedure:

- Subject arrived at testing site in appropriate workout apparel
- The weight and height of the subject were recorded
- The seat of the cycle ergometer was set at an appropriate height for the subject
    - $5\text{-}10^{o}$ of knee flexion at the bottom of pedal stroke
- Subject was fitted with a polar monitor
- Warm-up—The subject cycled for 5 minutes at 60 rpm with 1.5 kg of resistance (540kgm/min)
    - Throughout duration of the warm-up the subject stayed within 2 rpms of this cadence to ensure work rate consistency
- 1 minute transition
- Wingate test
    - Monark Cycle ergometer was load with resistance equal to 7.5% of the subject's body weight
    - Cycle ergometer basket was suspended with electromagnet
    - Subject free-wheeled getting the wheel moving as fast as possible
    - Once maximum speed was achieved, the subject pushed a button on bike handle dropping the basket and applying resistance to the wheel
    - Subject pedaled as fast as possible for 30 seconds
- 4 min passive recovery period—subjects remained on the bike and either rested or cycled at a low cadence without resistance
- repeat Wingate test and 4 min recovery for a total of 5 Wingates
- 1 hour recovery period
- OGTT

Moderate Intensity Exercise

In order to ensure that the total work output was the same for both moderate and high intensity exercise, work performed during the high intensity trial was totaled. The duration of moderate exercise was adjusted accordingly.

Instruments:

- Exercise Physiology lab
- Body weight scale
- Polar heart rate monitor
- Stop watch
- Monark Cycle ergometer with 1 kg basket
- Cycle ergometer weights

Testing Procedure:

- Subject arrived at testing site in appropriate workout apparel
- The weight and height of the subject were recorded
- The seat of the cycle ergometer was set at an appropriate height for the subject
    - 5-10^{o} of knee flexion at the bottom of pedal stroke
- Subject was fitted with a polar monitor
- The subject cycled at 60 rpm with 1.5 kg of resistance (540kgm/min) until work totaled that of the high intensity trial including warm up (approximately 20 minutes)
    - Throughout duration of the warm-up the subject stayed within 2 rpms of this cadence to ensure work rate consistency
- 1 hour recovery period
- OGTT

Resistance training:

Since work output couldn't be standardized for comparison to the cycle ergometer. Effort was instead put into making the workout duration similar to the other trials. Like both cycle conditions, resistance training took approximately 20 minutes to complete.

Instruments:

- Horner Center weight conditioning facility
- Squat rack
- Deadlift platform
- Bench press apparatus
- Lat pull down machine
- Barbell
- Weight plates
- Body weight scale
- Stop watch

Testing Procedure:

- Subject arrived at testing site in appropriate workout apparel
- The weight and height of the subject were recorded
- The following was completed for each lift
    - Subject completed one warm-up set per lift at a weight of their choosing
    - Subject performed 3 work sets of 8-12 reps at their 15 rep max

    - Subject was given 30 seconds of rest between working sets
- The lifts were as follows:
    - Squat
    - Deadlift
    - Bench press
    - Bent row
    - Press
    - Lat pull down
- 1 hour recovery period
- Perform OGTT

Oral Glucose Tolerance Test (OGTT):

The following test was performed 1 hour after each exercise condition at the same time of day for all of a subjects trials.

Instruments:

- Exercise Physiology lab
- Accu-Check Glucometer
- Uni-stik 2 Lancet
- Alcohol wipes
- Tissue paper
- Stop watch
- 75g Sun-dex glucose supplement drink

Testing Procedure:

- Subject sat calmly and quietly for 5 min
- Resting blood glucose was taken
- Subject ingested 75g glucose drink orally
- Stop watch was started
- Blood Glucose Levels were recorded every 15 min for an hour
- For each reading:
    - Finger was cleaned with alcohol wipe
    - Finger was pricked using lancet
    - Blood glucose reading taken using Accu-Check Glucometer
    - Excess blood cleaned with tissue paper
    - Sharps and Biohazards were properly disposed of

Exercise Volume Calculations

In order to make exercise intensity the only difference in cycle trials, total work output was calculated after the high intensity trial.

Work output for 5 min warm-up:

$$6\ m/rev * 1.5\ kg * 60\ rev/min * 5\ min = 2700kgm$$

Work output for Wingate trials:

The total energy generated during each Wingate was obtained using the computer readout produced by the Monark Cycle Ergometer. However, the energy was recorded in Joules. Therefore, after the energy from each trial was summed the following conversation rate was used:

$$9.8067J = 1Kgm$$

Duration of Moderate Intensity Exercise:

The energy total (in Kgm) of all Wingate repeats as well as the warm-up were combined and put on the left side of the following equation:

$$E = 6\ m/rev * 1.5\ kg * 60\ rev/min * X\ min$$

X was then solved for in order to determine moderate intensity exercise duration. The resistance of 1.5kg and 60rpm were arbitrarily chosen as these parameters provided moderate exercise (as shown by heart rate) and an exercise duration similar to that of the high intensity trial (approximately 20 minutes).

Data Treatment

The blood glucose levels over the course of the hour OGTT were graphed. Peak blood glucose and area under the curve (AUC) after each condition were compared in order to get an indication of improvement in insulin sensitivity.

Pilot Data Development

Pilot work has developed this study greatly. When this study first began it was important for the high intensity exercise to be above the lactate threshold because exercise above the lactate threshold has been shown to provide greater improvements in insulin sensitivity (20, 21). The original thought was that in order to prescribe exercise above the lactate threshold a predictive VO2max test would need to be performed. The first pilot data session was a YMCA predictive VO2 max test. After further research, repeat Wingates were chosen for the intense exercise protocol because earlier research used them (3, 15, and 21) and they've been found to be a high enough intensity, "the initial 30-second Wingate test can use almost a quarter of the stored muscle glycogen, and although the rate of glycogenolysis is reduced in subsequent bouts, significant amounts of lactate accumulate" (1).

