# The Benefits of Exercise Warm-Up on Grip Strength and Fatigue Time

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**Lab 601**

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## Abstract

Strength and endurance are two key factors in any athlete's ability to perform. This experiment was designed to measure the correlation between an exercise warm up and grip strength and fatigue time. Two groups, a control and an experimental, were tested. The control group subjects participated in two separate sessions over the course of a few weeks, neither of which included an exercise warm up. The experimental group subjects participated in two separate sessions over the course of a few weeks, the first of which was recorded as a baseline measurement and the second occurred after a warm up exercise. The purpose of the research group's experiments is to determine whether there is a positive correlation between an exercise warm up and an individual's strength and endurance.

## Introduction

Physical fatigue is a lowered actual muscular contractile response compared to the anticipated response of a given stimulus (Fitts, 1994). The causes of fatigue are numerous; although many theories have not yet been proposed, it is suspected that any point in the pathway--from spinal cord to muscle cell--can lead to fatigue. It is suspected that one reason for fatigue is a reduction of neural drive to working muscle caused by a "spillover" of serotonin. During a high level of exercise, serotonin production increases, causing it to bind 5-$HT_{1A}$ receptors on the initial segment of motor neurons, and thus, inhibiting nerve impulse initiation (Cotel et al., 2013). Similarly, another cause of fatigue is the inability of a nerve to maintain a high-frequency signal during maximum muscular exertion; this fatigue does not cause soreness. It can be overcome with repetitive training until the nerve generates maximum contractions (Robergs, 2004).

The most common mechanisms thought to explain fatigue deal with the muscle fiber; specifically, it is thought that the depletion of substrates or the accumulation of metabolic products involved in muscle contraction are the main reasons for fatigue. Deficiency in ATP, creatine phosphate and glycogen reduces available energy, hindering contraction. Also, when exercise intensity increases, more ATP is used up, releasing more protons. The increasing need for ATP results in the need for regeneration by non-mitochondrial sources, further increasing proton release, causing acidosis (Robergs, 2004).

Muscular fatigue can greatly affect an athlete's performance; physical and technical abilities become impaired since technique and motor skill execution is reduced. Decreased throwing velocities, kicking power, mental concentration, and throwing and shooting accuracies have been associated with physical fatigue (Knicker et al., 2011). Understanding some mechanisms in which fatigue can be reduced or avoided would greatly benefit not only professional athletes, but also anyone performing physical activity.

Extensive research has been conducted on the effects of warming up before exercise as it pertains to increasing the physical performance of athletes. In a study that assessed the effects of warming up on injury prevention, it was found that soccer players increased their strength and were more likely to prevent injury if they warmed up beforehand. The pre-exercise warm-up included strength, muscle control, balance, and running exercises (Daneshjoo, 2012). Similarly, an experiment to assess the effects of a dynamic warm-up on power and agility performance found that strength and endurance of the subjects who incorporated the dynamic warm-up improved in comparison to those that did not (McMillian et. al, 2006). The warm-ups incorporated in these experiments produced an increased breathing rate and heart rate, and these physiological changes result in or accompany improved physical performance. An increase in breathing rate during exercise leads to more oxygen intake by the body, providing more oxygen for muscles to work (Tatsuya, 2004). An increased heart rate, which is characterized as more heart contractions per minute, increases the amount of blood that can get to the muscles, which improves their productivity ("Blood Pressure vs. Heart Rate," 2012). This also has to do with the amount of oxygen that gets to the muscles from the lungs. Both breathing rate and heart rate are related, and both increase during exercise. The increases in these variables are the presumed causes of increases in strength and endurance, which is the relationship that is going to be tested in this experiment.

