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**HIGH INTENSITY SPRINTING THROUGH METABOLIC PATHWAYS:
A BIOCHEMICAL ANALYSIS OF EXERCISE AND FITNESS**

**A thesis submitted to
Regis College
The Honors Program
in partial fulfillment of the requirements
for Graduation with Honors**

by

Halli Benasutti

May 2014

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APPROVAL PAGE

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Accepted by

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Firstly, I would like to thank my parents for their love, direction, and encouragement (see introduction). Their passions and zeal for life have shaped me into the happy and active woman that I am proud to be today and I would not have been able to complete this thesis without their faith in me and my abilities as a student. Next I would like to thank my siblings for always being my cohorts in sports and outdoor activities and for always pushing me to be better for them and for my parents.

I would like to extend a special thanks to my thesis, research, and academic advisor Dr. Stacy Chamberlin for her continued guidance and support. Her spirit, dedication, and love and have challenged me to be a better student, daughter, and friend and her joy, energy and passion have inspired me to pursue a future in the field of biochemistry. My sincere thanks also goes to Dr. Ken Sagendorf, my thesis reader, who provided more direction and assistance than I can begin to describe. This work would not be what it is without him.

Thank you to Dr. Thomas Howe, Dr. Catherine Kleier, and my classmates in the Regis University Honors Program. You have been my encouragement and motivation throughout this entire process and I am honored to be graduating alongside all of you. Finally I want to thank my dearest friends and roommates for their ability to push me and lift me up when I wanted to quit.

I love you all so much.

INTRODUCTION:

I was 11 when I started working out. At that point I had been playing volleyball for a year, soccer for three years, tap dancing for six years, and skiing for nine. Needless to say, I have always led an active lifestyle. It was in the 6th grade though that I started to read magazines; I'm not talking about the celebrity gossip magazines such as *People* or *US Weekly*. Rather, my mom, a dedicated and passionate lifelong runner, received *Runner's World* and *Shape and Fitness*, all of which were focused on self-improvement via health and exercise. I would pick one out of an ever-growing stack on the living room coffee table and skim the pages looking for workouts and new exercise moves, which I would proceed to tear out and slide into my "Fitness Folder," a binder containing page after page of articles regarding "Toned Abs" or "Firm Butts."

You see, to be totally honest, I would like to say that being healthy was a motivation of mine, in reality it wasn't. In my uncomfortable, awkward and unbearably self-conscious middle school years I was willing to do just about any and everything to boost my self-confidence, including waking up at the crack of dawn to workout in an effort to obtain the curvy, fit body my peers seemed to be growing into all around me. I was a late-bloomer to put it delicately, and that combined with the often vicious way that young teens can treat one another, I was eager to make a change to my physical appearance. Little did I know that in my effort to change my body I would stumble upon one of my greatest and hopefully lifelong passions.

So I began by collecting workouts from various resources around me: magazines, books, the Internet. Turned out that with all of my after-school activities, the only time I

really had to work out was in the mornings. Luckily for me, my dad's schedule only permitted him the same time slot, usually between the hours of 5 am and 6 am. And so we would share the living room in the basement, both working around one another and often migrating into other various crevices in an effort to find more space. We would have some TV show or movie playing in the background, or we would watch some workout video my dad had found used on EBay, and perform the various workouts together. Sometimes we did our own things, sometimes we did the same things; it didn't matter because we were there together. Conversation was usually minimal at such early hours of the day, but that didn't matter either. I do not know that my dad will ever understand just how much our workouts together in the mornings meant to me in such a formative time when I was struggling so relentlessly to define myself.

Fast-forward a year and I have added track to my after school activities. My mom, being the athlete and avid marathon runner that she is, was so excited to see me following in her footsteps that she volunteered to be the assistant coach of the middle school track team. It wasn't long after that that she had convinced me to train for a half marathon with her. I crossed the finish line after 2 hours and 13 minutes at the age of 13. To this day whenever I run with my mom, I am constantly and pleasantly surprised by how she can still push me. She has really challenged me over the years in our training together to love working out and appreciate it for more than merely a way to obtain a skinny figure. My mom has nurtured and fostered her passion for running in me, and my love of exercise and fitness has exponentially grown as a result.

Later on, in high school, I ran cross country and played on the varsity soccer team, both of which contributed to a decline in the frequency of my morning workouts with my dad and a lack of time to train with my mom. My ardor for fitness did not cease though; as a matter of fact it grew and flourished even more as I began to mature and my knowledge on and experience with the subject grew. Then three years ago I made the life-changing decision to become a certified fitness instructor. After weeks of preparation and studying, I passed the 3-hour exam and was promptly hired at my university fitness center. It didn't take me long to discover how much I loved to teach exercise classes; having the chance to share my passion and knowledge of fitness with others has brought me more joy than I could ever imagine.

While I can attribute so much of my love for exercise to my parents, I must also give them credit for instilling in me a desire to impact the lives of others. I had always imagined the opportunity to do so would come in the form of international service work or volunteering for a non-profit. However, I would never have guessed that I would find such fulfillment in teaching exercise classes to others. And it isn't just that I am improving my participants' fitness or health, but in teaching I am also able to share my experiences with working out and self-esteem in an effort to help them obtain the confidence I now possess.

As I said earlier, when I first began to workout, my primary motivation was trying to look more thin and fit. However, over the years I began to fall in love with working out because of how it made me feel physically and emotionally, regardless of how my body looked. And now I cannot stress enough the importance of loving oneself and

working out to feel good, not just gain confidence, to my fitness class participants.

Everyday I remind them that they are not there just to burn calories or shrink fat. They are there to find joy and feel strong, physically and emotionally, and I strive to ensure that no participant ever leaves feeling self-conscious or discouraged. Today I am proud to say that I have never cared less about my weight or how toned I might look. I exercise solely because of how good I feel after a workout, an appreciation of which I hope to instill in all of my participants. As my education has progressed, I've come to find out that the physical and psychological benefits are largely in part because of biochemistry!

Thus for this thesis I have decided to further investigate my two passions, exercise and biochemistry, which happen to be so conveniently interdependent. The following is a biochemical examination of exercise in which I compare various intensities, durations, types and overall benefits of workouts and exercises. I am pursuing this line of investigation in hopes of determining and designing the ultimate workout in which an individual would receive the maximum biochemical benefit for his/her time and effort. I have collected data from various studies, scientific journals, published articles, and testimonies given by experts in their fields to contribute to my research and workout development. The ultimate result of a workout that we are seeking is a quick return to biochemical homeostasis and the measure of a workout's effectiveness will be based upon how far out of homeostasis a workout pushes the body and how quickly the body can recover to homeostasis following that workout.

As previously stated, over the course of this thesis I will be including testimonies provided by four fitness experts regarding the topics examined in this thesis. These

individuals supplied me with various viewpoints that contributed immensely to the quality and application of my thesis. Malia Crouse is a lifelong athlete and marathon runner who, at 30 years old, has completed 5 full marathons and numerous triathlons distancing half of an ironman triathlon. Jay Campisi, PhD, is an Assistant Professor of Biology at Regis University in Denver, CO, who specialized in integrative physiology and immunology. Doug Emmerich didn't begin running until the age of 50, and only a few years later his diet and regular workouts are crucial components of his daily routine. Finally, Pat Johnson began lifting weights at age 18, but was negatively motivated with appearance being his primary goal. He has found a way out of that mentality though, and is now preparing to compete in a power-lifting meet. Each of these participants pulled upon their personal experiences and knowledge to answer questions regarding ideal workout intensity, duration, type, muscle type, and long-term benefits before providing speculation on what they thought the "ideal biochemical workout" would look like. The varied perspectives of these contributors provided me with an array of insights that in turn have granted me with new and different views regarding my overall understanding of exercise, but also my comprehension of the social and societal implications of health and fitness.

In the conclusion of this exercise story, I am going to explore the Jesuit values and put them into context of my own personal experience and how exercise practice and overall health can make such a difference in the world. In achieving biochemical homeostasis, from a Jesuit standpoint, you are able to obtain what your body and mind truly need, and thus you experience a better overall life with God. Attaining biochemical

homeostasis results in a homeostasis of your mind and spirit, and with the Jesuit ideals at the very core of it all, the quality of life and overall well-being of an individual are significantly improved. The overall experience of writing this thesis has broadened my education and even furthered deepened my appreciation and love of fitness. I hope you enjoy my research and findings as much as I enjoyed exploring the biochemical world of exercise.

Disclaimer

Research has shown that physiological responses in men and women differ greatly due to the female menstrual cycle, which causes variations in hormone concentrations depending on where in her cycle the test subject is. Due to this, researchers have found that experiments performed on male subjects are therefore easier to conduct and require less hormone regulation. In fact, as of 2011, only about 8 studies total have taken the menstrual cycle into consideration when examining variations in endurance exercise performance. Estrogen has been shown to blunt VO_2 max from a metabolic and respiratory rate in that the female body is unable to access the carbohydrates it needs to fuel exercise. Additionally, fluctuations in estrogen and progesterone affect internal fluid balance, and at high levels cause a drop in plasma volume, an increase in core temperature, a change in metabolism to spare glycogen and increase reliance on fatty acids (resulting in reduced ability to use glucose and thus ability to build lean muscle), increased muscle catabolism (reducing ability to recover and build lean muscle), and an increased amount of total body sodium losses and a reset of plasma

osmolality.¹ These all affect women and their various metabolic processes before, during, and after exercise, in addition to influencing overall fitness performance. The following thesis considers various studies, a majority of which focus on male participants; this research limitation should be taken into consideration. For more information, see Dr. Stacy Sims' article "Women are not small men: How gender dictates nutritional needs during training and recovery" at <http://cyclingtips.com/2015/08/women-are-not-small-men/>.

CHAPTER I: INTENSITY AND DURATION

The duration of one's workout is very subjective to not only the individual and his/her drive or performance, but also the workout itself that is being performed. For example, a man in his 40s who has only just begun to workout on a regular basis might perform a significantly shorter workout than a young college student training in her soccer off-season. Likewise, their workouts will vary greatly in focus and intensity. A less active middle-age man trying to lose weight will perform exercises for different lengths of time and at a different intensity than a fit twenty year old trying to maintain her strength and endurance. So how does one determine what duration of time and at what intensity to perform a certain exercise at? Is it better to workout with more intensity for shorter amounts of time or less intensity for longer amounts of time? Better yet, how long should one's workout be total in order to reap the benefits of working out?

To begin to examine these questions biochemically, we must first narrow them down and explore the intensity of the workout and/or specific exercises within the workout. One of the golden standards for examining the potential and varying effects of intensity and duration of exercise is by looking at VO_2 , which is a measure of the oxygen uptake that one endures while working out. It is essentially the amount of oxygen consumed in liters per kilogram of body mass per minute, usually measured as a maximum, and it ultimately reveals to us the aerobic fitness of the individual being examined. In simplest terms, VO_2 max is the maximum amount of oxygen uptake an individual is able to obtain. VO_2 max is genetically determined and training can only affect it $\pm 10\%$ and so, as this only reveals information about an individual, we typically

examine a change in VO_2 max over time. This allows us to ultimately determine relative aerobic fitness of individuals.

Another way in which we examine the effects of intensity and duration of a workout is with muscle glucose uptake as this is the primary determinant of concentration of blood glucose.ⁱⁱ As glucose is the primary source of energy for the body, the measure of blood glucose (also known as blood sugar) present in the body indicates the amount of readily available energy the body has (see Figure 1). These levels vary from individual to individual in addition to hormone imbalances, sleep cycle, diet, and fitness habits. Muscle glucose uptake refers to the rate at which the body pulls upon the blood glucose stores for energy. When you are exercising, if you have a higher blood sugar (dependent on what you ate that day, when you ate it, how much sleep you got, etc...) your body is able to pull from those stores more immediately than other stores (like glycogen, which is stored in the liver and needs to be converted to glucose first). It is essentially a more efficient source of glucose to power the body through a workout, and thus an increase in muscle glucose uptake indicates an increase in metabolism, which uses glucose for power, which in turn indicates a higher overall biochemical effectiveness. And although a person with a higher VO_2 max or better lactate clearance capability can exercise at a higher intensity while using fat (more energetically dense than glucose) as a primary fuel source before they have to dip into glucose, glucose is the body's preferred fuel source at workouts of higher exertion,ⁱⁱⁱ and thus it is used as the reference measurement.

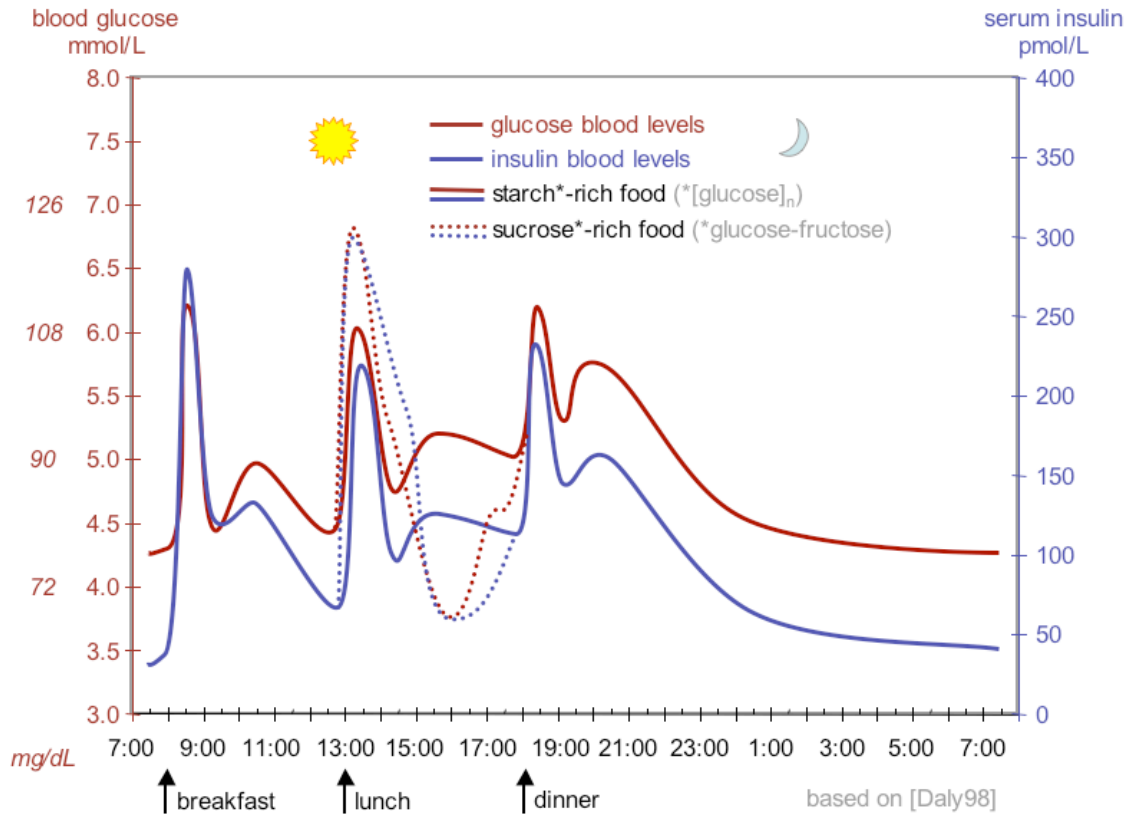


Figure 1: Blood glucose and insulin levels over the course of a day. The above graph illustrates the fluctuations in blood glucose levels that occur over the course of a single day and how these levels (shown in red) correlate with insulin blood levels (shown in blue) with clear peaks in both seen following meals. This demonstrates that blood glucose levels are incredibly dependent on nutrient and energy consumption and thus exercise efficiency and overall effectiveness thus depends on energy sources in the form of glucose present in the blood. Adapted from Suckale, J., Solimena, M., (2008). Pancreas islets in metabolic signaling—focus on the beta cell. *Frontiers in Bioscience: a journal and virtual library* 1(13). 7156-7171.