The second round of pilot data collection tested the repeat Wingate trials and determined total work output to be from 76,699-95,000J (not including warm-up) Therefore the cadence of 60 rpm and 1.5kg of resistance were chosen in order to create the same total work output in a similar time span (approximately 20 min).

The third step in pilot data development was to begin determining if exercise interventions improved glucose disposal. Therefore, each protocol was tested in order to determine its effectiveness. Initial, control results did not look like textbook glucose curve.

Figure 1:

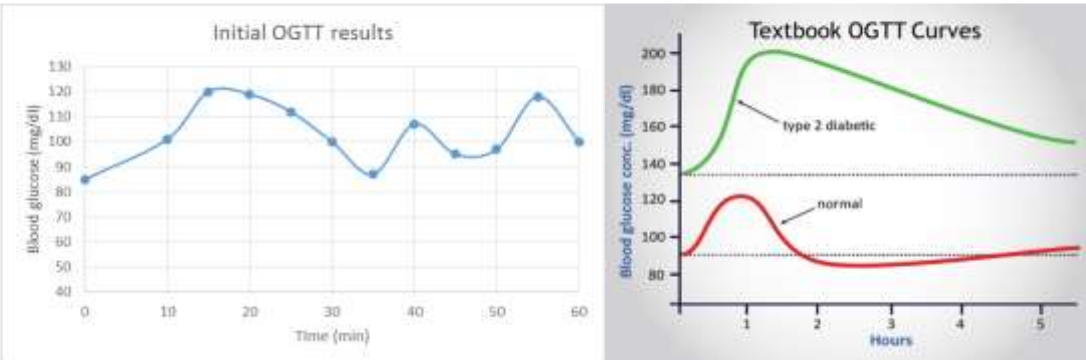


Figure 1: initial OGTT Curves vs Text book curves

This discrepancy was initial thought to be an issue with the lab glucometers. However, earlier laboratory efforts had compared the glucometers to a Cholestetech LDX Analyzer and found them to be accurate and reliable. The discrepancy was determined to be a result of the high frequency of readings (every 5 minutes) and the use of a single finger. While earlier studies took readings every 5 minutes (20), they used a venous blood draw instead of a finger stick. The high frequency finger sticks likely induced a stress response in the subject as well as trauma in the finger altering blood glucose readings. A new OGTT protocol was tested taking readings every 15 minutes using various fingers. This produced much better looking glucose curves.

Pilot Data

Figure 2:

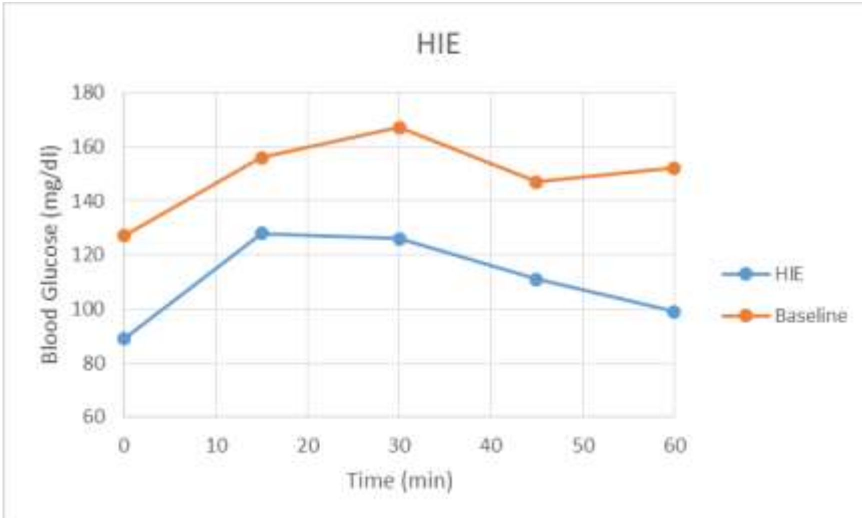


Figure 2: The effect of high intensity exercise of glucose disposal

The pilot data above was collected in order to determine the effect of high intensity exercise on glucose disposal. The blood glucose levels were taken using a finger stick glucometer and the test were a minimum of 3 days apart. As seen in the figure, blood glucose was lowered at ever measurement point, including a fall in the peak blood glucose from 167mg/dl to 128 mg/dl—a reduction of 23.4%. It is also worth noting that the peak happened earlier in the OGTT. After the HIE, blood glucose peaked after 15 minutes while it took 30 min for blood glucose to peak in the control trial. AUC also fell by 23.4%. All of these results indicate a large sensitizing effect from the HIE. These results support hypothesis 2—insulin sensitivity will increase after intense exercise.

Figure 3:

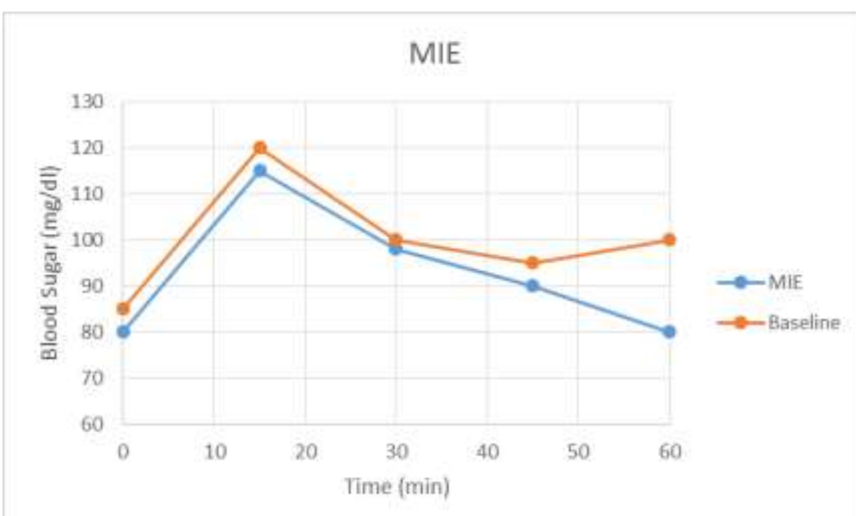


Figure 3: The Effects of Moderate Intensity Exercise on Glucose Disposal

The pilot data above was collected in order to determine the effect of moderate intensity exercise on glucose disposal. The blood glucose levels were taken using a finger stick glucometer and the test were a minimum of 3 days apart. As seen in the figure, blood glucose levels decreased at all measurement points, including a fall in peak blood glucose from 120mg/dl to 115mg/dl. AUC also fell 4.2%. These results are similar to the results seen in HIE only to a much lesser degree. However it is worth noting that this subject handled glucose very easily and quickly peaking at only 120mg/dl after 15 minutes in the control. These result support hypothesis 1—insulin sensitivity will increase after moderate exercise and hypothesis 5—high intensity exercise will increase postprandial insulin sensitivity significantly more than moderate exercise.

Figure 4:

Figure 4: The Effects of Resistance Training on Glucose Disposal

The pilot data above was collected in order to determine the effect of resistance training exercise on glucose disposal. The blood glucose levels were taken using a finger stick glucometer and the test were a minimum of 3 days apart. As seen in the figure, resistance training has not shown an insulin sensitizing effect. Peak blood glucose increased 18.9% from 174 mg/dl to 207 mg/dl. AUC also increased by 7.9%. These results are non-supportive of hypothesis 3—insulin sensitivity will increase after resistance training, but supportive of hypothesis 4—moderate intensity exercise will increase postprandial insulin sensitivity significantly more than resistance training and hypothesis 6—high intensity exercise will increase postprandial insulin sensitivity significantly more than resistance training.

Chapter Four

Results

Figure 1

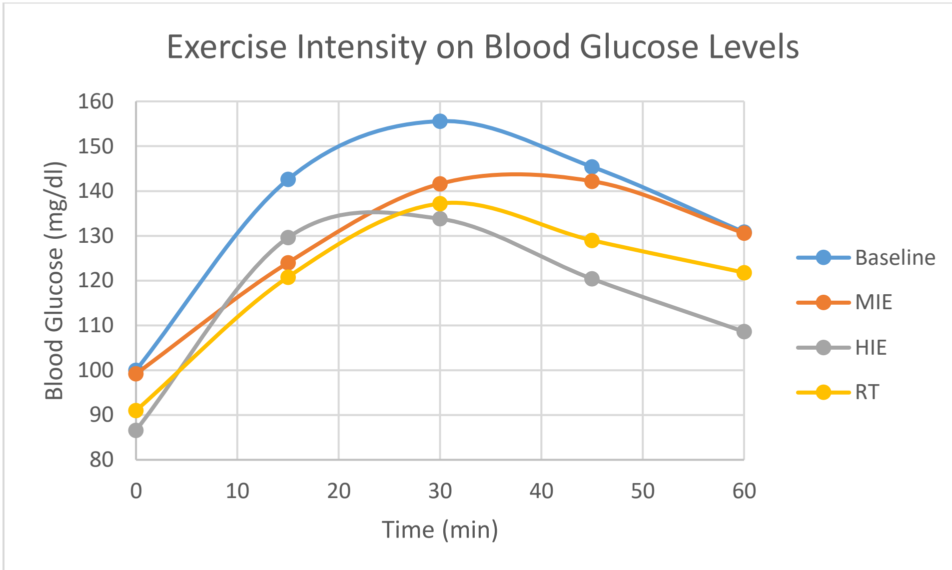


Figure 1: Mean blood glucose levels throughout the one hour glucose tolerance test following each exercise condition.

This figure depicts the mean blood glucose levels during the one hour OGTT. It is apparent from the graph that each exercise intervention reduced mean blood glucose at all collection points. Using glucose uptake as a surrogate for insulin sensitivity hypotheses 1, 2, and 3 (Insulin sensitivity will increase: after moderate exercise, after intense exercise, and after resistance training respectively) were accepted.