The object of this experiment is to determine how manipulating two variables, heart rate and breathing rate, will affect both the fatigue time and the maximum grip strength of the subjects. However, the results of this experiment are not intended solely for the analysis of hand strength and fatigue time—the research group intends to relate the findings to overall physical muscular performance. With a successful experiment, the research group will be able to then propose a new hypothesis; that an increase in heart rate and breathing rate will result in an increase in overall physical muscular performance. Failure to reject the hypotheses will give the implication that by warming up and elevating an individual's heart rate and breathing rate, they are preparing to improve their strength and endurance. Aside from measuring grip strength and fatigue time, the research group will also observe heart rate and respiratory rate. Manipulation of these variables will be accomplished through a warm-up exercise of biking for 3 minutes.

This study will be based on two hypotheses. The first hypothesis is that an exercise warm-up, defined by an increase in heart rate and respiratory rate, will induce a significant improvement in grip fatigue time. The second hypothesis is that an exercise warm-up, defined by an increase in heart rate and respiratory rate, will induce a significant improvement in grip strength.

**Methods**

In order to measure changes in muscle fatigue and contractile strength induced after a pre-workout warm-up, the research group first recorded basic information and data from each participating test subject. Participating subjects were taken from the pool of students enrolled in the University of Wisconsin-Madison Physiology 435 course and included the research group members as well. Prior to the collection of data on the participants, a consent form concerning the details of the study was given to participants to read and sign.

The participant data collection included basic information about each subject such as their name, sex, age, weight, height, and hours of physical activity per week, hours of sleep, breakfast consumption the morning of the study, left or right handedness, illnesses, workout status, alcohol and caffeine consumption, wrist injuries, and whether or not the participant has previously used an Electromyography (EMG) device. The purpose of this specific data collection was to provide behavioral or physiological basis for removal of statistically determined outliers.

Once this information was collected, the participant was asked to wear a BSL Respiratory Effort and a Pulse Oximeter in order to record their resting breathing rate and resting heart rate, respectively. The resting breathing rate of the participant was recorded while the participant was completing their consent form and questionnaire. To ensure that the participant was not aware of when their breathing was being monitored, they were not told that their breathing was being recorded. The experimenters also did not speak with the participant at this time, so that the breathing rate would not be altered by the action of talking. Breathing rate data was assessed by taking the average of the breaths per minute measured for every inhale/exhale cycle in a 20-second time interval. The periods of inhalation and exhalation were represented, respectively, by a rise and fall of the graph. To calculate the average breaths per minute, the research group recorded the values designated by the distance between troughs and used them to calculate the average breathing rate.

The Pulse Oximeter reading, which measured number of heart beats per minute, was also taken and recorded prior to the use of the EMG device. Next, the participant calibrated the EMG device with a two-second squeeze, which was immediately followed by the invitation to squeeze the EMG recording device with all of their strength for as long as they could. The Fatigue Time was recorded when the participant's Grip Strength dropped to half of their Maximum Grip Strength value, at which point the participant was told to stop squeezing and relax. Maximum Grip Strength was recorded in kilograms and Fatigue Time was measured in seconds.

Participants from the first trial were split by sex, and each sex was then assigned to one of two groups by randomly dividing their consent forms into a control and experimental population. This was accomplished by shuffling the consent forms and drawing them out of a hat. Of the thirteen total males, six were in the control group and seven were in the experimental group. Similarly, of the fifteen total females, eight were in the control group and seven were in the experimental group. The participants were each called back to perform another test after their category was assigned. The participants were not informed of the reason for the second test, in an attempt to reduce bias. Participants were tested for the second time one to three weeks following their initial test. Again, each participant was asked to fill out the basic information survey. The control group repeated the initial experiment described above, in exactly the same manner. The experimental group performed a different experiment.

The experimental group's participants' heart rate and breathing rate were first measured at rest while filling out the same questionnaire sheet as the first week. Then, the participants were placed on a stationary bike, which constituted the pre-workout warm-up. They were instructed to pedal on the bike for three minutes. The participants' heart rates and breathing rates were measured after they dismounted the bike and were sitting down. Again, care was taken by the experimenters not to influence the breathing rate of the participants when the recording of the breathing rate was being taken (the BSL Respiratory Effort was not removed throughout the experiment).