Ultimately what this all goes to indicate is a deviation from homeostasis; the more often you push your biochemistry out of homeostasis and the further out of homeostasis you push it, the more your body will adapt to have a faster homeostatic recovery. Working out pushes you out of homeostasis, which is clear from our various measurements we use (i.e. VO_2 max, glucose uptake, etc...). These are the body's

responses to the physical stress you are experiencing. In pushing your body out of homeostasis, it adjusts so that it might return to a level of equilibrium more quickly. And thus, the further you push your biochemistry out of homeostasis, the more effectively you will train your body to return! That is why measurements like the ones outlined above are so effective in determining the value of a workout; they are measurements of how far out of homeostasis a workout pushes you and how that changes with time and training. It is ultimately your body adapting and becoming more successful.

INTENSITY

VO₂ max also tells us about various biochemical functions and pathways that occur during exercise and is a measure obtained through high intensity exercise (often the most intense one can perform an exercise). The slow component of VO₂ max is often regarded as the more significant of the two components for various physiological and functional reasons. The fast component has been shown to remain unchanging with work rate throughout various levels of exercise intensity, and thus we will primarily focus on the slow component, as it is variable and linked to aerobic processes (a majority of exercise is conducted in an aerobic state).

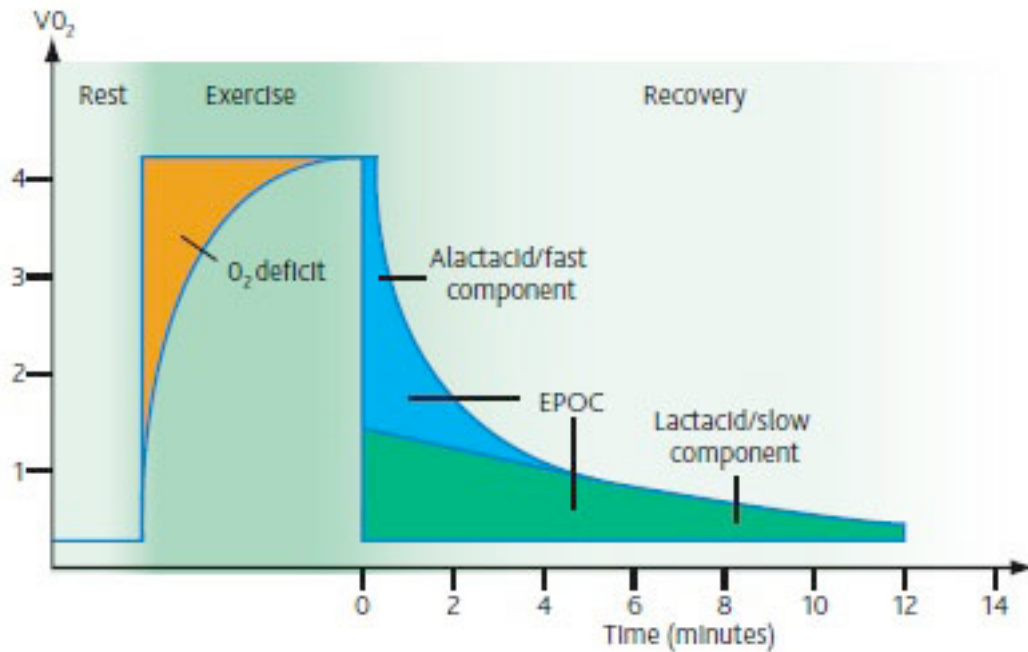


Figure 2: Excess post-exercise energy consumption (EPOC) highlighting the fast and slow components of VO_2 . The green and blue shading indicate EPOC (an increased intake of oxygen consumption following exercise) with blue highlighting the fast component and green representing the slow component. Overall the EPOC indicates the extra volume of O_2 that is required to restore energy systems to homeostasis. The orange signifies the O_2 deficit, which is the volume difference between an ideal oxygen uptake and the actual oxygen uptake.

Adapted from <https://alamedapersonaltraining.wordpress.com/tag/exercise/>

The intensity of an exercise is typically measured relative to an individual's VO_2 max. High intensity exercise is exercise performed at intensities close to VO_2 max (maximum oxygen consumption) and it is often performed over shorter durations of time, as the body is unable to maintain this level of intensity for long. With time and consistent training at high intensities, one's VO_2 max will increase and thus the intensity of their workout can increase. Moderate intensity workouts are typically performed at 50%-75% of VO_2 max and low intensity is measured at 25%-50% of VO_2 max. These are the values to which I will be referring throughout the remainder of this thesis regarding

exercise intensity. It is important to note as well that as one trains, intensity of a workout must increase so that the relative intensity remains the same and thus one obtains the same biochemical benefits as the body adapts and becomes more fit.

Evidence regarding exercise of higher intensity has indicated that improvements in endurance performance can be achieved only via high intensity training, ultimately producing a higher VO_2 max achievable^{iv} (this particular study was conducted using highly trained endurance athletes and thus results might not apply to the general population). However it has also been shown that VO_2 remains higher for a longer period of time at intensities below VO_2 max and above the lactate threshold, which is an intensity at which the blood concentration of lactate begins to increase exponentially^v (see Figure 3), though it is important to note that one limitation of this study is that participants cannot maintain higher intensity activities for as long as they can maintain activities of lower intensities (they all cycled until exhaustion, which is dependent on each individual participant's fitness ability).

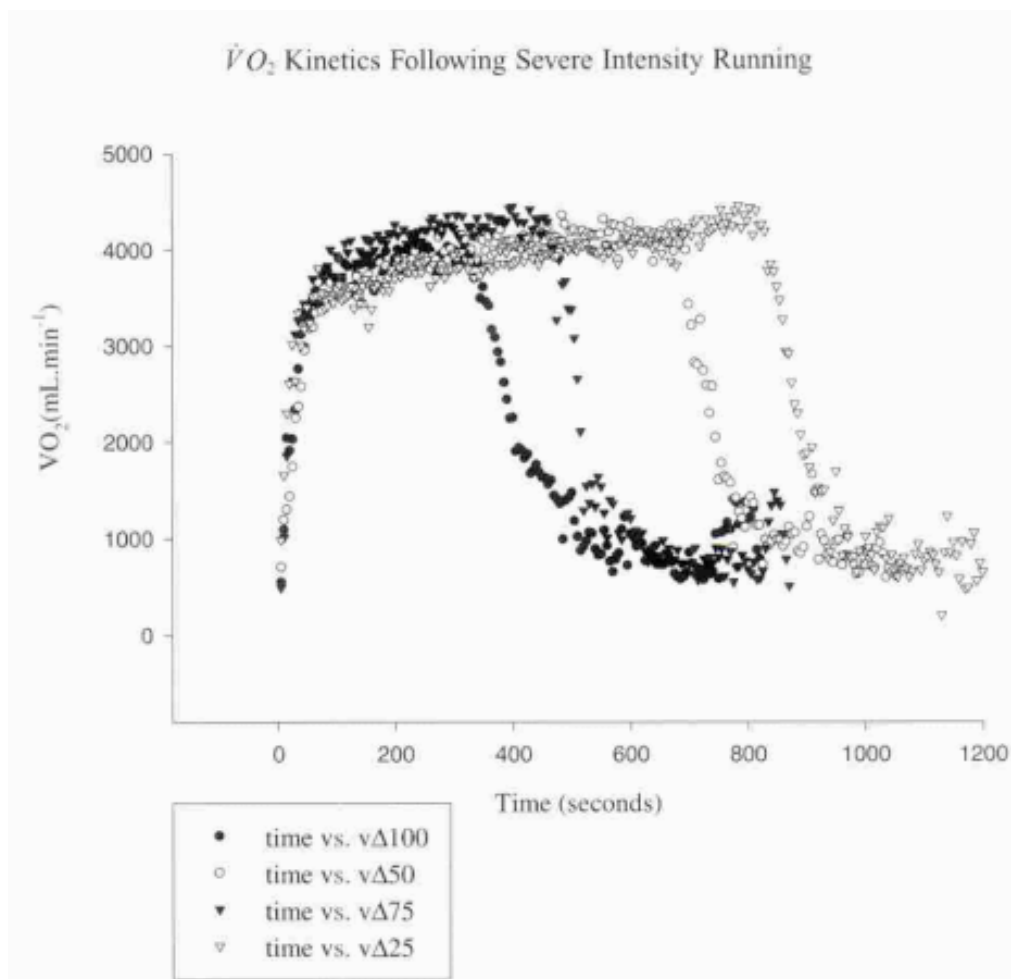


Figure 3: $\dot{V}O_2$ time course during and after exhaustive runs at varying intensities. In this study, 9 long-distance runners performed four supra-lactate threshold runs until exhaustion at velocity at the lactate threshold +25, 50, 75, and 100% of the difference between velocity at the lactate threshold and $\dot{V}O_2$ max (v Δ 25, v Δ 50, v Δ 75, v Δ 100). These data show that participants running at an intensity of v Δ 25 were able to maintain higher $\dot{V}O_2$ for longer periods of time compared to participants running at an intensity of v Δ 50, v Δ 75, or v Δ 100. We then see a decrease in time spent at higher $\dot{V}O_2$ as the intensity of the run is increased. Adapted from Billat, V. L., Hamard, L., Koralsztein, J. P., (2002). The Influence of Exercise Duration at $\dot{V}O_2$ max on the Off-Transient Pulmonary Oxygen Uptake Phase During High Intensity Running Activity. *Archives of Physiology and Biochemistry* 110(5). 383-392.

This biochemical sweet spot of intensity suggests that maybe maximum intensity is not necessary to obtain $\dot{V}O_2$ max, but rather lower intensities help to keep it at higher

percentages for longer relative periods of time than maximum intensities; however we do achieve the same levels of VO_2 max across all levels of intensity according to this study. We can further examine this implication from another approach by considering what other processes are affected and in turn affect one's biochemistry from varying levels of exercise intensity.

Aerobic processes are pathways that require oxygen in order to occur and thus tend to require higher rates of breathing so that more oxygen may be obtained and distributed by hemoglobin to muscles undergoing physical and biochemical stress, such as is induced by exercise. Conversely, anaerobic processes don't require oxygen but both aerobic and anaerobic result in ATP production, which ultimately fuels muscles. However anaerobic exercise is significantly less efficient than aerobic metabolism, producing $1/16^{\text{th}}$ of the amount of ATP for every oxygen molecule that aerobic metabolism produces. The more intensely one exercises, the greater is his/her need for aerobic energy production because of its efficiency. A higher intensity has a greater demand for energy, and as aerobic respiration is more biochemically efficient than anaerobic, it makes sense to resort to this type of metabolism. Additionally, if one were to remain under anaerobic conditions for an entire workout, muscles would fatigue quickly and severe cell damage would occur due to the acidic byproducts of anaerobic metabolism.

High intensity exercise has been shown to increase aerobic fitness more than moderate intensity exercise, resulting in improved cardiovascular function, glucose control, aerobic capacity, and diastolic blood pressure (minimum arterial pressure).^{vi}

These results suggest that the engagement of aerobic exercise at higher intensities is more beneficial than moderate intensities in both long and short-term results. Overall heart health is improved in addition to the greater overall levels of aerobic fitness are achievable with high intensity training.

Additionally, evidence supporting high intensity aerobic exercise shows an exponentially greater increase in sympathetic drive than moderate and low intensity exercise.^{vii} In addition to stimulating the body's flight-or-fight response, the sympathetic nervous system maintains homeostasis within the body. High intensity exercise has been shown to stimulate a severe response from the sympathetic nervous system by pushing the body further out of homeostasis. Thus the concentrations of norepinephrine and epinephrine are dramatically increased^{viii} with this training as they help the body adapt to deviation from homeostasis. Norepinephrine causes increases in heart rate, blood pressure, blood glucose levels and cardiac output. Epinephrine, also known as adrenaline, additionally increases heart rate and blood glucose levels.

The result of the increase in these two hormones during high intensity exercise is that the body becomes more accustomed to their presence and begins to adapt to their concentrations. This allows norepinephrine and epinephrine levels to return to baseline (homeostasis) more effectively when the body is at rest. These are typically considered to be stress hormones and therefore their release when at rest is the result of an extreme external stressor, at which point the body waivers from homeostasis. Norepinephrine then works to return the body to balance and epinephrine stimulates muscle activity in order to return muscles and bodily functions and signals to their normal homeostatic

states. Additionally, because epinephrine mobilizes fat molecules to activate muscle energy, higher concentrations of epinephrine result in higher rates of fat burn.^{ix} The increased heart rate that results from an increase in this hormonal concentration also helps the body to perform more efficiently as blood flow is increased and thus oxygen delivery is increased and exercise endurance, overall fitness, and aerobic training is improved. This increased heart rate in conjunction with the constriction of blood vessels from adrenaline signaling results in high blood pressure, working one's heart harder and improving overall cardio endurance and strength.

Remember though that the greatest benefit comes from training the body to quickly and efficiently return to homeostasis. High intensity exercise, regardless of the type of exercise (aerobic and anaerobic), has been shown to decrease the muscle buffer capacity by decreasing protein-buffering capacity of skeletal muscle.^x Muscle buffer capacity is the ability of muscle cells to neutralize the acid (lactic acid, a byproduct of anaerobic respiration) that accumulates *during exercise*. The proteins that are required for muscle buffering capacity to occur on effective levels are depleted during high intensity exercise (both continuous and intermittent) because during exercise, protein is used to fuel and repair muscles. As the body's use of protein increases during exercise particularly high intensity and long duration workouts result in more protein use.^{xi} While protein is not a usable fuel source for any activity in the body, it can be converted to glucose via gluconeogenesis (a very expensive metabolic process) in the liver. Ultimately what this means is that high intensity exercise results in a decrease of the body's biochemical ability to get rid of lactic acid in the muscles because of the high

amounts of fuel required to power this particular intensity of exercise. This indicates that high intensity training results not only in high concentrations of acid in muscles, but also that it damages the muscles' ability to deal with this acidity over time.