Figure 2

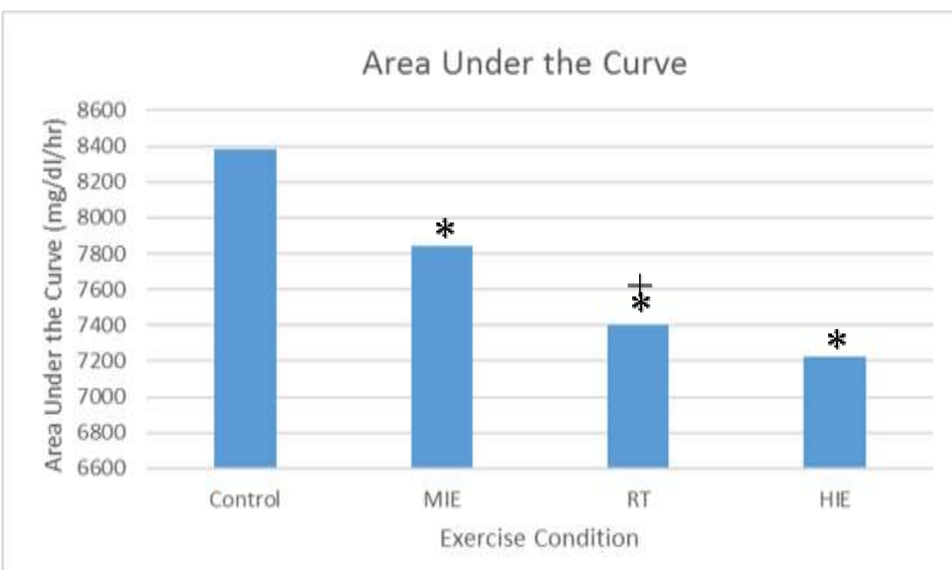


Figure 2: Mean incremental AUC for the glucose responses to a 1-hour OGTT

The figure above depicts the AUC for the glucose responses to a 1 hour OGTT for all exercise conditions. The OGTT was performed 1 hour after the cessation of MIE, HIE, and RT and compared with a no-exercise control condition. Compared to the control, AUC was reduced 13.9% by HIE, 11.7% by RT, and 6.5% by MIE. Using AUC as a surrogate for insulin sensitivity, hypothesis 1, 2, 3 (Insulin sensitivity will increase: after moderate exercise, after intense exercise, and after resistance training respectively) were accepted. Although the trend appears to support hypothesis 5 and 6 (HIE will increase postprandial insulin sensitivity significantly more than MIE and RT respectively), the data was found to be not statistically significant. It is believed that a larger and more robust study would confirm these trends. Hypothesis 4 (MIE will increase postprandial insulin sensitivity significantly more than RT), was rejected on the grounds of RT had a significantly greater sensitizing effect than MIE. This was believed to be due to the usage of greater muscle mass.
*, significantly different from control ($P < .05$) as determined by a single tailed Wilcoxon signed rank test.
+, significantly different from control ($P < .05$) as determined by a single tailed Wilcoxon signed rank test.

Figure 3:

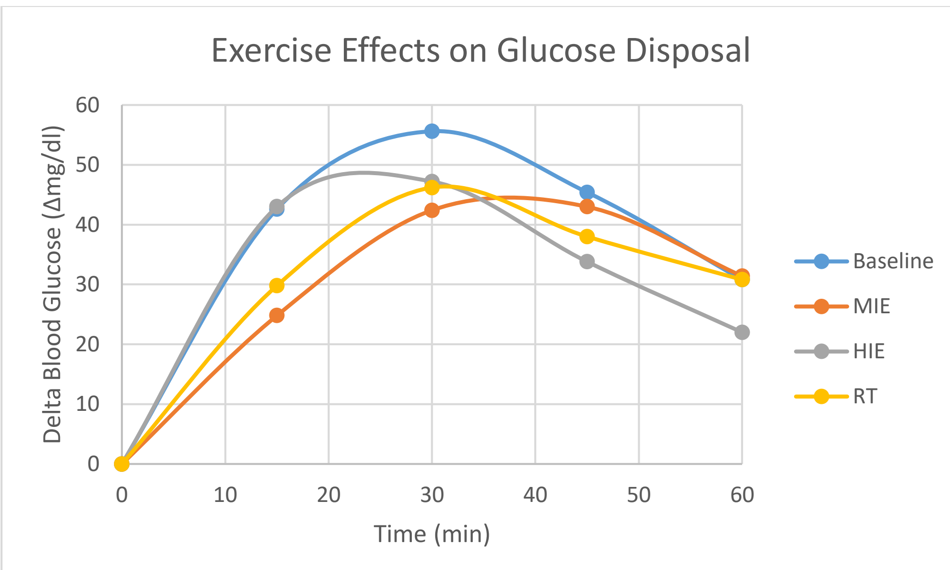


Figure 3: Mean blood glucose levels throughout the one hour glucose tolerance test following each exercise condition expressed as delta values.

The figure above shows the mean blood glucose levels during the one hour OGTT expressed as delta values. This was done in order to show whether or not the exercise actually had a sensitizing effect or if AUC was merely reduced as a result of a lowered starting blood glucose due to the glycogen demands of exercise. With the exception of the 15-minute mark, HIE reduced mean delta blood glucose at all collection points and at the 60-minute mark was 28.6% lower than the baseline. This is in agreement with the results found by Rynders et al. which found an initial reduction of insulin sensitivity prior to its sensitizing effect. MIE and RT reduced delta blood glucose throughout the hour, but at the 60-minute mark RT was equal to baseline mean and MIE was 1.9% higher. This indicates that while all exercise forms had a sensitizing effect, HIE may result in a longer lasting effect than the other forms.

Figure 4:

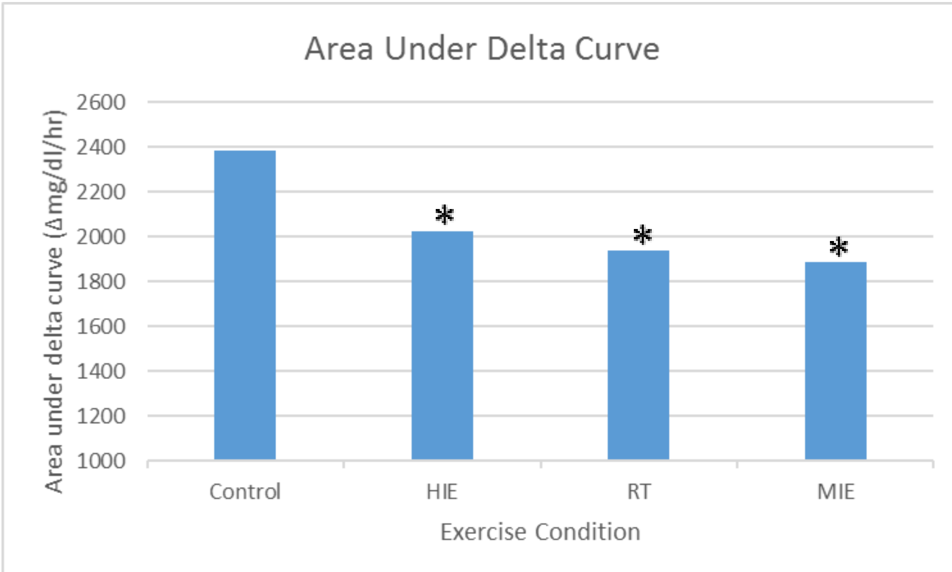


Figure 4: Mean incremental AUC for the delta glucose responses to a 1-hour OGTT

When AUC was assessed using delta blood glucose values, HIE reduced AUC by 15.1%, RT by 18.6%, and MIE by 20.1%. While this indicates that all exercise conditions were more effective at improving insulin sensitivity than assessing raw blood glucose values (further supporting hypothesis 1, 2, and 3), it reorders them in terms of effectiveness. Though no statistical significance could be found between non-control conditions, HIE was least effective at decreasing AUC of the delta curve. This would make it seem that HIE was the least effective at increasing insulin sensitivity. However, it is worth noting that at the end of the OGTT delta blood glucose of HIE condition was 28% lower (see figure 3). It is likely this trend would continue after the one hour mark. It is also worth mentioning that HIE was the most effective at lowering initial blood glucose values as more glycogen was used during exercise. Regardless of when it was removed, lower overall glucose values would reduce the amount of possible damage by glucose in a patient with metabolic syndrome. *, significantly different from control ($P < .05$) as determined by a single tailed Wilcoxon signed rank test.