After the breathing rate was taken, the participants were asked to repeat the Grip Strength test. During the Grip Strength test, Grip Strength and Fatigue Time were recorded in the manner previously described. The time elapsed between the end of the warm-up and the Grip Strength test was minimized; it lasted no more than 2 minutes. This reduced time-lapse and ensured that any observed effects on Grip Strength performance was due to the pre-workout warm-up.

Statistical analysis was performed using Microsoft Excel. Statistical analysis compared the two populations, control and experimental, in terms of the change in individual fatigue time and the change in individual grip force. The percent change in individual fatigue time was calculated by comparing the value recorded during the second series of measurements from the measurement recorded at the first session. The same method, with the appropriate data set, was used to determine the percent change in individual grip strength. Each data set was subjected to a quantile-quantile plot in order to determine if the data was normally distributed. When both the control and experimental data sets of the same variable were found to be normally distributed, a t-test was performed. The type of t-test and the number of tails were determined by the standard deviations and the corresponding hypothesis, respectively. A p-value less than 0.05 was considered significant.

Further statistical analysis was performed to test for any relationships not predicted and left out of the hypothesis. Linear regression was performed in order to observe relationships between respiratory rate, heart rate, grip strength, and fatigue time. Data points three standard deviations from the mean were considered outliers and omitted from all further statistical analysis.

**Materials**

- Handynamo SS25LA (Biopac Systems, Inc., Aero Camino Goleta, CA)
- Electromyography II (Biopac Systems, Inc., Aero Camino Goleta, CA)
- Pulse Oximeter Model 9843 (Nonin Medical, Inc. , Minneapolis, MN)
- BSL Respiratory Effort Xdcr SS5LB (Biopac Systems, Inc., Aero Camino Goleta, CA)
- Stationary Bicycle
- Signa Gel-Electrode Gel (Biopac Systems Inc., Fairfield, NJ)

The Handynamo SS25LA was used in cooperation with the Electromyography II on the Biopac program to measure grip strength in kilograms. The Pulse Oximeter Model 9843 was used to measure heart rate. The device works by having the subject place their index finger into a slot that is programmed to record the heart rate. The BSL Respiratory Effort Xdcr SS5LB was used to measure breathing rate. This device consisted of an elastic band with a recording unit that was placed around the torso of the subject.