However this same study also showed that high intensity exercise results in an increased muscle buffering capacity *post-workout*. This occurs because of both protein and non-protein buffering (due to an increase in carnosine), unlike muscle buffering capacity *during* exercise, which is solely protein buffering based. And as our desired result is to return to homeostasis *post-exercise*, this is advantageous! Additionally, training over time results in increases in protein concentration and thus active individuals have characteristically higher protein concentrations than sedentary individuals.^{xii} So ultimately, even though high intensity training decreases muscle buffering capacity, more training at high intensities results in higher protein concentrations and thus improved muscle buffering capability, further training muscles to adapt quicker to deviations from homeostasis. In fact, another study showed that in fact blood lactate levels decrease at relative work loads with prolonged high intensity exercise training compared to moderate intensity training, demonstrating the effects of this training over time. This was attributed to a metabolic phenomenon in which trained skeletal muscle trained at high intensities results in a reduction of anaerobic glucose consumption in order to increase aerobic metabolism, a phenomenon that does not occur in moderate intensity trained muscle.^{xiii}

This biochemical change that occurs with high intensity training is one of many beneficial morphological and biochemical changes that occur. While advantageous

changes result with any repetitively practiced specific pattern of muscle activity, when the activity is performed at higher intensities, the changes that occur are significantly more beneficial with high intensity training. Another example of this is in the immunopositivity for myosin skeletal slow protein, which is shown to be drastically increased in high intensity training as compared to low intensity and no training.^{xiv} Immunopositivity simply refers to the positive response when tested for a specific antigen or antibody (in this case it was the slow myosin antibody) and the myosin skeletal slow protein is expressed by slow muscle contractions (see “Muscle Type”). Additionally, the percentage of slow fibers that are aerobically linked and are developed over the course of the workout is significantly greater with high intensity training versus low intensity training. Additionally, the expression of mitochondrial complex enzymes is increased.^{xv} This means that aerobic endurance, ATP-resynthesis, and overall mitochondrial volumes are increased, and thus mitochondrial complex enzymes are increased. As mitochondria are the powerhouse of the cell, it thus implies that cells are therefore able to provide more energy via ATP to push muscles through the workout. Interestingly, it was also accompanied by blood lactate level reduction, another biochemically beneficial result of high intensity training!

When comparing high intensity training to moderate or lower intensity training, continuous activity at moderate intensity did not produce the same results in regards to mitochondrial enzyme expression or muscle fiber composition that prolonged high intensity training produces.^{xvi}

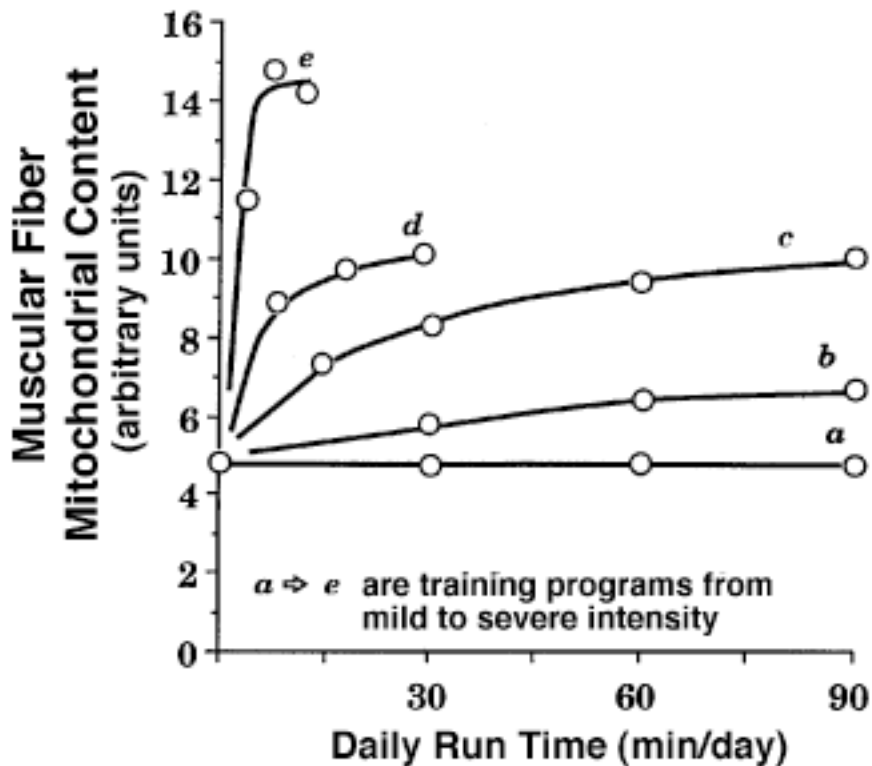


Figure 4: The influence of exercise bout duration and intensity on muscular fiber mitochondrial content. This graph compares various training programs of varying intensities and the resulting relative muscular fiber mitochondrial contents. The training program *e*, which was the most severe, shows the most dramatic increase in relative muscular fiber mitochondrial content, not only with regards to time, but also in overall mitochondrial content as well. Adapted from <http://www.gssiweb.org/Article/sse-54-muscle-adaptations-to-aerobic-training>

Moderate intensity exercise shows markedly lower levels of carbohydrate oxidation (which results in energy production), blood glucose, and lactate when compared to high intensity exercise, all signifying a beneficial push further out of homeostasis. High intensity training also resulted in increases in tricarboxylic acid intermediates and monosaturated fatty acids.^{xvii} The increase in monosaturated fatty acids in turn results in reduced cholesterol, lowered risk of cancer and disease, loss of weight, and a decrease in inflammation. These all indicate that training at levels of

higher intensity cause higher energy production, better energy stores, improved endurance, and increased aerobic respiration.

In fact, low intensity exercise has been shown to have a negative effect on cortisol release.^{xviii} Additionally, when low intensity exercise has been compared to high intensity exercise, high intensity exercise has been shown to significantly increase post-exercise energy expenditure and fat oxidation compared to low intensity exercise.^{xix,xx} The increase in post-exercise energy expenditure signifies that the amount of energy that one's body uses following a workout is increased. This implies an increase in the rate of metabolic processes and overall metabolism following a workout of higher intensity compared to a workout of low intensity. This post-exercise energy use is typically for muscle cell recovery and glycogen replacement within the cell. The increased fat oxidation that we see results in greater fat usage and burn following a workout consisting of high intensity exercises compared to a lower intensity workout. The effects of these benefits that result from high intensity training compared to training at lower intensities suggest that one's body and metabolic pathways are significantly more active, effective, and efficient following a workout.

This and all the previous research examined suggest that high intensity exercise is much more biochemically beneficial than training at moderate and low intensities. Increasing one's VO_2 max is incredibly beneficial in that one's oxygen delivery is thus improved and as follows overall metabolic function is improved. This additionally results in increased muscle recovery and vital organ function, which in turn all contribute to slower fatigue and overall improved fitness capability. However keep in mind that

balance is important; make sure that you are not constantly pushing to your VO₂ max as your body needs time to recover, be it between sets or intervals or workouts.

Expert Testimony

When asked about the ideal intensity of a workout, all of the contributors (mentioned in the introduction to this thesis) gave identical answers regarding the ultimate goal of one's workout. "It depends" was a point that each interviewee made explicit to me regarding almost every question asked. So I narrowed it down; in your research or experience, what intensity of a workout makes one/you feel the best physically and mentally? Each person then stressed the importance of balance regarding and variety in a workout.

Malia talked about the variety of her running workouts over the course of a week, while Dr. Campisi pointed out that the "gains you can make metabolically are faster than the gains you can make orthopedically because you can build cardiovascular respiratory strength faster than orthopedic strength" and thus variety is key in training these systems and preventing orthopedic injury. Doug said that he achieves a "happy sore" and feels the best after an hour spent at 70% of his capability and Pat stressed the importance of listening to your body regarding the intensity of a workout. From these answers I was further able to conclude that balance and personal goals are key in determining intensity of a workout.

DURATION

It is fairly common knowledge that physical activity of any type, performed on a regular basis, contributes to improved temperament and overall health. In fact, “according to the best available science, you should walk or otherwise work out lightly for 150 minutes a week in order to improve your health.”^{xxi} The next big question comes in determining exactly how much exercise induces these psychological and physiological changes. It is known that in order to improve one’s athleticism and physical capabilities, a workout must be increased both in duration and intensity.

In the first few minutes of exercise, a number of different things occur. In the initial seconds following the commencement of exercise, be it running, weight lifting, etc... ATP levels drop drastically as all ATP stores are used up almost instantly to power muscles. As cells perceive the imminent need for energy and simultaneously detect the decrease of stored energy, the creatine phosphate pathway is activated. Also known as phosphocreatine, creatine phosphate is a molecule that is rapidly mobilized to anaerobically donate a phosphate group to ADP in order to produce more ATP. Cells utilize this molecule in the first few seconds of exercise because neither aerobic nor anaerobic metabolism are activated as rapidly upon the beginning of a workout. It essentially fills in for these pathways before they kick in so that your biochemical bases are covered (see Figure 5).

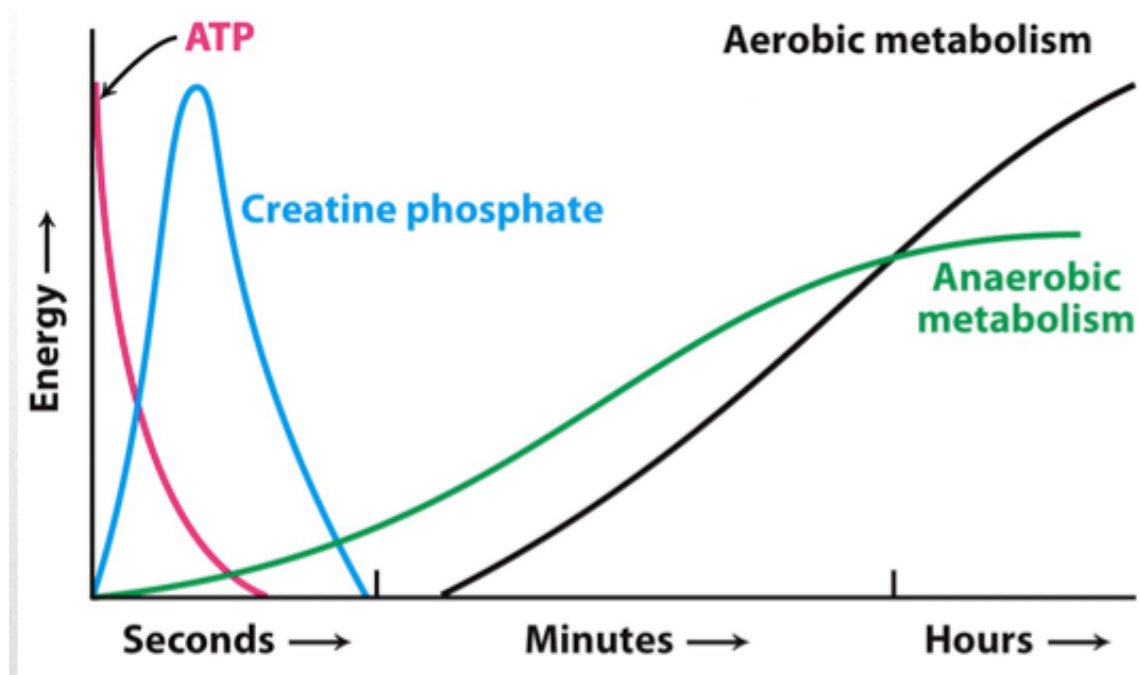


Figure 5: Sequential contribution of the four energy sources for muscle contraction. The first of these to be exhausted is ATP previously stored in the muscle (0-10 seconds of commencement of muscle activity), which is when phosphocreatine (creatine phosphate) kicks in to cover the next 20-30 seconds of contraction. The purpose of phosphocreatine is to bridge the delay between the end of direct ATP-driven contractions and the start of anaerobic ATP synthesis. Anaerobic respiration then follows for the next minute or so as it is faster at ATP production but less efficient and accompanied by a number of harmful byproducts. Finally aerobic metabolism is occurring at maximal rates to efficiently produce ATP to power muscles. Adapted from Freeman, W. H., (2002). Chapter 15. 7th Ed. *Biochemistry*.

At some point in our evolution, our ancestors needed to be able to escape natural predators. If they were relying solely on their anaerobic and aerobic pathways, then the first few seconds into the first few minutes of their fleeing would be slow and inefficient and overall just largely ineffective, and thus we likely would not be alive today.

However, because of the presence and incredible speed of the phosphocreatine pathway, we are able to produce more energy to be utilized in the first few seconds of exercise

after our energy stores have been depleted, allowing us to push through the first few seconds of exercise on energy reserves (before we are able to produce energy).

One downfall of this process is that phosphocreatine stores cannot be restored as rapidly as they are used. Thus, after the initial energy sources that get one through the initial seconds of a workout are often not available to aid later in the workout or after a prolonged respite from working out. The other product of the phosphorylation of ADP to ATP is creatine, which is a biochemical waste product that is secreted in the urine. Thus, phosphocreatine can only be restored via the ingestion of meat or internal production by the liver and kidneys to provide and replenish the phosphocreatine supplies. However it requires the use of ATP when replenished internally, and during a workout the body needs to utilize all ATP as efficiently as possible to power muscle contractions, and thus there is often not enough ATP to be diverted to the formation of creatine phosphate. In addition, this would make the role of phosphocreatine naught, as it would be utilizing the same ATP that it is making to fuel muscles in the initial seconds of exercise. And thus phosphocreatine is only effective while its stores are being consumed; once they are depleted, creatine phosphate cannot make any significant energy contributions to the workout.

However, creatine phosphate is an incredibly crucial molecule, especially when working out. It does get you through the first 10 seconds of your activity, giving you the initial energy and push that ultimately motivates you to continue on until you get your second wind. Have you ever noticed that the first few minutes of your run are always the fastest? Or that you can lift more weight in the first few seconds of your workout than

after a couple of minutes of training? Well my personal training and group fitness instruction has told me that this is a commonly occurring phenomenon. This is because of your body's use of phosphocreatine, which provides that initial jolt of energy in the crucial seconds following the depletion of your ATP stores. Once all the ATP present has been used, there is about a 10 second gap before anaerobic respiration is activated during which, if we had no creatine phosphate, muscle fatigue would instantly set in and you would have no motivation or desire or likely even physical ability to continue on with your workout (or flight from predators, in the case of our ancestors).

Then, after your aerobic pathways are fully activated about 90 seconds later, which are the final pathways to kick in after you have commenced exercising, your body's efficiency is greatly increased and other biological benefits result. However, it often can take upwards of minutes for aerobic respiration to occur. For example, in repetitions of 10-second sprints, only about 13% of the required energy to fuel this activity comes from aerobic metabolism. However, during a four-minute high intensity run, 80% of the required energy comes from the ATP produced aerobically.^{xxii} Thus, biochemical efficiency is dramatically increased when exercise is more prolonged than, say 30 seconds.

It has also been shown that there is a positive relationship between the amount of time someone spends working out at their VO_2 max and “the time constant of the oxygen kinetics in the off-transient phase.”^{xxiii} Oxygen kinetics consists of a fast phase and a slow phase, which describe portions of VO_2 decline post-exercise. The fast phase is an “exponential component corresponding to the phosphocreatine and myoglobin oxygen

replenishment stores” and slow phase has a “slower time course for the oxidation of lactic acid.” A transient response is the body’s way of returning functions to homeostasis after they have been deferred from equilibrium, and off-transient phase is the sum of the two phases of oxygen kinetics (see Figure 2).

Therefore, this means that the longer an individual engages in activity at VO_2 max, the longer the individual experiences the results of fast and slow phase oxygen kinetics, and thus the most prolonged interval within a workout that we are able to achieve is ideal. When one finishes exercising, VO_2 does not immediately return to rest levels, but rather remains slightly elevated in order to help restore metabolic processes to rest conditions; both the fast and slow phases of oxygen kinetics persist from this endured length of time at VO_2 max.^{xxiv} Thus, phosphocreatine and myoglobin oxygen replenishment stores are increased even more. We likewise see an increase in lactic acid oxidation (the ability to get rid of lactic acid *post-exercise*). Myoglobin acts like hemoglobin in that it delivers oxygen to tissues from the lungs. However, it has a higher binding affinity for oxygen than hemoglobin does, and thus binds to oxygen easier and faster than hemoglobin. While it cannot distribute as much oxygen as hemoglobin (only 7% of the body’s oxygen is distributed by myoglobin, compared to the 66% that hemoglobin releases to tissues), it can release oxygen faster under anaerobic conditions, again aiding in the first few seconds of exercise. The replenishment of these stores essentially means your body is priming itself for future biological stressors, such as exercise, and the increase in these processes indicates improved preparation for exercise

to come. Thus, the longer you remain at VO_2 max, the more prepared your body will be for the next time you work out, contributing to your overall fitness capacity and ability.