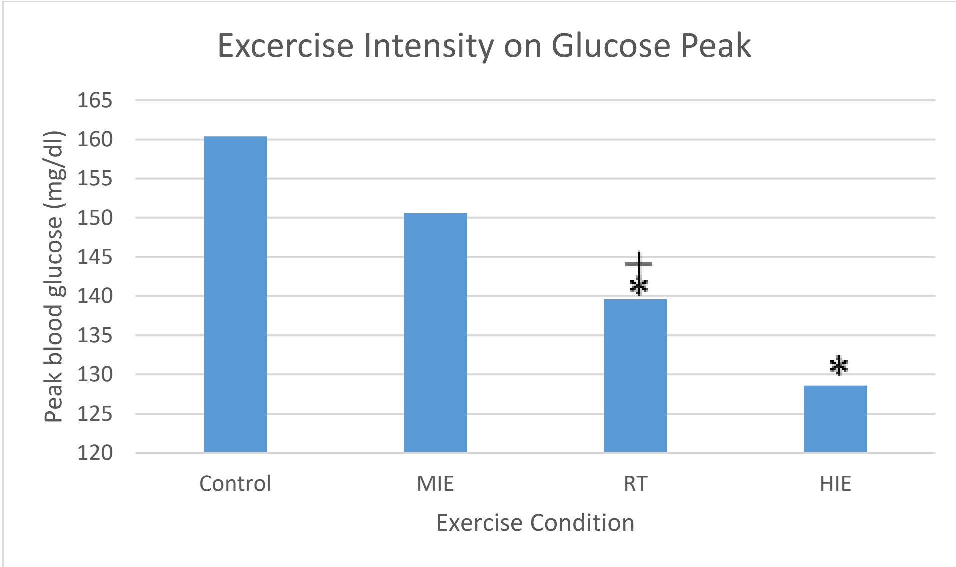


Figure 2: Mean peak blood glucose levels for the glucose responses to a 1-hour OGTT
All exercise interventions were able to reduce the mean peak blood glucose levels during the 1 hour OGTT compared with a no-exercise control condition. Glucose peak was assessed because even though peaks last a relatively short period of time, wide fluctuation in blood glucose have be correlated with high hemoglobin A1c (24). Clinically, OGGT glucose peaks are used to assess glucose fluctuations. Although only RT and HIE were found to be statistically significant reducing glucose peak by 13.0% and 15.5% respectively, the trend suggested that MIE was also effective at reducing glucose peak reducing the average by 6.1 percent. It is believed a more comprehensive study with more subjects may show a significant difference. Like AUC data, glucose peak data supports hypotheses 1, 2, and 3 (Insulin sensitivity will increase: after moderate exercise, after intense exercise, and after resistance training respectively). It also partially supports hypothesis 5 and 6 (HIE will increase postprandial insulin sensitivity significantly more than MIE and RT respectively). However, this data was not found to be statistically significant. It is believed that a larger and more robust study would confirm these trends. Hypothesis 4 (MIE will increase postprandial insulin sensitivity significantly more than RT), was rejected on the grounds of no statistical significance and the trend indicated that RT had a greater sensitizing effect. *, Significantly different from control ($P < .05$).
*, significantly different from control ($P < .05$) as determined by a single tailed Wilcoxon signed rank test.
+, significantly different from control ($P < .05$) as determined by a single tailed Wilcoxon signed rank test.

Hypotheses

1. Insulin sensitivity will increase after moderate exercise

Accepted based upon MIE significantly reducing AUC of both blood glucose (6.5%) and delta blood glucose (20.1%). Further supported by the trend of MIE reducing glucose peak (6.1%) although this was not found to be significant

2. Insulin sensitivity will increase after intense exercise

Accepted based upon HIE significantly reducing AUC of both blood glucose (13.9%) and delta blood glucose (15.1%). Further supported by HIE significantly reducing glucose peak (15.5%)

3. Insulin sensitivity will increase after resistance training

Accepted based upon RT significantly reducing AUC of both blood glucose (11.7%) and delta blood glucose (18.6%). Further supported by RT significantly reducing glucose peak (13.0%)

4. Moderate intensity exercise will increase postprandial insulin sensitivity significantly more than resistance training

Rejected based upon RT to reducing glucose AUC and glucose peak values to a greater degree than MIE. No statistical significance found between the delta-glucose AUC. RT is believed to have a greater sensitizing effect due to the larger amount of muss mass used in RT compared to MIE. Even though RT has an inherently low glycogen demand compared to MIE, the increased muscle mass used may have resulted in a greater total glycogen usage.

5. High intensity exercise will increase postprandial insulin sensitivity significantly more than moderate intensity exercise

Rejected based upon no statistical significance found between the glucose AUC, delta-glucose AUC, and glucose peak values between the two exercise conditions. However, the HIE trended to be superior in reducing both glucose AUC (13.9% vs 6.5%) and glucose peak value (15.5% vs 6.1%). And although MIE trended to reduce delta-glucose AUC more than HIE (20.1% vs 15.1%), this is believed to be due to the temporary insulin retarding effect of HIE (20). HIE resulted in 28% lower delta blood glucose at the 60-minute mark. If OGTT was carried out longer than 60 minutes it highly likely that HIE would have relucted in a greater reduction in delta glucose AUC. It is believed that a more robust study including more subjects may confirm the trend of HIE increasing insulin sensitivity to a greater degree than MIE.