## Timeline

**Week 1&2 Control group/Week 1 Experimental Group**

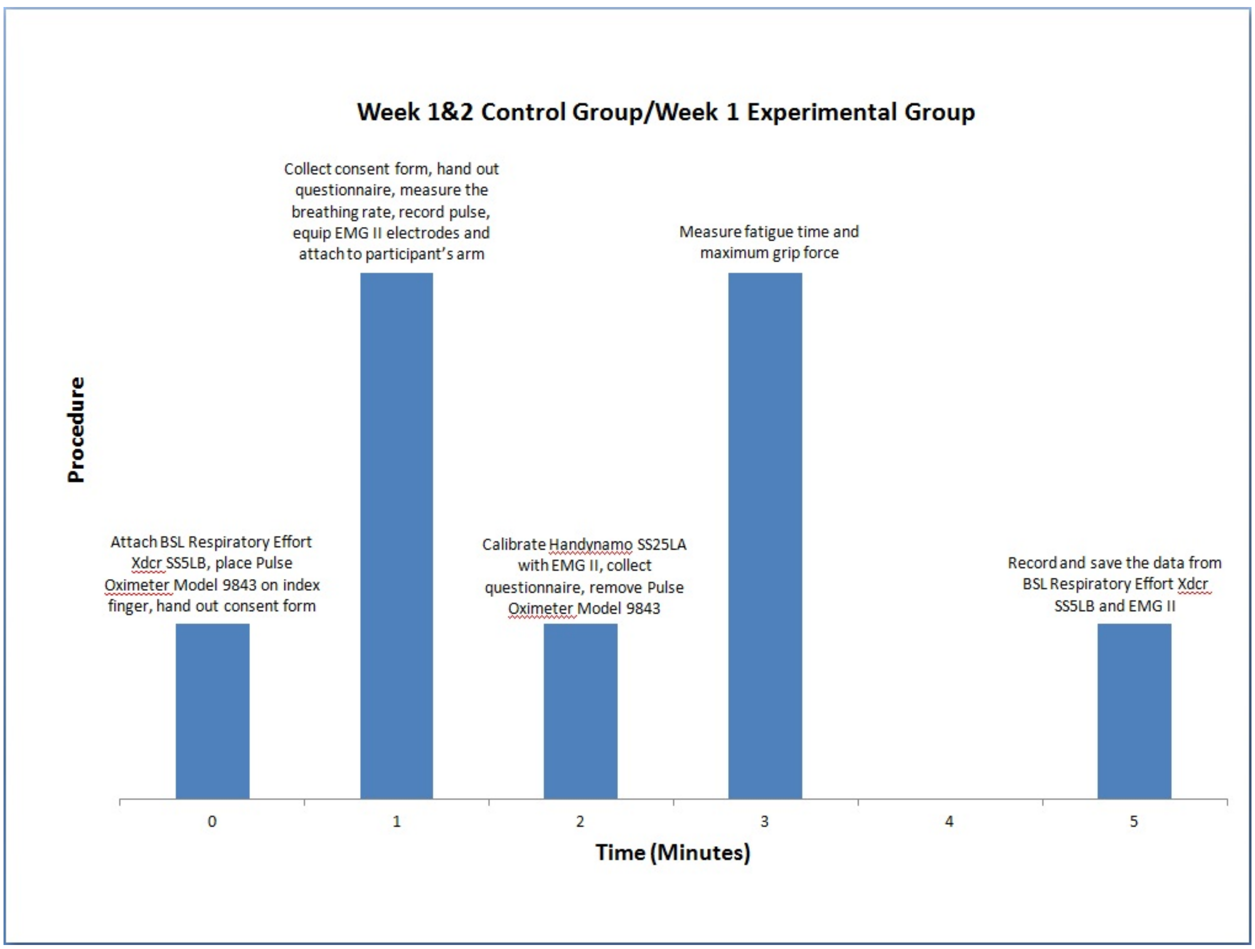


**Figure 1 –** The measurements that were taken from participants over a time period of five minutes; this is according to the control trial.