During exercise, we see a slowing of the oxidation of lactic acid, which is beneficial for a number of reasons. Oxidation of lactic acid results in pyruvate, which under aerobic conditions powers the Krebs cycle—also known as the citric acid cycle or TCA (which in turn produces ATP, the most important biological energy source)—and under anaerobic conditions produces lactic acid. Lactic acid is what causes the burning in your muscles that you feel during a particularly strenuous exercise. The benefit of slowing down the conversion of lactic acid back to pyruvate is that more NAD^+ (a byproduct of the reduction of pyruvate to lactic acid) remains in the environment. NAD^+ is required to power glycolysis, and thus the increased presence of it or rather the slowed decrease of it results in more glycolysis. Glycolysis is the biochemical pathway in which glucose is converted to pyruvate and glucose is the preliminary form of energy that the body uses to make ATP. Thus, pyruvate can be produced by an alternative pathway to the oxidation of lactic acid, increasing the productivity of these various processes.

Research regarding the biochemically ideal length of a workout is extremely limited, and thus based on the information and biochemistry outlined above, the ideal duration of a workout is the length of time in which one's body is pushed the furthest out of homeostasis. Thus, the threshold between aerobic and anaerobic exercise is perfect because it never allows the body to settle into one or the other; it must adapt to the low energy point between the two. The result of this is that one's body reaps the benefits of both types of respiration but also adapts to fulfill the energy requirements necessary to

push past this threshold. As this threshold occurs around 90 seconds, we will conclude that the ideal duration of an interval in a workout is 90 seconds long.

When comparing strictly aerobic and anaerobic processes, biochemically speaking, anaerobic metabolism results in lactate formation accompanying ATP and NAD⁺ production, whereas aerobic metabolism results in higher ATP production with only CO₂, H₂O, and NAD⁺ as byproducts, none of which are as detrimental to cells as lactic acid can be. Phosphocreatine release, while incredibly efficient at providing energy to muscles, occurs within the first 30 seconds of exercise before anaerobic metabolism kicks in, and, as stated earlier, biochemical efficiency is increased after the first 30 seconds of exercise. Thus, training for durations longer than 90 seconds is the most ideal for maximum biochemical benefit.

Now, realistically, most individuals will not go to the gym to work out for a minute and a half before showering and going home. Rather what this means is that a workout must be both anaerobic and aerobic to obtain the most biochemical benefit and thus it must be longer than 90 seconds as your aerobic metabolism is not active until 90 seconds after the commencement of a workout. This also does not speak to the type of exercise in which one should participate; any type of exercise performed for over 90 seconds will push one's metabolism into the aerobic zone. And as research regarding specific durations of workouts is limited if not completely non-existent, it is suggested that individuals experiment with workout durations that accommodate their specific needs and preferences and are more prolonged than 90 seconds.

Ultimately though, “manipulation of the intensity and duration of work and rest intervals changes the relative demands on particular metabolic pathways within muscle cells, as well as oxygen delivery to muscle.”^{xxv} While the previous information may indicate that exercise at higher intensity and for a minute and a half duration is the most biochemically beneficial, it by no means implies that this is the only type of workout one should participate in. As stated, variation in one’s fitness routine creates variety in which metabolic pathways are utilized and made to be more efficient. Thus, mixing up workouts, rest periods, and days off is crucial to developing one’s overall physiological and metabolic health.

Expert Testimony

The interviewees’ responses to the ideal duration of a workout were slightly more congruent than their responses regarding intensity. While again each individual stressed the dependence of duration on personal goals and ability, Malia, Doug, and Pat all claimed that they felt the best after workouts 60-90 minutes long because it allows a warm up, higher (but not extreme) sustained intensity, and they all felt that anything shorter doesn’t provide sufficient mental satisfaction. However, they all stressed the fact that workout duration is not the same from day to day and how changing up the duration of one’s workout is as important as changing the workout itself. Dr. Campisi pointed out how important recovery is and that there is such a thing as a workout that is too long, so it is ultimately about finding variations of duration based on your personal ability. Again, I found it interesting that each participant emphasized the significance of variety and

balance in the duration of one's workout, which again plays into the balance and variety that I just mentioned.

CHAPTER II: TYPE AND MUSCLE

As a fitness instructor, I often classify and advertise my exercise classes as sustained cardio (i.e. spin class), body weight, high intensity interval training, kickboxing, yoga, etc... My personal training and instructing experience combined with my research of exercise has lead me to believe that the general population tends to classify workouts by the types of exercises being performed and less by the muscle group being targeted or the length of the workout. For example, at 24 Hour Fitness, a popular gym located in urban regions, commonly advertised classes include cycle, cardio, strength, Pilates, senior fitness, yoga, boot camp, aqua, and many more. A majority, if not all, of these classes are classified on the *type* of exercise they practice, leading one to wonder which type of exercise is the best to perform. Let's break it down even more: what type of exercise is the best for an individual's biochemistry? In the variety of today's exercise options and in an ever expanding fitness world, it can be challenging, neigh, overwhelming to pick and choose which types of exercise to perform and when.

TYPE

Most have heard that cardio is better for weight loss and lifting weights is better for building muscle mass and yoga is good for flexibility. When I first began, I set out to compare strictly cardio/endurance (steady-state based) and resistance/weight training; however my research led me to also examine high intensity interval training (HIIT). The term cardio is short for "cardiovascular exercise", referring to any exercise that raises your heart rate for a prolonged period of time like running, bike riding, and swimming.

Your cardiovascular system is your circulatory assembly that delivers oxygen from your lungs to your muscles and extremities via hemoglobin in your blood. The heart serves as the ultimate muscle that powers this system, pumping blood through your veins, and thus cardiovascular exercise, which increases your heart rate, increases your circulation and therefore your oxygen delivery.

Resistance training is classified as any sort of training in which muscles are forced to contract in opposition to an external resistance (such as weights). The ultimate goal of resistance training is usually an increase in strength or muscle tone, but it can also be used to improve endurance. High intensity interval training involves repeated bouts of short duration intervals performed at high intensities. These intervals are broken up by rest intervals that usually consist of lower intensity activity for an active recovery phase. While HIIT could be classified as cardio exercise, for our purposes we will examine them separately as cardio will refer to continuous activity with no rest period.

To begin, we can compare endurance exercises (cardio training) with high intensity interval training, two popular styles of workout. It has been shown that both of these types of workouts are incredibly beneficial as they result in increases in oxidative capacity and whole-muscle markers of mitochondrial content in addition to inducing acute activation of signaling pathways (measured in whole-muscle homogenates). Additionally these workouts result in increased aerobic capacity and exercise performance as well as changes in muscle fiber oxidative and glycolytic capacity, glycogen storage, and whole-muscle capillary density. While all of these are valuable, there is an observed, noteworthy difference between these types of training; an increase

in anaerobic exercise performance and muscle glycolytic capacity with high intensity interval training, but not with endurance performance.^{xxvi} These results are, as one would expect, HIIT involves more anaerobic activity than endurance exercise does (shorter intervals don't allow your body sufficient time to enter aerobic respiration); thus improved anaerobic exercise performance would result.

Additionally, HIIT has been shown to increase muscle glycogen content.^{xxvii} Muscle glycogen is converted to glucose in muscle cells and serves as an immediate glucose reserve for working cells before metabolic respiration is activated. The glycogen stored in a muscle cell is restricted to and used solely by that muscle cell, and thus increased muscle glycogen content would indicate an increase of energy stores within the cell, priming the cell better for future energy expenditure. Additionally muscle glycogen concentration influences glucose uptake during exercise because a lower concentration of glycogen prior to exercise results in a dramatic increase of glucose uptake during the first 60 minutes of exercise. This occurs because cells need fuel, and with less glycogen present, they must rely on fuel supply from external sources. This indicates that low muscle glycogen content results in an increased use of present glucose.^{xxviii} As HIIT increases this concentration, it is therefore an effective way to train one's body to be better prepared for future workouts, ultimately allowing it to return more quickly to homeostasis following a workout.

Following this line of HIIT research, practice of HIIT has also been shown to result in an increase in the maximal activity of citrate synthase and the concentration of the active form of pyruvate dehydrogenase.^{xxix} Citrate synthase is the initial enzyme in

the Krebs cycle and it catalyzes the reaction that forms citric acid, which goes on to feed the cycle further. As such, an increase in the activity of citrate synthase means that the cell is creating more energy via the Krebs cycle to be used to fuel the continuation of cell use (exercise). Pyruvate dehydrogenase is the enzyme that oxidizes pyruvate into carbon dioxide, NADH, and Acetyl coenzyme A, which becomes oxaloacetate and is then used in the citric acid cycle. Pyruvate dehydrogenase essentially links glycolysis to the citric acid cycle in addition to releasing energy via the formation of NADH from NAD⁺ and a hydride. The result of this is further energy production, especially when an increase in pyruvate dehydrogenase is observed.

Additionally, HIIT results in an increase in β -HAD activity.^{xxx} β -HAD (beta-hydroxyacylcoA dehydrogenase) is a key enzyme in the beta-oxidation of fatty acids to acetyl coenzyme A; it essentially aids in the oxidation of fat, and thus an increase in its activity implies more fat oxidation and hence more fat loss. This ultimately indicates that HIIT results in increased fat loss *post-exercise* when resting. So HIIT can make your homeostasis a more effective, prolonged burn period!

As if that wasn't enough, further research shows that HIIT causes a reduction in net muscle glycogenesis and lactate accumulation.^{xxxi} Glycogenesis is the biological pathway in which glycogen is synthesized from glucose. This means that during high intensity exercise, less glucose is being used for the synthesis of glycogen so it can rather be used to fuel the active muscles; thus one's muscles are able to better re-direct resources in order to power one's exercise. As glycogen is the body's primary source of stored glucose, providing a pool of energy for various tissues to pull from in times of

high-energy expenditure, such as high intensity interval training. Thus, high intensity interval training has been shown to require higher amounts of energy and thus promote more biochemical metabolic pathways to occur. And while this information appears to contradict the previous evidence showing that glycogen stores increase with HIIT, this phenomenon of decreased glycogenesis occurs *during* exercise. The increased glycogen stores are a result of HIIT that occur *post-exercise*, and thus this information all further contribute to supporting the biochemical benefits of HIIT.

As mentioned previously, lactate accumulation is likewise decreased with HIIT. Lactate is the conjugate base of lactic acid and is the result of the breakdown of glucose to pyruvate for energy and lactate accumulation occurs when there is a lack of oxygen or when the cell's demand for energy is higher than internal energy production. It is lactate that causes your muscles to burn during your workout, and long term it can cause severe muscle damage as in high concentrations it creates an acidic environment that can result in apoptosis (cell death). Thus, decreased lactate accumulation protects your muscles, prevents soreness, and allows for better recovery after a workout.

HIIT also increases muscle oxidative potential and can up to double the endurance capacity of an individual.^{xxxii} Muscle oxidative potential is the ability of muscle to generate ATP via oxidative phosphorylation; it is essentially the conceivable efficiency at which a muscle can generate ATP for energy. An increase in this potential means an increase in muscle efficiency and thus an increase in the ability to return to homeostasis following a workout. This, combined with an increase in endurance capacity, indicates

that HIIT can dramatically affect one's biochemistry so that it works for his/her benefit in an even more extreme way.

Likewise, it has been shown that brief bouts of very intense exercise result in stimulating aerobic energy metabolism, which in turn causes overall improvements in fitness ability and rate of return to homeostasis.^{xxxiii} High-intensity, intermittent exercise performed three times a week for 20 minutes at a time for 15 weeks has been shown to increase respiratory ability and fat loss and decrease insulin in overweight individuals when compared to steady-state aerobic exercise performed three times a week for 40 minutes at a time for 15 weeks.^{xxxiv} HIIT results in an increase in the overall capacity for fat oxidation due to enhanced mitochondrial capacity, which is in turn due to the fact that it provides a "power stimulus for increasing the enzyme contents of many of the metabolic pathways in the mitochondria in a short period of time."^{xxxv} This short-term increase of enzymes is a biochemical adaptation due to the push out of homeostasis, and the high populations of enzymes present will ultimately help to return the body back to equilibrium. Thus, HIIT causes an increase in enzyme concentrations that in turn results in a faster return to homeostasis, as is desired.

In the end, we can see that high intensity intermittent training improves both aerobic and anaerobic ability, supplying more overall energy to the body.^{xxxvi} This is due to the intensive stimuli applied to both aerobic and anaerobic systems, which provides interesting results as HIIT is often associated with more anaerobic activity and sustained, moderate intensity training is typically thought to rely more on aerobic metabolism. However, intermittent sprinting (high intensity bouts of training) results in significant

improvement of both aerobic and anaerobic systems, indicating that both metabolic and respiratory efficiency are significantly improved with high-intensity intermittent exercise.^{xxxvii}

On the other hand, there has been sufficient research to show that resistance and endurance training are extremely beneficial in both the short and long terms. In fact, resistance training is often prescribed to combat accelerated muscle wasting that often accommodates aging. Various studies show that resistance training induced muscle fiber hypertrophy additionally contributes the oxidative capacity of skeletal muscle.^{xxxviii} Muscle fiber hypertrophy is the growth of muscle cells resulting in an increase in muscle mass and cross sectional area. It occurs when muscles are overloaded by stimuli (in the case of resistance training, the stimuli is weight) and it is the body's mechanism to protect itself against the overloading of weight again. In fact, it has been demonstrated that induced muscle fiber hypertrophy additionally improves the oxidative capacity of muscle so that muscle is more efficient at producing ATP to further power cells.

Excess post-exercise oxygen consumption (EPOC) is yet another measurement of increased rate of oxygen intake following a workout and is used to measure the effectiveness of a workout by measuring biochemical processes post-workout. The increased oxygen consumption occurs in an effort to return the body's oxygen levels to homeostasis. Following resistance training, EPOC is increased because resistance training disturbs the working muscle cells' homeostasis and subsequently more energy is required to restore the cells to their resting homeostasis.^{xxxix} Additionally, eccentric exercise, which is muscle contractions during which the muscles lengthen and produce

force such as weight/resistance training, has been shown to result in particularly elevated EPOC levels for a longer period of time than non-eccentric exercise due to the additional protein synthesis and cellular repair that must occur in these muscle cells following a workout.^{x1} This data suggests that weight training results in an increased EPOC, which then allows for a faster return to homeostasis. However, while specific types of training like circuit training and heavy resistance training do lead to a significant EPOC effect, HIIT has actually been shown to be the most effective type of training in stimulating the EPOC effect because it allows for ATP replenishment during rest intervals but they are also short enough that demand on the anaerobic energy pathway is greater and thus the overall EPOC effect is greater. This is because “the oxygen deficit is the difference between the volume of O₂ consumed during exercise and the amount that would be consumed if energy demands were met only through the aerobic energy pathway.”^{xli} Thus we see that in regards to EPOC, HIIT is more biochemically beneficial than resistance training.