6. High intensity exercise will increase postprandial insulin sensitivity significantly more than Resistance training

Rejected based upon no statistical significance found between the glucose AUC, delta-glucose AUC, and glucose peak values between the two exercise conditions. However, the HIE trended to be superior in reducing both glucose AUC (13.9% vs 11.7%) and glucose peak value (15.5% vs 13.0%). And although RT trended to reduce delta-glucose AUC more than HIE (18.6% vs 15.1%), this is believed to be due to the temporary insulin retarding effect of HIE (20). HIE resulted in 28% lower delta blood glucose at the 60-minute mark. If OGTT was carried out longer than 60 minutes it highly likely that HIE would have relucted in a greater reduction in delta glucose AUC. It is believed that a more robust study including more subjects may confirm the trend of HIE increasing insulin sensitivity to a greater degree than RT.

Chapter Five

Discussion

Glucose uptake and the function of insulin

After carbohydrates are broken down into glucose and absorbed into the blood stream through the small intestine they still need to be brought into muscle or liver cells before they can be utilized as a fuel. This is known as glucose uptake or glucose disposal. However, due to the large size and polar nature of the glucose molecule, it cannot simply diffuse through a cell membrane like a water or oxygen molecule. Instead, its diffusion must be facilitated by a carrier protein. If glucose uptake did occur through simple diffusion when blood glucose dropped glucose would diffuse out of the cell and no longer be able to serve as a fuel source.

The primary carrier protein used in glucose disposal is known as GLUT-4, but this protein doesn't always reside within the cell membrane. When uptake is not occurring GLUT-4 sits dormant within the cytoplasm of the cell. During this time glucose is unable to enter the cell and stays within the bloodstream. A high concentration of glucose in the bloodstream causes the pancreas to release a hormone known as insulin. This hormone travels through the bloodstream and membrane receptor on the outside of the cell. This begins a chain reaction resulting in the movement of GLUT-4 into the cell membrane. Once GLUT-4 is inserted into the cell membrane glucose can diffuse into the cell where it is stored as glycogen and eventually used as a fuel substrate.

While this complicated process does allow for longer term storage of glycogen, it is susceptible to breaking down, which is known as diabetes. Type 1 diabetes prevents insulin from being created and released by the pancreas. Type 2 diabetes results in breakdown somewhere in the chain reaction of insulin binding to the receptor and the translocation of GLUT-4. In both cases, glucose is unable to enter the cell and float along in the bloodstream—a condition known as hyperglycemia. Hyperglycemia results in a host of problems including damage to pancreas (as it is trying to release insulin on overdrive to bring insulin levels down), and damage to the cardiovascular system. The high glucose levels reduce the ability of arteries to vasodilate and weaken their endothelial lining. This leads to destruction of small vessels and the tell-tale symptoms of chronic diabetes—namely nerve damage, blindness, loss of sensation in peripheries, and even heart attack or stroke.

Moderate Intensity Exercise

Moderate intensity exercise is commonly prescribed in order to maintain a healthy cardiovascular system. It is widely considered any activity requiring 3-6 METs and can include several modalities including brisk walking, light jogging, and moderate cycling. Moderate exercise has a number of benefits including psychological benefits, reducing obesity, and triglycerides, and raising HDL. It is particularly beneficial in preventing and treating life-style induced diseases such as heart disease, diabetes, and metabolic syndrome. Its main effect is the burning of excess calories which reduces abdominal adiposity. This reduced adiposity increases insulin sensitivity (4, 13, 20), thereby raising HDL since the body can use glucose properly and no longer relies on the glycerol. The increased HDL levels and insulin sensitivity reduces SNS activity and retention of $H2O$, which in turn lowers blood pressure. Moderate exercise can be done by anyone regardless of age or fitness level and is a vital part of a healthy lifestyle.

Moderate exercise improves insulin sensitivity by increasing the quantity of GLUT-4 carrier proteins and their ability to translocate (11). This is desirable for the cell because skeletal muscle relies on intramuscular glycogen stores as a source of energy during exercise, and the only way these stores can be replenished is through the uptake of new glucose molecules (25). Simply walking 12 miles a week for six months can improve insulin sensitivity by 85% for sedentary overweight individuals (13). However, benefits of moderate exercise begin immediately. A single bout of moderate exercise can improve insulin sensitivity by 51% (20). And these of single bout are believed to last for 48 to 72 hours (19).

The finding of the current study support the notion of moderate intensity exercise improving insulin sensitivity. Improving it by 6.5% when assessed blood glucose AUC and

20.1% when assessed be delta blood glucose AUC and this was in young fit subjects who already possess good insulin sensitivity. Either way it is assessed moderate exercise provides a significant sensitizing effect that would be beneficial as lifestyle disease intervention or merely a vital aspect of a health promoting lifestyle.

High Intensity Exercise

Vigorous exercise has been shown to have all the health benefits of moderate exercise plus direct effects on raising HDL (23), reducing psychological stress, and reducing blood pressure. Psychological stress is improved through metabolism of catecholamines and the release of endorphins. Blood pressure is directly reduced thought the production of nitric oxide, which increases the endothelial linings ability to vasodilate. Vigorous exercise can definitely promote health to an even greater degree than moderate exercise provided that a person is willing to complete it regularly.