Muscle oxidative potential is also increased after endurance training, similar to HIIT, however it's also been shown that with endurance training there is also a tighter coupling between ATP demand and supply overall indicating a higher metabolic efficiency produced by this specific type of training. This coupling occurs when

“The ADP used to regenerate ATP is replenished from ATP produced by the metabolic pathways...and bound to the outer surface of the inner mitochondrial membrane. The increase in the mitochondrial protein concentration of skeletal muscle that occurs with endurance training has a direct effect on improving work capacity [and]... the [resulting] effect of these changes is to produce a more effective use of fat and carbohydrate reserves.”^{xliii}

This indicates the resistance training, like HIIT, results in improved overall metabolic processes.

Conversely, resistance training has been shown to lower relative muscle mitochondrial content, resulting in reduced fatigue resistance, a decrease of oxidative ATP synthesis and compromised capacity for fatty-acid oxidation.^{xliii} Research has likewise shown that endurance training results in reduced muscle glycogenolysis due to a decrease in phosphocreatine and the utilization and overall accumulations of free phosphate and AMP.^{xliv} Glycogenolysis (opposite of glycolysis) is the process in which glycogen is broken down into glucose-6-phosphate, a form of the carbohydrate that muscles can use for ATP synthesis. This reduction in glycogenolysis occurs because resistance training results in the decrease of the accumulation of the substrates phosphate and AMP, which are activators of phosphorylase activity. Thus lack of these substrates results in decreased phosphorylase activity. As phosphorylase is an enzyme that catalyzes the phosphorylation of glycogen, a decrease in phosphorylase results in the inhibition of phosphorylation and thus a decrease in the production of glucose-6-phosphate. The ultimate consequence of this is decreased ATP production from glycogen stores and thus muscles must rely on other possible energy sources (i.e. reprocessing of ATP already produced or blood glucose). This ultimately negatively effects the efficiency and potential of muscles as glycogen is not utilized but rather unnecessarily stored.

Furthermore, this decrease of carbohydrate utilization with endurance training is accompanied by decreases in the rate of glucose appearance, the glucose metabolic

clearance rate, and plasma glucose uptake.^{xlv} The decrease in glucose appearance rate suggests a decrease in the synthesis of glucose, which is used by virtually every tissue in the body for fuel (especially during endurance exercise), and the glucose metabolic clearance rate refers to the ability of the various tissues to use glucose (how fast they use the glucose being produced). Thus, if less glucose appears, it would follow that tissues would uptake less glucose. Together with the decrease in plasma glucose, these results would appear to indicate that endurance training results in a less efficient and effective use of biochemical pathways and substrates. However, it is important to note that the researchers that discovered these patterns suggest that rather these decreases imply that there must be a shift in the sources of carbohydrates utilized during endurance exercise and that it likely comes from a compensatory increase in skeletal muscle glycogen utilization.

Another study showed that endurance-training results in a decline in the maximum force exerted by slow twitch muscle fibers (see subchapter Muscle) due to a reduction in the contractile protein of the muscle.^{xlvi} Contractile proteins are any proteins that generate force to power muscle contractions, and thus there is a decline in the force that these specific fibers can produce. Additionally, resistive exercise compared causes a shift in the heart rate-to-oxygen cost of exercise compared to aerobic exercise,^{xlvii} implying that the decreased heart rate of resistance compared to aerobic exercise in turn results in a lower VO_2 . These results are congruent with previous evidence and conclusions that aerobic/cardio training results in a higher VO_2 . This same review declared,

“Performance of a severely intensive resistive exercise session, therefore, induces a state of energy imbalance in skeletal muscle. The decline of mixed muscle ATP content indicates the rate of hydrolysis of this substance dictated by the intensity of the exercise session was greater than the rate of ADP phosphorylation via the enzyme systems of energy supply. The decline of high energy phosphate and glycogen contents and the accumulation of glycogenolytic/glycolytic intermediates including lactate indicate substantial activation of anaerobic energy machinery.”

As reviewed earlier, anaerobic metabolism is not as efficient as aerobic metabolism and likewise results in high levels of lactic acid accumulation, which can cause severe muscle atrophy and damage. We can conclude from this data that perhaps resistance and endurance training, while overall biochemically beneficial, are accompanied by a number of undesirable biochemical effects.

Thus, these results all indicate that resistance exercise is not nearly as biochemically effective as high intensity intermittent training, or any other aerobic training for that matter. Additionally, what this research demonstrates is that, from a biochemical standpoint, endurance training compared to high intensity intermittent training is neither as effective nor beneficial. However, it is important to note that this evidence does not endorse complete refrain from resistance and endurance training. Rather, it suggests that cardio and weight lifting are extremely beneficial biochemically and physiologically and should be practiced regularly in addition to HIIT. Solely from a physiological standpoint it is crucial to practice both types of training regularly in order to train all metabolic and biological systems equally so as to develop a balance of biochemistry.

Rest Duration

When further examining HIIT, we must also consider duration of rest intervals, as intervals are such a key component of this type of training. How long one should rest for between sets or repetitions is extremely dependent upon the type of training one is practicing. For example, muscular endurance training typically requires rest intervals 30-90 seconds long whereas power training requires intervals of up to 3 minutes in length.^{xlviii} Specifically regarding HIIT, research has shown that the ideal ratio of workout to rest is 2:1.^{xlix} The reasoning for this was that rest intervals any shorter reduced the intensity of the active exercise interval because muscles were not allowed sufficient time to recover. Longer durations of exercise to rest intervals in the ratio 1:1 resulted in participants having identical levels of intensity. This in combination with the fact that we are trying to force a faster homeostatic recovery (and shorter rest intervals force faster adaptation and return to homeostasis) suggests that to optimize recovery, intensity, and overall duration of the workout, the work to rest ratio of 2:1 is ideal.

However, another study examining the consequences of resistance training notes that “it appears that additional enzyme systems of energy supply make a significant contribution to the exercise effort when greater numbers per set and shorter duration rest periods between sets are used.”¹ This means that shorter rest intervals between sets of high repetitions are extremely effective at increasing enzymatic activity. Thus shorter rest periods induce more metabolic activity by pushing body more quickly and repetitively out of homeostasis, ultimately training it to have a faster homeostatic recovery. This implies that the shorter the rest interval, the more biochemical benefit

with resistance training, however the rest interval is still a crucial component of the workout as muscles need sufficient time to replenish ATP stores and injury is less likely to result if muscles are permitted sufficient recovery time.

It is important to note as well that a rest interval does not have to be a period of inactivity. A rest interval could actually be a period in which low intensity, low aerobic exercises are performed instead of full rest. For example, a plank or boat pose would be an ideal way to actively spend your rest interval as you are working key interior core muscles without the cardio component of HIIT. This sort of rest interval is more ideal when you are at a higher, more advanced level of fitness.

Expert Testimony

When I spoke to my contributors, I found the variety of answers regarding the type of workout to be of particular interest. I'm sure a significant reason for this is that they all come from such different backgrounds and histories regarding fitness; however variety was still a key point each participant made. Malia personally prefers as much variety as she can get, switching between cycling, running, and swimming, as it contributes to her mental wellness in addition to preventing injuries. Dr. Campisi said that the body prefers a balance of strength/resistance and cardiovascular endurance as they play into one another and thus you can't neglect either. In fact, you strengthen both with cross training. Doug's top preference is cardio because of its ability to strengthen the heart in addition to other muscles, closely followed by a focus on core because of the long-term benefits it provides for hips, back, etc... Pat on the other hand "hates cardio,"

but he understands the benefit of cardiovascular strengthening. He thinks that aerobic workouts combined with compound movements are ideal because they don't focus on a single muscle as weight lifting so often does. It also provides more variety than running or cycling. These different answers I attribute not only to personal preference, but also to past experiences and social opportunities that each of these participants has found in his/her respective workout of choice. To me, this testimony only furthered to strengthen the argument that variety of the type of workout is crucial in one's fitness regimen.

MUSCLE

When I began this investigation, I had envisioned my examination of muscles to consist of research regarding specific muscles or muscle groups such as core muscles, larger muscles groups, or even as specific as the quadriceps femoris. However, as was soon made clear by my research, this is not a method of biochemistry investigation. And while the examination of specific muscle groups would likely aid in the determination of the ultimate biochemical workout, because biochemistry occurs on a microscopic level. Thus examining a comparison of the biceps femoris and the quadriceps femoris would provide insufficient information to determine which specific muscles have more beneficial biochemical contributions as they both undergo the same biochemical pathways in similar, if not identical, manners. Thus we will be investigating the muscle type as opposed to a specific muscle or muscle group, and ultimately this will help in the resolve of designing the most biochemically beneficial workout.

Muscle is often classified into two categories depending on the fiber type and biochemical processes that occur within the fiber. Type I, also known as slow-twitch, is the type of muscle that aerobically contracts and thus produces its own ATP (use of O₂ in glycolysis and the Krebs cycle results in ATP), which fuels muscle contractions. Thus, because they have their own, self-sustaining energy source, they are able to maintain activity for longer amounts of time, although with less force. Type II, or fast twitch, muscle fibers contain high populations of mitochondria (produces ATP through oxidative phosphorylation) and additionally are the first to be activated when a muscle contracts (see Figure 6). A combination of these and Type I muscle fibers exists throughout the body. Interestingly, tonic muscles and soleus muscles, which are involved in maintaining posture, contain significantly higher densities of Type I muscle fibers.


Characteristic	Slow-twitch	Fast-twitch IIa	Fast-twitch IIb
Force production	Low	Intermediate	High
Contraction speed	Slow	Fast	Fast
Fatigue resistance	High	Moderate	Low
Glycolytic capacity	Low	High	High
Oxidative capacity	High	Medium	Low
Capillary density	High	Intermediate	Low
Mitochondrial density	High	Intermediate	Low
Endurance capacity	High	Moderate	Low 

Figure 6: A comparison of muscle fiber types. This table demonstrates the numerous differences in characteristics of Type I and Type IIa/b, illustrating the differences in these fibers regarding their force production, speed, metabolic capacities,

and various densities. The fiber types are rated on a scale of either low/slow, medium/intermediate/moderate, or high/fast regarding these characteristics. It is unclear what the red hexagon indicates. Adapted from McCall, Pete, (2015). Slow-Twitch vs. Fast-Twitch Muscle Fibers. Retrieved from <https://www.acefitness.org/blog/5714/slow-twitch-vs-fast-twitch-muscle-fibers>.

There are two classifications of Type II (fast-twitch) muscle fibers; fast oxidative glycolytic, which utilize O_2 to produce ATP, and fast glycolytic, which rely on stored ATP. Type II fibers are recruited when the overall muscle demands are more than the Type I fibers can manage because Type II not only generate more force, but they also reach peak force quicker than Type I fibers can. As a result though, Type II fibers fatigue much quicker than slow-twitch, and thus cannot maintain or endure activity for as long. For example, phasic muscles, which are involved in movement generation (i.e. eye movement, foot movement, and other movements that cannot be sustained for long periods of time), have higher densities of Type II muscle fibers than most other muscles in the body.

When further examining differences between these two types of muscle fibers, it has been observed that Type II (fast-twitch) muscle fibers produce a significantly greater amount of initial heat production (five- to six-fold greater) than Type I (slow-twitch) fibers. Additionally, the energy expenditure is increased in fast-twitch fibers compared to slow-twitch fibers and the VO_2 max of Type II fibers is three to five times greater than the VO_2 max of Type I fibers.^{li} This means that while Type II fibers require more energy, they ultimately produce more power than Type I fibers. Additionally, working muscles that consist predominantly of Type II fibers results in achieving a higher VO_2 max, indicating that more oxygen can be employed and thus metabolic pathways can proceed

at a faster, more efficient pace. In fact, individuals with higher percentages of fast-twitch fibers generate higher power and torque at a given velocity than individuals with higher percentages of slow-twitch fibers as peak power has been shown to occur at a ratio of 10:5:1 for Type IIb:IIa:I fibers.^{lii}

However this increased power output of Type II fibers compared to Type I fibers is not necessarily as beneficial as it may sound. For example, Type I muscle fibers are actually more efficient (regarding oxygen cost and caloric expenditure) than Type II in endurance-trained cyclists.^{liii} This specific study demonstrated that “variability in the oxygen cost and thus caloric expenditure of cycling at a given work rate” is related to differences in the participants Type I muscle fiber percentage. Thus, the oxygen cost and caloric expenditure (energy use) was lower and more efficient with higher percentages of slow-twitch muscle fibers than higher percentages of fast-twitch fibers. Additionally, minimal recruitment of Type II fibers delays the onset of fatigue and provides higher performance.^{liv} This is because the recruitment of Type II fibers and the accompanying acidosis (from anaerobic respiration) contribute to a decrease in mechanical efficiency^{lv} and muscle recovery, as muscle fatigue is attributed to high concentrations of lactic acid and low supplies of ATP, glycogen, or creatine phosphate and recovery is attributed to the cells’ ability to neutralize the acid.

The relative percentages of slow-twitch fibers to fast-twitch fibers in an individual’s muscles are genetically determined and thus the attempt to alter one’s muscle composition poses a problematic challenge. Individuals with predominantly Type I muscle fibers have a greater advantage in long-endurance exercises and thus likely

perform better at endurance-based activities like running or cycling. On the other hand, individuals that have predominantly Type II fibers are better at explosive exercises with quick bursts of speed, strength, and power and tend to be the most successful in weight training and sports like golf or football. The greatest success in your fitness will come from an “exercise program that applies the right training strategies for your muscle fibers,”^{lvi} ultimately maximizing enjoyment and efficiency. And there are various ways to target both of these muscle fibers when working out.

To train your slow-twitch fibers, the best exercises feature sustained isometric contractions that involve little-to-no joint movement in order to support the fibers in contraction for an extended period of time, ultimately improving their ability utilize oxygen to produce energy. Resistance with lighter weights, and at slower tempos and circuit training with shorter recovery periods (no more than 30 seconds) and lighter weights, are also very effective in that they are both sustained for longer durations and thus push Type I muscle fibers to engage aerobic metabolism. More generally, workouts in which slow-twitch fibers are maximally engaged involve lighter weight/resistance, higher repetitions, and slower tempos or sustained movement are the most beneficial.^{lvii}

In order to train your fast-twitch muscle fibers, exercises tend to be more explosive over shorter durations. Resistance training with higher weight promotes more Type II fibers, because greater weight recruits a higher number of fast-twitch fibers. Power-based movements performed in quick bursts are highly effective; however because these muscles fatigue so quickly, heavier weights and more rapid movements are best. Due to this fatigue and ultimately slower recovery, it is also important that rest intervals

are longer in length (60-90 seconds) so as to allow the fibers to replenish spent ATP stores and prepare for the next set or interval.^{lviii}

The results of these examinations show us that not only is it important to focus on antagonist muscle groups for overall safety and strength, but that Type II muscle fibers have VO_2 max, have a higher power output, and produce more heat, which indicates that more exergonic reactions are occurring and thus more compounds are being broken down and utilized. Thus, strictly biochemically speaking, it is more beneficial to focus your workout on your fast-twitch fibers, despite the fact that Type I fibers are slightly more efficient, durable, and enduring (biochemically this isn't as relevant). While it is not really possible to alter the relative amounts of these fiber types in an individual, it is possible to focus on a single type in workouts in order to gain that biochemical benefit and ultimately the quick return to homeostasis that we are seeking in this investigation.

As in every other aspect examined, balance is key. It is crucial that you strengthen both agonist and antagonist muscles in order to prevent injury and improve overall performance; these are muscles that act in opposite directions in order to complete an action. Agonist muscles act in response to voluntary or involuntary stimulus in order to complete a movement required to accomplish a task. Antagonists work in opposition to the agonist muscle in order to return the specific body part back to its resting position after the task has been completed (see Figure 7).