Though not statistically significant, HIE tended to produce a greater sensitizing effect than moderate intensity exercise. This has been a widely-debated topic in the field of exercise physiology. Early studies comparing the effects of moderate versus intense exercise concluded that increasing intensity does not result in greater insulin sensitivity benefits (13). However, in many of these early works the high intense exercise conditions fell below the lactate threshold. This study and other recent works indicate that HIE above the lactate threshold is highly effective at increasing insulin sensitivity (1, 3, 15), and suggest that it may have a great effect than moderate intensity exercise (20, 21). This is believed to be a result of a number of physiological difference between exercise above the lactate threshold and exercise below the threshold. During HIE, glucose become the almost the exclusive muscle fuel resulting in a rise in glucose utilization by 3 to 4-fold and a rise utilization by 7 to 8-fold (26). This increased glycogen demand makes increased insulin sensitivity intuitively make sense as there is a greater need of uptake post HIE than MIE even when the caloric demand is the same. This is further supported by insulin secretion during exercise. During moderate exercise insulin secretion is temporarily reduced due to activation of the β-cell α-adrenergic receptor. During HIE, the β-2 adrenergic receptor is activated and insulin decrease minimally, if at all (26). The β-2 receptor is activated a part of the fight or flight response, so again it is intuitive that the body would not slow the process of glucose so that it may be used as fuel. That's not even to mention the other aspect of the stress responses including a 14 to 18-fold rise in plasma catecholamine and a rise in hormone levels including epinephrine, norepinephrine, and growth hormone all of which are known to boost insulin secretion when withdrawn post exercise (20). While it was not found to be statistically significant it is believed that HIE trended to improve insulin sensitivity 7.4% better than MIE due to the fundamental differences in exercise above the lactate threshold (LT), but further research is necessary to confirm these trends.

Resistance Training

The health benefits of resistance training have long been ignored by the scientific community. It was once thought to be solely the pursuit of athletes and people who wanted to get big and strong, while aerobic exercise was used for health benefits. Now a growing body of work has been showing the wide-reaching health benefits of resistance training. It improves strength and coordination and increases resting metabolic rate and NEAT. Strength has been shown to decrease risk of osteoporosis, hip fractures, and all-cause mortality (27, 28).

Resistance training may also have a positive benefit on improving insulin sensitivity (8, 10). This study found RT to reduce glucose AUC by 11.7% and glucose peak by 13.0%. Although resistance training has a relatively low glycogen demand compared to MIE and especially compared to HIE (7), a full body strength routine such as the one used in this study uses a much greater much mass than either cardiovascular exercise conditions. It is believed that this large amount of muscle mass offset the low glycogen demand and caused a similar degree of total glycogen usage to MIE and HIE. Other studies have found insulin sensitizing effects as a result of long term RT programs (8, 10), but this study suggest that like MIE and HIE effects may begin in as little as a single session. While this is the first known comparison of these modalities studies that looked at the sensitizing effect of RT saw relatively modest improvements in insulin sensitivity (8, 10, 14) compared to the results seen with MIE (4, 13, 20) and HIE (1, 3, 15). However, this study found a similar degree of sensitization to HIE and MIE. In terms of reducing glucose AUC RT had a 11.7% improvement while HIE had 13.9% and MIE 6.5%. When insulin sensitivity was assess using delta blood glucose RT saw and 18.6% improvement compared to the 15.1% of HIE and the 20.1% of MIE. This was supported by RT reducing glucose peak by 13.0% compared to HIE’s 15.5% and MIE’s 6.1%. It is well known that the muscle building and hormonal effects last 48-72 hours after RT. Because of this and the possibly of RT occluding blood vessels during the training bout more studies are need to determine the effects of RT on insulin sensitivity at different time frames post RT.

Significance of this study

This study indicates that all three exercise conditions had positive effect on insulin sensitivity. This gives diabetic and metabolic syndrome patients a greater degree of options when trying to treat their conditions using lifestyle interventions. These options may allow patients to find a form of exercise they enjoy, which should improve program drop-out rates and patient health. Furthermore, past studies have shown that the insulin sensitizing effects of exercise to typically last 24-48 hours. The trend of HIE to produce a greater sensitizing effect raises the question: would HIE effects last longer than MIE, due to the greater impact to clear glucose from the bloodstream? If so, HIE could be advantageous as an every other day intervention as opposed to daily MIE.

Conclusion

These finding indicate that MIE, HIE, and RT do improve postprandial insulin sensitivity. Data trends indicate that HIE may have greatest sensitizing effect followed by RT and MIE, but a more robust study with greater number of subjects would needed to determine a statistical significant between these exercise interventions.

Works Cited

1. Adams, P. (2013). The impact of brief high-intensity exercise on blood glucose levels. Diabetes, Metabolic Syndrome and Obesity: Targets and Therapy, 113. doi:10.2147/dmso.s29222

2. Aragon, A. A., & Schoenfeld, B. J. (2013). Nutrient timing revisited: Is there a post-exercise anabolic window? Journal of the International Society of Sports Nutrition, 10(1), 5. doi:10.1186/1550-2783-10-5

3. Barbraj. (2009). Extremely short duration high intensity interval training substantially improves insulin action in young healthy males. BMC Endocrine Disorder. Retrieved November 4, 2016, from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2640399/.

4. Boulé, N. G., Haddad, E., Kenny, G. P., Wells, G. A., & Sigal, R. J. (2001). Effects of Exercise on Glycemic Control and Body Mass in Type 2 Diabetes Mellitus. Jama, 286(10), 1218. doi:10.1001/jama.286.10.1218

5. CDC. (2015). 2014 National Diabetes Statistics Report. Retrieved November 30, 2016, from http://www.cdc.gov/diabetes/data/statistics/2014statisticsreport.html

6. Donga, E., Dijk, M. V., Dijk, J. G., Biermasz, N. R., Lammers, G., Kralingen, K. W., . . . Romijn, J. A. (2010). A Single Night of Partial Sleep Deprivation Induces Insulin Resistance in Multiple Metabolic Pathways in Healthy Subjects. Endocrinology, 151(5), 2399-2399. doi:10.1210/endo.151.5.9998