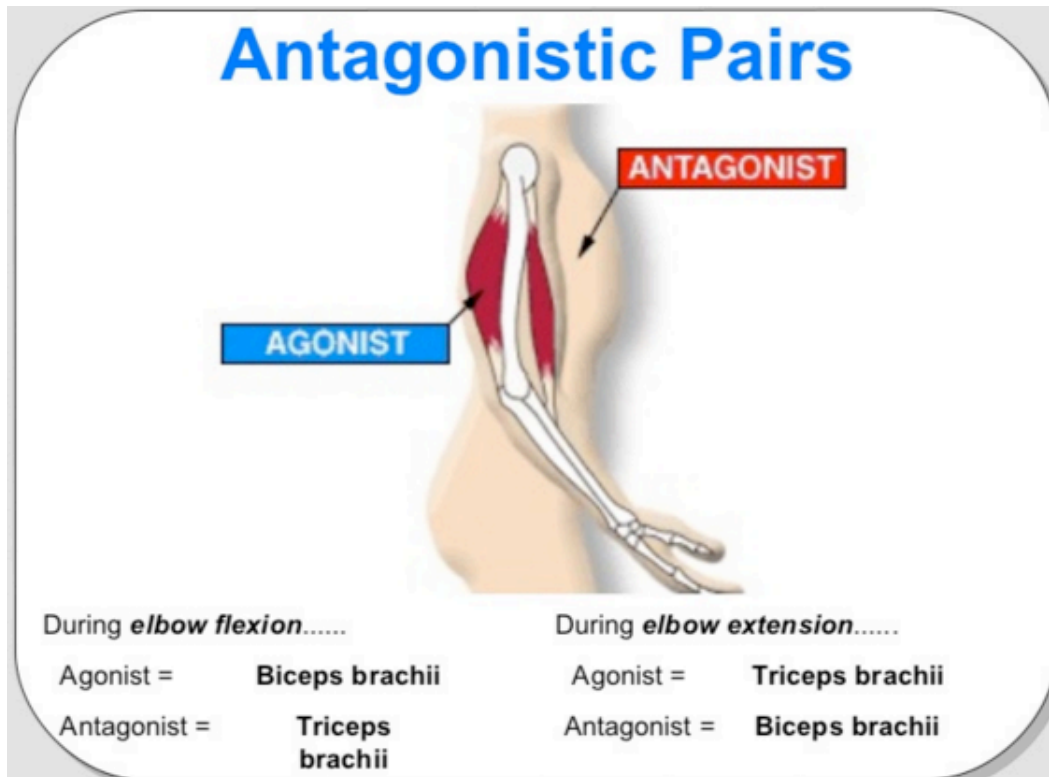


Figure 7: Antagonist muscle pairs in contraction and extension. This figure demonstrates the interchangeability of antagonist muscle pairs such as biceps brachii and triceps brachii. During contraction of the bicep (elbow flexion), the agonist is the biceps brachii and the antagonist is the triceps brachii. However when the opposite motion is occurring to return the limb to its original position, the roles are reversed and the agonist is thus the triceps brachii and biceps brachii becomes the antagonist. Adapted from <http://www.slideshare.net/hchapman28/muscles-and-movement-2>

While agonists and antagonists work as pairs to achieve full range of motion for action, muscles are not classified as specifically one or the other. A muscle can be an agonist in one instance and an antagonist in another depending on the motion being performed. This is because the agonist is always the contracting muscle that initiates movement while the antagonist simultaneously lengthens in order to permit the movement to occur. When returning the body part to its normal position, the antagonist muscle needs to initiate the movement, making it the agonist in this case, and the agonist

that initiated the movement before needs to lengthen to allow the new agonist to complete the movement, making it the new antagonist. Coupled with agonist and antagonists are other muscles known as synergist muscles and, more specifically, stabilizers/fixators and neutralizers. However the action that both of these muscles perform does not typically need additional attention like the attention we give agonists and antagonists in working out because they are controlled involuntarily and thus are utilized and strengthened with the use and strengthening of other, more specific muscles.

It is important to exercise and strengthen these muscles evenly because it significantly contributes to injury prevention. For example, eighty percent of running disorders are overuse injuries, which are the result of an imbalance in the endurance and strength between connective tissue (i.e. stabilizers/fixators) and supporting tissue (i.e. fixators).^{lix} However, the agonist-antagonist muscle pairs cannot be fully activated concurrently under conditions of voluntary co-contraction (simultaneous contraction of both agonist and antagonist), even with maximal effort. Additionally, the antagonist always has lower levels of muscular activity than the agonist when measured under maximal voluntary effort.^{lx} This suggests that muscles must be targeted separately and specifically as working a single agonist muscle does not produce an equivalent amount of work for the antagonist. Thus, for every agonist targeted, its equivalent antagonist must likewise be targeted equally in order to ensure a balance in muscle development and strength, ultimately preventing injury.

Expert Testimony

I again found my participants' responses to be particularly interesting regarding the most beneficial muscle groups or types. I was surprised when 3 of the 4 people interviewed mentioned the importance of focusing on small trigger and supporting muscles. I had expected answers to be more focused on the larger muscle groups, however for the sake of injury prevention and overall structural force and balance, these smaller muscles cannot be neglected or forgotten. Dr. Campisi discussed the significance of antagonist muscle pairs, again stressing the importance of balance and Pat said that if there is one and only one exercise for anyone to ever do it is the squat. Pat justified this by outlining the number of muscles it worked in a single move and discussed how spent he feels after performing squats. This to me was another contribution to the balance aspect of musculature in addition to the variety and importance of working a variety of muscles whilst exercising.

CHAPTER III: NUTRITION AND LONG TERM BENEFITS

While performing even a signal exercise and working out are biochemically beneficial, they are only a small part of one's overall biochemical and psychological health. It is important to take the time to consider the other aspects of health and fitness, such as the fuel that is required to work out and supplied by diet or the ultimate benefits that come after practicing and maintaining a healthy lifestyle (diet and exercise) for a long duration of time. We have all been told to eat healthy and workout regularly to maintain a healthy body weight, and while the majority of this thesis has examined biochemistry over the duration of a single workout and recovery period, it is also important to note how eating affects your workouts and how working out affects your biochemistry over time. These factors additionally will affect the ultimate biochemical workout, as so much of your biochemistry is determined by what you ingest and your pre-existing biochemistry as determined by your lifestyle choices.

In examining exercise and overall fitness from a biochemical perspective, it would be negligence to omit or disregard information regarding the necessary nutrition and long-term benefits of regular exercise. However, the information that is necessary to consider is extensive and could alone compose an entire other research thesis; thus generalizations in some areas and specificity in others has resulted. The ultimate purpose of this particular examination is to provide enough information to establish the guidelines for a healthy diet and to highlight the importance of exercise and overall fitness; not just for the immediate benefits outlined previously, but for the continuous and lasting benefits that working out regularly provides as well. From my personal experience, lack of

motivation is often due to an absence of education and ultimately is commonly a reason that fitness participants do not continue on with their training. In fact, loss of motivation to continue to workout is incredibly common in participants who are not seeing the immediate weight loss or muscle gain results that they desire. However, these are not direct indicators of results; we obtain biochemical results we may never directly see evidence of, but that doesn't mean we aren't experiencing them!

NUTRITION

One of the most crucial aspects of fitness and overall health that we often forget to address when we talk about working out is nutrition. The common expression “you are what you eat,” is not very far from the truth when it comes to what you ingest both before and after exercising, as food provides not only the energy required to fuel your workout, but also the necessary resources to recover your muscles.

But before we examine what types of nutrients are best to power your fitness habits, I am going to emphasize the importance of hydration. Water is one of the most vital and necessary elements to life, and it is unbelievable how much it affects exercise performance and overall fitness achievements. During exercise, one of the primary functions of water is to maintain thermoregulation (so as to prevent overheating), metabolism, blood pressure, heart rate, and overall hydration. “Hydration is important because the body is comprised mostly of water, and the proper balance between water and electrolytes in our bodies really determines how most of our systems function, including nerves and muscles,” says Larry Kenney, PhD, a professor of physiology and

kinesiology at Penn State^{lxi}. Performance is significantly improved when hydrated compared to when an individual is dehydrated.

Dehydration can result in increased risk of oxidative stress and oxidative cellular damage both pre- and post-exercise^{lxii}, which indicates the presence of an imbalance between the production of reactive oxygen species and the antioxidants produced by the body to counteract, detoxify, and repair the resulting damage. Reactive oxygen species are also known as free radicals and are oxygen atoms that have an unpaired valence electron. This makes them incredibly chemically reactive and they often cause damage to DNA, protein, and lipids of cells in addition to disrupting cellular signaling; overall they are incredibly toxic compounds. They are produced by a variety of internal biological and external environmental factors, and in the case of dehydration, and especially dehydration during exercise, free radicals are produced by normal metabolic processes but the lack of water prevents them from being deactivated, resulting in oxidative stress.

The body naturally and regularly produces antioxidants that counteract the effects of the free radicals by donating an electron. This neutralizes the free radical and prevents it from causing damage. However when working out in a state of dehydration, the body is unable to utilize antioxidants at the rate that it is producing free radicals and thus oxidative stress and cellular damage result. Kenney also points out that “Very slight changes in body water may create some performance issues in sports; as little as a 2% decrease in body water can lead to dehydration and performance detriments in sports. When your water levels decrease by higher levels like 3% or 4%, there are physiological changes that occur that may have health consequences, such as increased heart rate and

body temperature.^{lxiii} Thus, as such small percentage decreases of body water have such effects, we are often on the brink of encountering the problem of dehydration; and the effects of dehydration on exercise performance and overall health are detrimental! So should you take one thing away from this thesis, let it be to hydrate before, during, and after exercise, as the effects are immediate and can be severely damaging.

Okay, now that I've had my say about hydration, we will move onto nutrition. A healthy, well-balanced diet is the no-fail option, but while we've all heard that not many of us know what it means. According to the American Dietary Guidelines as determined by the Scientific Report of the 2015 Dietary Guidelines Advisory Committee and the USDA, the key recommendations of following a healthy diet are eating patterns that include a variety of vegetables from all of the subgroups (dark green, red and orange, legumes, starchy, and other), whole fruits, grains in which at least half are whole grains, fat-free or low-fat dairy (milk, yogurt, cheese, and/or fortified soy beverages), oils, and a variety of protein foods (seafood, lean meats and poultry, eggs, legumes, nuts, seeds, and soy products). Additionally, it recommends limiting saturated fats, trans fats, added sugars, and sodium. Ultimately, one should consume less than 10% of calories per day from added sugars, less than 10% of calories per day from saturated fats, less than 2,300 mg per day of sodium, and alcohol in severe moderation (up to one drink a day for women and two drinks a day for men).^{lxiv}

Based on a diet in which the subject consumes 2,000 calories a day as recommended by Healthy U.S.-Style Eating Pattern, an individual should consume 2½ cup equivalents of vegetables per day, 2 cup equivalents of fruit per day, 6oz equivalents

of grains (at least half of which are whole grains) per day, 3 cup equivalents of dairy per day (for adults; children 9 and younger have different recommendations), 5½oz equivalents of protein foods per day (26oz equivalents per week of which are meat, poultry, and eggs), 8oz equivalents of a variety of seafood per week, and 27 g of oils per day.^{lxv} For more information and further references on how to follow a healthy, well-balanced diet, visit <http://health.gov/dietaryguidelines/2015/guidelines>. Now that we have established how to fuel your body on a regular basis, we will examine how to fuel your body before, during, and after a workout.

Now let's say that you are trying to get energized before you workout: what are the best types of fuels to consume pre-workout? Some fitness articles tell you carbohydrates, others suggest protein, and there are some who say sugar is the way to go. To make things easy, let's begin with carbs. You have likely heard of the term "carbo-loading," which refers to athletes' habits of consuming high levels of carbohydrates in order to pack muscles with glycogen prior to a workout, ultimately helping to reach peak performances. An exercise routine practiced by athletes of varying levels for near 40 years now, carbo-loading has in fact been shown to have no statistical effect on participants' performances. Rather, it caused a noticeable weight gain in the participants as stored carbs pull water into muscle cells, resulting in additional pounds of water weight that could in fact affect the athletes' performance.^{lxvi} Rather, if you are exercising for 90 minutes or less, the additional carbs your body needs is minimal, as a healthy and well-balanced diet provides your body with sufficient carbohydrate amounts to fuel your regular workout.

Should your workout, regular or out-of-the-ordinary, extend beyond this 90-minute duration though, additional fuel will be necessary. Your regular diet should consist of about 5% higher carbohydrate consumption than the standard recommended daily allowance. Having higher stores of muscle glycogen ultimately improves performance and delays the onset of fatigue; current recommendations for intermittent or sustained exercise of a duration over 90 minutes suggest consumption of 10-12 grams of carbs per kilogram of body mass per day in the 36-48 hours prior to exercise.^{lxvii} Additionally, you should carry carbohydrates with you to fuel along the way, consuming 200-300 calories' worth of carbohydrates per hour of exercise.^{lxviii} And while gels and energy bars are often our go-to source of energy, we often disregard the power and nutritional content of natural foods. As stated earlier, a healthy and well-balanced diet often provides more than enough nutrients to power standard workouts. Real, simple, and natural is the way to go more often than not.

Now that we've considered carbohydrates as pre-workout fuel, we will examine protein as an alternative. It has been shown that protein consumption, both pre- and post-workout increases lean body mass, training session recovery, physical performance, strength, and muscle hypertrophy.^{lxix} This study claimed that after a protein is ingested, regardless of the type, anabolism is increased for 3-4 hours following consumption. Anabolism is the set of metabolic pathways in which molecules are built up from smaller components. In relation to metabolism, anabolism is a way for new molecules to be synthesized and for energy to be stored in the form of molecular bonds. It results in the creation of new cells and the repair and maintenance of tissues, ultimately allowing for a

workout following the consumption of protein to be more effective in terms of muscle growth, protein synthesis, and tissue homeostasis. So a protein shake, a handful of nuts and seeds, or a cup of yogurt are all ideal ways to protein-load before a workout, giving you the extra energy in the form of protein biomolecules and increased molecular bonds that will drive you through your workout.

Okay, so now that you've eaten your pre-workout snack and successfully completed your fitness goals for the day, what should you consume that will most benefit your recovering muscles? Believe it or not, with all the fancy recovery drinks and supplements that are being produced and advertised all around, a complete combination of all of the best recovery nutrients can actually be found low-fat chocolate milk! As previously stated, real, simple, and natural is the way to go more often than not. Low-fat chocolate milk provides the ideal ratio of carbohydrates and protein (four grams of carbs to one gram of protein) to aid in muscle gain, energy replenishment, fat loss, and increased endurance capacity in addition to reduced muscle damage and improved muscle recovery.^{lxx} Sixteen ounces of low-fat chocolate milk should be consumed in the 30-60 minutes prior to and/or following exercise.

In fact, chocolate milk is beneficial before, during, and following a workout. The reason this ratio is so effective prior to a workout is that a combination of carbs and proteins results in increased protein synthesis. Then, during exercise,

“Create[ing] a CHO:PRO ratio of 3 – 4:1 may increase endurance performance and maximally promotes glycogen re-synthesis during acute and subsequent bouts of endurance exercise. Ingesting CHO alone or in combination with PRO during resistance exercise increases muscle glycogen, offsets muscle damage, and facilitates greater training

adaptations after either acute or prolonged periods of supplementation with resistance training.^{lxxi}

This ratio is beneficial in aiding in fitness recovery as well because high levels of carbohydrate consumption stimulate muscles glycogen re-synthesis and the protein enhances this process. Additionally, the protein provides amino acids, which help synthesize proteins in muscles.^{lxxii} If that's not evidence enough to drink more chocolate milk then I don't know what is!

LONG TERM BENEFITS

Ultimately, all of this research comes down to a “so what?” So I exercise and eat healthy, so what? Why should I exercise any of these lifestyle practices, especially for an extended duration of time? Aside from the obviously generic and broad, to be healthy, I can provide you with a great number of reasons why one should exercise and eat healthy. And it is all thanks to the biochemistry of exercise and diet and the biochemical benefits that result from exercise that affect one both short- and long-term. For example, some long-term benefits of exercise are decreased risk of cancer and disease, longer lifespan and increased physical capability, and increased quality of life due to happiness and health.

To begin, we will examine endocrinology and what changes exercise can produce in one's endocrinology. Endocrinology is the study of the endocrine system, which produces hormones and the effects they have on various biological, cellular, and metabolic processes. The endocrine system most prominently features the pituitary gland, the thyroid gland, the pancreas, and the adrenal gland. When one engages in

exercise, the pituitary gland releases a growth hormone that promotes the increased production of bone, muscle, and tissue cells. Simultaneously, the thyroid gland secretes hormones to regulate heart rate, blood pressure, and core body temperature in addition to regulating the focus and vigilance required when exercising at high intensities. Your pancreas regulates insulin, which in turn regulates blood glucose levels; when you work out, your insulin sensitivity is increased. Low sensitivity to insulin results from high levels of blood glucose and thus insulin concentrations, which can result in obesity and type 2 diabetes. Working out increases your insulin sensitivity, which in turn reduces the amount of insulin secreted, ultimately decreasing blood glucose levels and risk of diabetes and heart disease. Finally, the adrenal gland secretes aldosterone, adrenaline, and cortisol. Aldosterone regulates heart rate, muscle contraction, and hydration levels in addition to converting stored carbs into energy. Adrenaline is a stimulant and increases strength and rate of heart contractions, and, similar to aldosterone, breaks down stored carbohydrate glycogen into glucose for immediate conversion into muscle energy. When exercising, aldosterone and adrenaline levels are increased, which is yet another reflection of pushing one's biochemistry out of homeostasis via exercise (so that it is ultimately trained to return to homeostasis faster).

Cortisol levels are also increased during exercise, however after exercising and over long durations of time, overall levels are decreased. Cortisol is the stress hormone of the body and is released when the body is in conditions of low blood-glucose or in response to environmental, biological, or emotional stressors (i.e. anxiety, fear, pain, starvation, infection, etc...). It is secreted in high levels when you experience varying

states of hunger (nutrition deficiency), high caffeine intake, sleep deprivation, and situations of high work or personal stress. Chronically high levels result in the suppression of the immune system, an increase in blood sugar via gluconeogenesis, and a decrease in bone formation, ultimately halting various processes for the ultimate purpose of supplying enough fuel to the body so that it may withstand the stress for a longer duration. Cortisol also causes a release of fatty acids in adipose tissue, which can serve as a fuel for other tissues so that the glycerol stores can be devoted solely to gluconeogenesis in the liver. Additionally, it stimulates the breakdown of muscle proteins for further fuel purposes.

The goal of cortisol is to restore blood glucose to normal levels in addition to increasing glycogen stores for future stress responses. While this hormone is beneficial in limited quantities at specific times (i.e. during exercise), during extended periods of stress, consistently high levels of cortisol result in a decreased ability to adapt and respond to stress, which in turn causes damage to bone, damage to muscle, and impairment of immune and endocrine function. High levels of cortisol have been linked with not only promoting obesity, but also increasing as obesity increases (due to the stress caused by chronic inflammation characteristic of obesity).^{lxxiii}

As an example of the effect of exercise on cortisol levels, yoga, an exercise traditionally practiced for meditative and religious purposes but now utilized as a physical and psychological workout, has been shown to improve antioxidant status, immune function, and decrease stress hormone release when practiced regularly.^{lxxiv}

Cortisol levels return to normal soon after a workout is completed, and small practices in inducing physical stress are actually beneficial as

“Biologically, exercise seems to give the body a chance to practice dealing with stress. It forces the body’s physiological systems—all of which are involved in the stress response—to communicate much more closely than usual: The cardiovascular system communicates with the renal system, which communicates with the muscular system. All of these are controlled by the central and sympathetic nervous systems, which also must communicate with each other. This workout of the body’s communication system may be the true value of exercise; the more sedentary we get, the less efficient our bodies are in responding to stress.”^{lxxv}

So although exercise may increase immediate biological stress, long term it causes an overall decrease in stress and thus cortisol levels because of the release of endorphins, which counteract the negative effects of cortisol, that exercise causes. This again is the push out of biochemical homeostasis to develop a quicker homeostatic recovery.

Psychologically speaking, the exercise-induced testosterone and endorphin release result in less tension and anxiety and increase motivation and overall happiness levels. Endorphins are endogenous opioid neuropeptides; protein-like molecules that neurons use to communicate with one another that produce a morphine-like response. The term “runner’s high” refers to the physiological and psychological high that results from the natural release of endorphins (your body’s natural feel-good drug), the secretion of which is induced by exercise. They ultimately produce a sense of well-being and provide pain relief in addition to contributing to cognitive functions such as reward, vigilance, and arousal as well as neuroendocrine, cognitive, limbic, and autonomic homeostasis.^{lxxvi}

When you exercise, your brain signals the pituitary gland to increase the secretion of

endorphins, resulting in decreased anxiety and depression and increased perceived euphoria. In fact, exercise and physical activity have been shown to have beneficial effects on depression symptoms equivalent to those of antidepressants.^{lxxvii} Thus, overall quality of life, both physically and psychologically, is significantly improved by the release of endorphins, which is stimulated by engagement in physical activity and exercise. In turn, as an example, this decrease in anxiety and depression in turn has been shown to result in a reduction in oxidative stress and cellular aging in obese men.^{lxxviii}

Obesity is an interesting and commonly discussed topic when it comes to health and fitness, especially regarding Americans today. More specifically, body mass index, or BMI, is a familiar term we all have heard. BMI refers to one's body fat ratio determined by the individual's ratio of weight to the square of his/her height. Individuals that fall within certain ratios are then classified as underweight (BMI<18.5), normal weight (BMI=18.5-24.9), overweight (BMI=25-29.9), or obese (BMI>30).

Classification	BMI(kg/m ²)	
	Principal cut-off points	Additional cut-off points
Underweight	<18.50	<18.50
Severe thinness	<16.00	<16.00
Moderate thinness	16.00 - 16.99	16.00 - 16.99
Mild thinness	17.00 - 18.49	17.00 - 18.49
Normal range	18.50 - 24.99	18.50 - 22.99
		23.00 - 24.99
Overweight	≥25.00	≥25.00
Pre-obese	25.00 - 29.99	25.00 - 27.49
		27.50 - 29.99
Obese	≥30.00	≥30.00
Obese class I	30.00 - 34.99	30.00 - 32.49
		32.50 - 34.99
Obese class II	35.00 - 39.99	35.00 - 37.49
		37.50 - 39.99
Obese class III	≥40.00	≥40.00

Figure 8: International Classification of Individuals According to Body Mass Index. This table represents the standard Body Mass Index according to the World Health Organization in which underweight, overweight, and obese individuals qualify for subcategories. These values are age, sex, and ethnically independent. BMI is calculated by dividing an individual's weight in kilograms by the square of his/her height in meters. Adapted from "[BMI Classification](#)". *Global Database on Body Mass Index*. World Health Organization. 2006.

While this scale is widely used, it is often regarded as inaccurate due to the lack of differentiation between muscle mass and fat mass, its disregard of variation in physical characteristics, and its variation from actual health patterns. However it is currently the most general and universally applicable system that is currently utilized, so for our purposes we will examine fitness in relation to BMI.

According to the National Heart, Lung, and Blood Institute (NHLBI), an individual who is overweight or obese is at a higher risk of developing heart disease, high blood pressure, type 2 diabetes, gallstones, breathing problems, and various cancers (colon, breast, prostate, and endometrium). Obesity occurs when more energy is ingested (in the form of calories) than is expended by the body's energy-consuming activities. When energy intake is higher than energy expenditure, the excess energy is stored as fat in adipose tissue. In order to maintain a steady weight, energy must be balanced in that as much energy is expended as is consumed. Energy is expended in the form of activities, such as working out, which is the most effective fuel-burning process for the body, followed by thermogenesis (heat production by uncoupled mitochondria).

However, as previously mentioned, many individuals find it difficult to stay motivated to work out regularly. It is crucial to exercise on a regular (almost daily) basis to maintain a healthy BMI, as it is the most efficient way to burn energy consumed. The Mayo Clinic suggests staying motivated by setting goals, making your workout routine fun, making your routine a daily habit, keeping track of your goals and progress, finding friends and family to help motivate you by joining you, rewarding yourself, and being flexible with your workout and schedule. It helps to set fitness goals for yourself, whether they are to run a marathon or make it to your 5000 steps for the day or lift 5 extra pounds on your next dead lift. Accomplishing these goals, no matter how small, is significant and empowering. It motivates you as the success you achieve pushes you to achieve again and again, ultimately pushing you further and further in your workout regimen. And then keep track of your progress and achievements. It is unbelievably

motivational to be able to look back at how far you've come and how much closer to your goal you are than when you started.

Making your workout fun is also crucial as it is hard to continue to do something that is tedious and un-enjoyable. Put together an awesome playlist filled with songs that get you pumped and pick a workout that not only leaves you feeling great, but that consists of exercises and patterns that you enjoy. It helps to have people to workout with too, not only so you motivate one another, but so that you also can enjoy your workouts together. Humans are social creatures and we perform much better in group settings than we do when working out alone. It's also okay to cut yourself a break every now and again; work gets busy, maintaining relationships takes time, school is a challenge. If you need to take a breather for a couple of days, that is fine! What is important is that you can come back to your fitness and continue down your path to success.

One important aspect of staying motivated that we often disregard is reward. While it is nice to treat yourself after you've accomplished a fitness goal (i.e. buying new tennis shoes for yourself after you complete your half marathon), I personally feel that the greatest reward of regular exercise is the sense of accomplishment that comes with completing a tough workout and the subsequent endorphin release. In the end, your workout isn't about losing weight or looking fit; it's about feeling strong and confident in your achievements. At the beginning of every workout class I teach, I remind my participants that they aren't there simply to burn calories or get rid of their "muffin top." They are there to feel good and to improve their overall wellness, physicality, mentality, and spirituality. One of the reasons I have developed such a love for yoga is because of

the purpose of the practice in addition to the constant reminders that you are there for *you* and *you alone*. You are not there to look skinnier; let's be real, that motivation is for others, not for us. Your workout is your own, it is yours and you get out of it what you put into it. I have been on the side in which body appearance was the most important objective and success would only come from being toned and skinny. I can tell you that not only is that not satisfying, but it is also an unattainable goal. We all have different physical attributes and while our biochemistry may be similar, we will never all look alike and we will most definitely not attain the "perfect body." True health and fitness comes from being healthy in your mindset and motivations to exercise, and thus the greatest reward that you can receive for your hard work and dedication to an active lifestyle is the strength in body, mind, and character that you will achieve.

Expert Testimony

When asked about the long-term benefits of exercise, each of the interviewees quickly responded that stress release, social relationships, and the overall increase in happiness were among the greatest benefits to result from regular exercise. Dr. Campisi pointed out that not only do we see positive results in a wide array of aspects our health (i.e. lower cholesterol, lowered risk of Type II Diabetes and strokes, etc..), but we also see a decrease in cortisol levels, proinflammatory cytokines, and neurodegeneration, all resulting in increased joy and improved overall quality of life. Pat said that he saw dramatic increases in every aspect of his life regarding motivation, academics, personal relationships, and life-long goals and aspirations. Doug lost weight and has easily kept it

off in addition to gaining stamina, which in turn has improved his workouts and training. While each participant saw a number of other physical changes, I believe the psychological changes to be the most beneficial because of the increase in well-being that so dramatically affects every aspect of our life and thus the lives of those around us.

CHAPTER IV: THE ULTIMATE BIOCHEMICAL WORKOUT

Over the course of this thesis, we have examined workout intensity, duration, type, muscle focus, nutrition, long-term benefits, and overall wellness of being. The research analyzed has produced a variety of results regarding the biochemistry of exercise, but the most important thing to note is that, from both biochemical and overall health perspectives, variety is key when it comes to working out. Variety in your workout routine, variety in your intensity, variety in your schedule, variety in your duration; all are crucial to developing and continually contributing to a balanced fitness lifestyle and goals. As we've seen, different variations of workouts promote different biochemical processes in different ways that are all beneficial to overall biochemical efficiency and productivity. Adding variety to your workout further helps to develop strength, both physically and mentally, as a new challenge for your body is likewise a new challenge for your mind. So much of a workout is your ability to overcome mental blocks and push your body beyond what your mind tells you.

Thus, the following workout and modifications are recommended on a strictly biochemical basis constructed on the research outlined above. While this investigation has resulted in what could be viewed as the ultimate biochemical workout, it is not necessarily the most beneficial for participants trying to attain other fitness goals such as endurance or strength. Rather, this workout is supposed to provide strictly the most biochemical benefit for the energy and time expended. While this workout is recommended for biochemical purposes, it is important to maintain one's health via a

healthy diet and regular exercise of various types, durations, and intensities with focus on all muscles.

THE WORKOUT

When examining intensity of a workout from a biochemical perspective, we observed that high intensity workouts resulted in improved endurance and fat burn, and simultaneously increased VO_2 max, aerobic fitness, sympathetic drive, and muscle buffering capacity. When compared to moderate or low intensity training, it is significantly more biochemically relevant and beneficial in various pathways and overall results. Following this we examined the biochemically ideal duration of a workout is any sort of workout or interval lasting longer than 90 seconds as it allows the body to achieve aerobic metabolism, where we see the most efficient ATP production as well as the least accumulation of damaging byproducts. While phosphocreatine is exponentially more efficient than aerobic metabolism, it occurs in such a short period of time that not enough other biochemical benefits are achieved and thus our goal is to achieve aerobic energy metabolism.

In the investigation of the most biochemically beneficial type of workout to engage in, research clearly indicated that high intensity interval training provides a myriad of advantages over resistance or endurance training. We saw increased muscle glycogen content, increased enzymatic activity, increased muscle oxidative potential and thus increased endurance, increased rates of aerobic metabolism, and increased EPOC all accompanied by a decrease in glycogenesis and lactate concentrations. When we

considered muscle groups and types of muscle, we found that Type II muscle fibers (fast-twitch) were biochemically more advantageous to focus on because of their heat production, higher VO₂ max, and increased power output. While Type I fibers provide delayed fatigue and are more resistant, from a purely biochemical standpoint in considering the ultimate workout, Type II muscle fibers are more beneficial to target in a workout than Type I.

So we can conclude that the ultimate biochemical workout will consist of high intensity interval training in which exercise intervals last 90 seconds (with rest periods half the length of the exercise interval) with a focus on fast-twitch muscle fibers and thus explosive movements with resistance. There are a variety of ways this workout could look but I am going to provide you with a sample workout followed by an alternative workout for participants unable to complete the first workout. The second proposed workout can be used as a stepping stone to ultimately complete develop the fitness sufficient to complete this ultimate biochemical workout.