7. Essen-Gustavsson, B., & Tesch, P. A. (1990). Glycogen and triglyceride utilization in relation to muscle metabolic characteristics in men performing heavy-resistance exercise. European Journal of Applied Physiology and Occupational Physiology, 61(1-2), 5-10. doi:10.1007/bf00236686

8. Ferrara, C. M., Goldberg, A. P., Ortmeyer, H. K., & Ryan, A. S. (2006). Effects of Aerobic and Resistive Exercise Training on Glucose Disposal and Skeletal Muscle Metabolism in Older Men. The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 61(5), 480-487. doi:10.1093/gerona/61.5.480

9. Fleur, S. E., Kalsbeek, A., Wortel, J., Fekkes, M. L., & Buijs, R. M. (2001). A Daily Rhythm in Glucose Tolerance: A Role for the Suprachiasmatic Nucleus. Diabetes, 50(6), 1237-1243. doi:10.2337/diabetes.50.6.1237

10. Frank, P., Andersson, E., Pontén, M., Ekblom, B., Ekblom, M., & Sahlin, K. (2015). Strength training improves muscle aerobic capacity and glucose tolerance in elderly. Scand J Med Sci Sports Scandinavian Journal of Medicine & Science in Sports, 26(7), 764-773. doi:10.1111/sms.12537

11. Goodyear, L. (n.d.). Exercise, glucose transport, and insulin sensitivity. Annual Review of Medicine.

12. Hermann, W. H. (n.d.). The Economic Costs of Diabetes: Is It Time for a New Treatment Paradigm? | Diabetes Care. Retrieved November 30, 2016, from http://care.diabetesjournals.org/content/36/4/775

13. Houmard, J. A., & E. (2004). Effect of the volume and intensity of exercise training on insulin sensitivity. Journal of Applied Physiology. Retrieved November 4, 2016, from http://jap.physiology.org/content/96/1/101

14. Ivey, F. M., & Ryan, A. S. (2014). Resistive Training Improves Insulin Sensitivity after Stroke. Journal of Stroke and Cerebrovascular Diseases, 23(2), 225-229. doi:10.1016/j.jstrokecerebrovasdis.2012.12.014

15. Little, J. P., Gillen, J. B., Percival, M. E., Safdar, A., Tarnopolsky, M. A., Punthakee, Z., . . . Gibala, M. J. (2011). Low-volume high-intensity interval training reduces hyperglycemia and increases muscle mitochondrial capacity in patients with type 2 diabetes. Journal of Applied Physiology, 111(6), 1554-1560. doi:10.1152/japplphysiol.00921.2011

16. Manders, R. J., Dijk, J. M., & Loon, L. J. (2010). Low-Intensity Exercise Reduces the Prevalence of Hyperglycemia in Type 2 Diabetes. Medicine & Science in Sports & Exercise, 42(2), 219-225. doi:10.1249/mss.0b013e3181b3b16d

17. Mayo Clinic Staff Print. (2016). Type 2 diabetes. Retrieved November 30, 2016, from http://www.mayoclinic.org/diseases-conditions/type-2-diabetes/diagnosis-treatment/treatment/txc-20169988

18. Richards, J. (2010). Https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2956910/. J Physiology. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2956910/.

19. Ross, R. (n.d.). Does Exercise Without Weight Loss Improve Insulin Sensitivity? | Diabetes Care. Retrieved November 30, 2016, from http://care.diabetesjournals.org/content/26/3/944

20. Rynders, C. A., Weltman, J. Y., Jiang, B., Breton, M., Patrie, J., Barrett, E. J., & Weltman, A. (2014). Effects of Exercise Intensity on Postprandial Improvement in Glucose Disposal and Insulin Sensitivity in Prediabetic Adults. The Journal of Clinical Endocrinology & Metabolism, 99(1), 220-228. doi:10.1210/jc.2013-2687

21. Sandvei, M., Jeppesen, P. B., Støen, L., Litleskare, S., Johansen, E., Stensrud, T.,. Jensen, J. (2012). Sprint interval running increases insulin sensitivity in young healthy subjects. Archives of Physiology and Biochemistry, 118(3), 139-147. doi:10.3109/13813455.2012.677454

22. Srikanthan, P., & Karlamangla, A. S. (2014). Muscle Mass Index As a Predictor of Longevity in Older Adults. The American Journal of Medicine, 127(6), 547-553. doi:10.1016/j.amjmed.2014.02.007

23. Thompson, P., Cullinane, E., Sady, S., Flynn, M., Bernier, D., Kantor, M., . . . Herbert, P. (1988). Modest Changes in High-Density Lipoprotein Concentration and Metabolism

With Prolonged Exercise Training. Journal of Cardiopulmonary Rehabilitation, 8(10), 380. doi:10.1097/00008483-198810000-00010

24. Ulf S, Ragnar H, Arne WP, Johnny L. Do high blood glucose peaks contribute to higher HbA1c? Results from repeated continuous glucose measurements in children. World J Pediatr. 2008;4(3):215–221.

25. Wojtaszewski, J. F., Nielsen, J. N., & Richter, E. A. (2002). Invited Review: Effect of acute exercise on insulin signaling and action in humans. Journal of Applied Physiology, 93(1), 384-392. doi:10.1152/japplphysiol.00043.2002

26. Marliss, E. B., & Vranic, M. (2002). Intense Exercise Has Unique Effects on Both Insulin Release and Its Roles in Glucoregulation: Implications for Diabetes. Diabetes, 51(Supplement 1).

27. Layne , J. (1999). The effects of progressive resistance training on bone density: a review. Med Sci Sports Exercise, 25-30.

28. Ruiz, J. R., Sui, X., Lobelo, F., Morrow, J. R., Jackson, A. W., Sjostrom, M., & Blair, S. N. (2008). Association between muscular strength and mortality in men: prospective cohort study. Bmj, 337(Jul01 2). doi:10.1136/bmj.a439