Modifications are important for all participants so that an individual doesn't hit a fitness plateau; they are thus allowed to continue to grow biochemically and physically in their training and capabilities. So this workout could be as simple as 90 seconds of sprinting followed by a 45 second recovery in which you are walking or jogging for a total of 12 sprints (27 minute workout) or it could be as varied as doing a separate exercise on every interval. For example:

90 seconds of judo roll with jump with a 45 second rest

90 seconds of kettlebell squats/one-handed swings with a 45 second rest

90 seconds of kettlebell jackknife sit-ups with a 45 second rest

90 seconds of burpees with a 45 second rest

90 seconds of single leg deadlift into jump with a 45 second rest

90 seconds of plank jacks with a 45 second rest

90 seconds of pistol squat roll with jump with a 45 second rest

90 seconds of kettlebell figure eights/around the world with a 45 second rest

90 seconds of kettlebell scissor/jumping lunges with a 45 second rest

90 seconds of plyo pushups with a 45 second rest

The reasoning for selecting the above exercises was their explosive nature in combination with resistance provided in the form of kettlebells. Kettlebells provide an excellent resistance technique as they not only are a single piece of equipment that varies in weight, but they are also incredibly effective in developing balance as they alter one's center of mass and thus muscles must effectively compensate. The result of this is efficient and successful work of antagonist muscle groups.

These exercises should be performed at maximum intensity in order to obtain the most biochemical benefit as the research examined earlier in this thesis concluded that maximum intensity is most biochemically favorable. Now, as a fitness instructor, I can tell you from personal experience that 90 seconds of any of the above exercises is an extremely long duration of an interval, and sustaining these exercises for such a long period of time is extraordinarily challenging. Even a participant who is athletically advanced in their training might have a difficult time completing the workout outlined above. Thus, in order to build up strength and endurance, it would be ideal to start at a

lower level of training until one is able to complete the above workout. To begin, it might be safer and more achievable to use kettlebells of lower weights or omit weights all together. For example:

40 seconds of kettlebell squat jumps with 20 seconds of rest

40 seconds of mountain climbers with 20 seconds of rest

40 seconds of kettlebell side lunges with 20 seconds of rest

40 seconds of pushups with 20 seconds of rest

40 seconds of bicycle crunches with 20 seconds of rest

40 seconds of kettlebell Russian twists with 20 seconds of rest

40 seconds of squat thrusters with 20 seconds of rest

40 seconds of box jumps with 20 seconds of rest

40 seconds of reverse lunge with knee-up with 20 seconds of rest

40 seconds of burpees with 20 seconds of rest

Repeat the above sequence of 10 exercises at maximum intensity 3 times for complete workout.

For the ultimate goal of biochemical advances and improvements, this workout (or one similar) should be performed 2-3 times a week for at least 20 minutes at a time with a variety of other workouts intermittently practiced (such as resistance, cardio, etc...). As mentioned numerous times previously, balance and variety are key in maintaining overall health and fitness; purely working out your biochemical pathways in this way may be beneficial, however you cannot ignore other aspects of your fitness to solely focus on biochemistry. As the research examined over the course of this thesis has

shown, all varieties of exercise provide biochemical benefits, however the workout outlined above will provide the maximal biochemical benefit compared to other types, durations, muscle types, and intensities. This workout is designed to push you out of homeostasis as far as possible and then allow scarcely sufficient time for homeostatic recovery before pushing you out of homeostasis again. Thus you are repetitively training your biochemistry to return to homeostasis faster. Again, this is not to say that other workouts will not develop quicker homeostatic recovery; rather other workouts will develop this differently and, I speculate, more slowly.

Expert Testimony

Interestingly, the four people that I interviewed for this thesis all provided an answer that, resembled HIIT. Malia said that, personally, she thinks the ideal biochemical workout would be a 75 minute run with tempo intervals (three 10 minute intervals with 2-3 minutes of recovery between) at a pace close to her 10K or half marathon pace (a little on the faster, higher intensity side). Dr. Campisi replied that one would ideally want a cardiovascular challenge that provides muscular strength for a long enough duration at an intensity that one can sustain. Doug felt that an hour run with lower resistance and focus on core, biceps, triceps, etc... was the way to go. And finally, as a weight lifter Pat follows the motto of Brian Urlacher, “You always have one more rep in you.” Pat believes in pushing a muscle past its comfort zone to fatigue is key, and he has applied this mentality to all aspects of his life. He said “pushing past where it’s comfortable to stop intrigues me in my workout and my life.”

All of these workouts that these contributors outlined contain elements of what I have determined to be the ultimate biochemical workout. Malia's was a perfect example of high-intensity interval training and her duration of overall workout as well as exercise intervals was ideal, although her exercise to rest ratio varies from the workouts outlined above. Dr. Campisi's workout addressed all of the key components of a good biochemical workout; similar to the workout I determined which would likely require challenging and pushing oneself to the edge of one's capability. Doug's workout was a little more uniform than the biochemical workout, however he certainly had the right idea in working different muscles and targeting antagonist pairs. And finally, Pat's workout certainly touched upon the idea of working out at a high intensity for a long duration (or is as long as is sufficient to exhaust muscles).

One thing that also really stood out to me in the testimonies of these individuals was that they all mentioned something about their motivations and what it is that keeps them going in response to this particular question. Malia uses her warm-up as an opportunity to talk herself up and give herself positive motivation that will help her through the workout. Doug and Pat both rely on their social relationships to push them through, Doug on his wife and Pat on his brother and friends. This to me was an incredible and beautiful way to conclude these interviews and this overall workout as motivation is a key component of regular exercise and sustaining one's fitness habits. Social motivators, personal goals, and variety are all fundamental components of commencing and maintaining healthy exercise habits. So to get started, set a goal for yourself, find a friend to workout with, play up your routine and try something new;

anything and everything you can do to motivate yourself and those around you to not only workout, but to workout regularly and push yourself to be better in your overall fitness.

CONCLUSION: FINDING BIOCHEMICAL, LIFESTYLE, AND SOCIAL HOMEOSTASIS

The ultimate goal that your body strives to achieve in every moment is biochemical homeostasis. While it may fluctuate in speed and immediate purpose, the overall objective of your metabolic pathways is to achieve equilibrium, a biochemical harmony if you will. Achieving this balance on a regular basis, by way of exercise for example, is incredibly beneficial not only biologically, but also socially and psychologically. I personally have found the biochemical homeostasis that I achieve through exercise to positively impact every aspect of my life as I am less stressed, more motivated and focused, more social, healthier, and overall more joyful!

As I narrated in the introduction of this thesis, exercise not only provided me more quality time with my family, but it also strengthened my relationships with each family member and is a huge point of bonding for all of us together. It also has provided me with innumerable opportunities to expand and cultivate my social relationships. I have made many friends and my love for people has grown indescribably through my interactions and experiences I have shared with others in workouts. This in turn has strengthened my community of friends and family and thus I believe we, my family and community, have been able to positively affect the lives of many individuals who had not previously experienced such relationships. Exercise has changed my life and I know it has changed the lives of so many others, and thus it has changed my social interactions more than even I can understand. This in turn has changed how I view the world and my

responsibility in the world and, in turn, the role of my education in helping me to fulfill that responsibility.

Over the course of my four years at Regis University, the key Jesuit values of *cura personalis*, *Magis*, men and women for and with others, unity of mind and heart, contemplatives in action, and finding God in all things have been instilled in me as they have resided at the very heart of my education. *Cura personalis* refers to having concern and care for the personal development of the whole person and implies a dedication to promoting human dignity and care for the mind, body, and spirit of the person.^{lxxix} It is an attention on the needs of yourself, a distinct respect for your unique circumstances and concerns, and an appreciation of your gifts and insights.^{lxxx} In this sense, the ultimate biochemical workout is an excellent place to start in taking care of yourself as achieving a healthy lifestyle and biochemical homeostasis can result in not just physical health, but mental health and well-being as well. As stated earlier, exercise dramatically decreases innumerable negative effects of a sedentary lifestyle and eating healthy makes a drastic difference in so many aspects of one's life. Additionally, an inactive individual who consumes highly processed food with high fat, sugar, and carbohydrate content is more likely to develop psychological issues. This only further illustrates the importance of caring for every aspect of yourself and recognizing that you have something to contribute. How can you contribute if you can't acknowledge and foster what gifts you have to contribute?

The purpose of this thesis was not only to educate my readers on the ultimate biochemical workout and the importance of healthy lifestyle choices, but also to

emphasize an acceptance and appreciation for you as you are. While our biochemistry might be similar, our hearts are all very different as we come from different walks of life. It is important to recognize and value this so that we may better contribute to the world in the ways that only we can; we all have something unique to offer and *cura personalis* implies an acknowledgement of that, a nurturing and growth of what it is you have to offer, and a sharing of that offering with the world.

The value of *Magis*, another key value I have been taught time and again at Regis University, implies an embodiment of the act of discerning the best choice in a given situation to better glorify or serve God; it essentially is a call to glorify God in all situations and circumstances, regardless of your religion or beliefs. God does not have to be who you worship in church or temple; God can be the goodness in the hearts of every human or the generosity or kindness. God can be love for anyone and everyone, and I have found that I embody love and thus God the most when I am sharing my passion for health with those who are in need of it most. I glorify Him in every circumstance by loving others and showing them how a healthy lifestyle with regular exercise and good food can bring you joy that in turn enhances your ability to love others and thus serve God.

Additionally, this thesis has provided me an opportunity to characterize the Jesuit value of men and women in service of others in that I am able to not only share my passion through these words, but I am able to share knowledge that could potentially contribute to lifestyle changes and motivation for some individuals. I hope that the information provided over the course of this project has contributed to the lives and

overall understanding of my readers regarding their health. Working out and living a healthy lifestyle is key to leading a happy and fulfilling life, and I want to make this very clear. This is how I want others to be served through this thesis; to inspire your motivation and routines to change in order to obtain a biochemical homeostasis that will significantly increase the quality of their lives. I want to serve others by sharing my knowledge and my passion and by encouraging and inspiring change and dedication that will change the lives of my readers.

In addition, in considering your own physical fitness you too are better able to serve others. I am a firm believer that you cannot help others if you cannot help yourself, as your ability to love others is hindered if your love for yourself is negligible. We have all been given a beautiful gift in that ability of our bodies and minds, and we must appreciate and care for them so that we can help others to do the same. You too must practice what you preach.

The importance of this biochemical homeostasis cannot be stressed enough, and I believe that this homeostasis can be achieved through a healthy lifestyle and that even further than that, this biochemical homeostasis will result in a balance of the physical and the psychological that is key to achieving joy. This unity of heart and mind is a Jesuit value that ensures care of every aspect of yourself and recognizing that your physical fitness and mental health are not separate aspects of your being, but rather they play into one another in every part of your life. It is incredible how much your mentality is improved, your stress is decreased, and your happiness is amplified with regular exercise, especially exercise that is so biochemically beneficial! In fact, endorphins improve

ratings of joy, euphoria, cooperation, and conscientiousness following long workouts,^{lxxxii} the effects of which do not promptly wear off and positively affect numerous aspects of your life. Living a sedentary lifestyle results in many negative psychological outcomes, as stated earlier, and thus the importance of considering both aspects of yourself when considering health is crucial. Taking care of your physical fitness in itself contributes to your mental fitness, and taking care of yourself psychologically results in a desire to ensure a bodily healthy lifestyle; your body and your mind are unified and dramatically play into one another.

Our current society faces an epidemic of health issues all connected to our diets and inactive lifestyles. The Jesuit value of contemplatives in action makes us consider how we can not only address social issues but also take action in solving those issues. This thesis represents a comprehensive analysis of the social problem of health, but that is only a small fraction of the action that must be taken to solve this issue. I personally, in my fitness instruction as well as personal practice, want to improve our society's physical and psychological health by inspiring and motivating those who don't lead healthy lifestyles; be it by sharing what I have learned in my experience, by being a better instructor and friend to my participants, or in my professional research from my career and future in biochemistry. While I want to always actively think about and reflect on my education and continue to expand my knowledge of the biochemistry of fitness, I also desire to share what I know on a level that will educate others and encourage them to take part in a fitness movement toward an ultimate social change of our lifestyles.

This value of contemplatives in action is not just applicable to my experience though. When an individual engages in a healthy lifestyle and achieves the biochemical homeostasis that accompanies working out and eating well, they exemplify a motivation that can only be found in the dedication that it takes to live right. This motivation is reflected in so many aspects of one's life that it in turn makes them more likely to not only think about and address social problems, but to act in response to these issues. I am a perfect example in this as the motivation I found in working out regularly translated to so many other aspects of my life and thus encouraged me further to act against social issues I am surrounded by. My motivations to become a fitness instructor and to teach my participants about wellness in a way that will improve their health and overall well being has all stemmed from the inspiration and motivation that originally sparked and continue to fuel my lifestyle choices regarding my health.

Finally, the Jesuit value that calls us to find God in all things has been a very key component of my education, biochemically in addition to fitness-related, in that my faith has been strengthened through my biochemical education. This value invites us to “search for and find God in every aspect and circumstance of life [as] God is present everywhere and can be found in all creation,”^{lxxxii} and my education in biochemistry has helped me to see Him in all things in a way I can't begin to explain. I always hear about the dichotomy between science and religion and how so many struggle to find a balance between the two; however for me it has never been about finding a balance because I have discovered that science is religion and religion is science. They are not explicit of one another, but rather completely co-dependent. One specific example of this is in the

biochemical pathways that occur in every cell of our body so quickly and frequently and are so dependent on every step of every pathway going exactly as is required. There is no room for error, and yet we are living, functioning creatures because of the rate of success that these pathways occur. It is a miracle, a statistical improbability, an act of God that more things do not go wrong in these long and complex processes on a more regular basis. Realizing this and developing an appreciation for the effectiveness and efficiency and overall biochemical beauty that allows us to exist has strengthened my faith in a higher power, in God, more than any other experience I've ever had.

It is my firm belief that if we all exercise regularly and follow a healthy eating pattern, then we will achieve biochemical homeostasis, and, in doing so, we will be so physiologically and psychologically well, all the while fulfilling the key Jesuit values. We will then seek the good in all things, all people, and all experiences. And the good can be God or Allah or Yahweh or just humanity's inherent goodness or generosity or whatever you believe to have resulted in and contributed to the creation and progression of humanity. The beautiful thing is that good is present in all things and we can find it around us, but only if we seek it; we tend to find exactly what we look for in others. And if we can find the good in others and in our experiences, then we as people will be even happier, more generous, more appreciative, and more cohesive.

A Chinese proverb reads "Where there is light in the soul there will be beauty in the person, where there is beauty in the person there will be harmony in the house, where there is harmony in the house there will order in the nation, and if there is order in the nation there will be peace in the world." What if the "light in the soul" to which this

proverb refers is a biochemical homeostasis? I know it's an idealistic view, but if we all were to exercise on a regular basis, then we would all find our biochemical homeostasis and inner light. If there is light in our souls, then we will radiate beauty. If we radiate beauty, we will find harmony in all of our closest relationships. If there is harmony in all of our houses, then there will be order in our community and across our nation. If each nation has order and harmony and beauty and light, then there can only be accord between all people and thus peace in the world. So it all starts with us and our inner light; us and our biochemical homeostasis, which can be achieved through exercise and fitness.

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