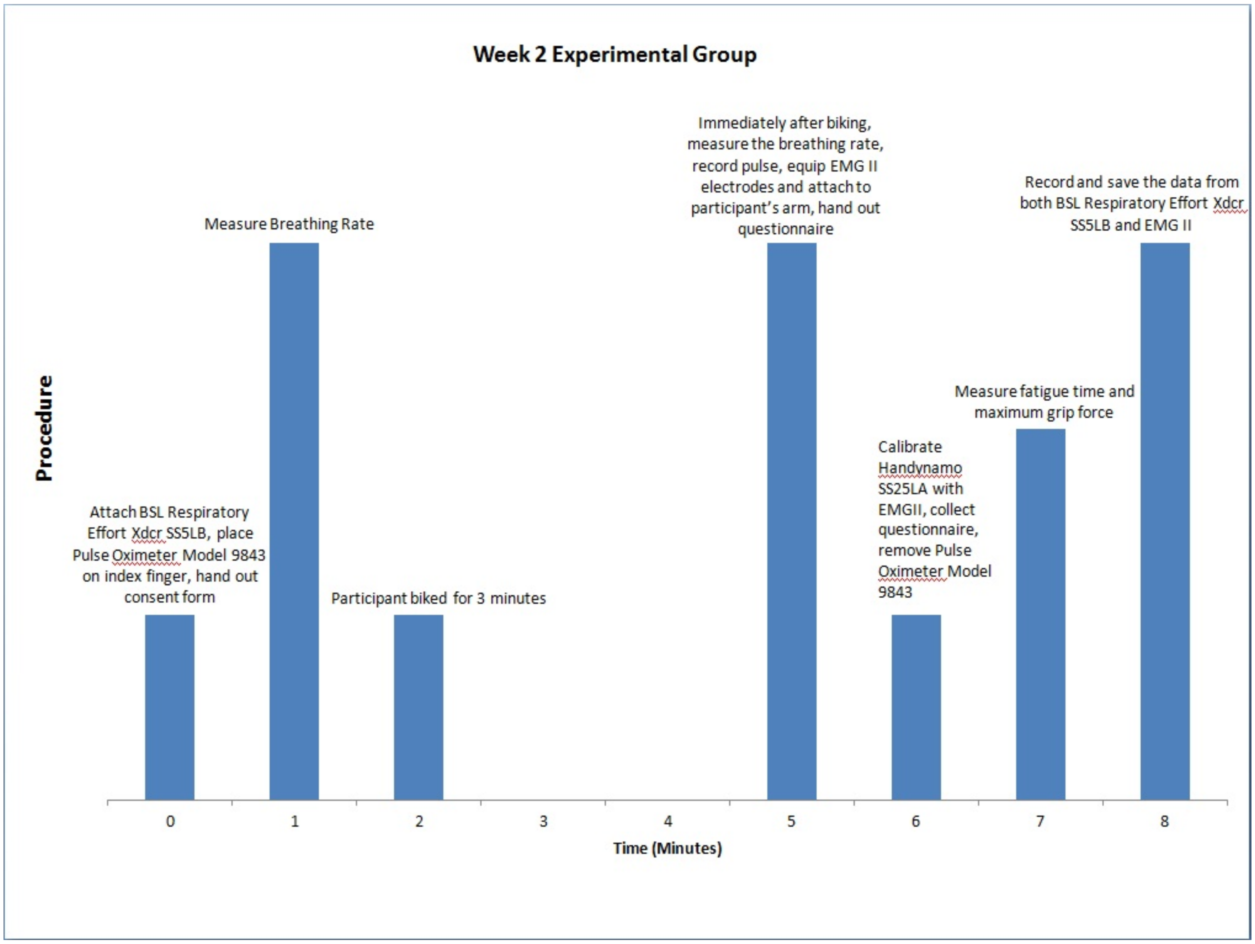


**Figure 2 –** The measurements that were taken from participants over a time period of seven minutes; this is according to the experimental trial.

## Results

Over the two separate occasions that participants were evaluated, statistical analysis of the control group reported a mean percent change for the grip strength and fatigue time of +3.0% and -1.9%, respectively. A positive mean percent change for grip strength indicates that on average, the control subjects showed a small increase in grip strength. A negative mean percent change in fatigue time indicates that on average, the control subjects showed a small decrease in fatigue time.

Over the two separate occasions that participants were evaluated, statistical analysis of the experimental group reported a mean percent change for grip strength and fatigue time of +23.3% and +42.7%. A positive mean change of 23.3% for grip strength indicates that on average, the experimental group showed a dramatic increase in grip strength from the baseline measurements recorded in the first week to the measurements recorded after exercise in the following evaluation. A positive mean change of 42.7% for fatigue time indicates that on average, the experimental group showed a dramatic increase in fatigue time from the baseline measurements recorded in the first week to the measurements recorded after exercise in the following evaluation.

A one tailed type 2 T-Test comparing the control and experimental groups for fatigue time reported a p-value of 0.009404. This value indicates that the results are statistically significant and the research group fail to reject the first hypothesis, which states that an exercise warm-up, defined by an increase in heart rate and respiratory rate, will induce a significant increase in fatigue time.

A one tailed type 2 T-Test comparing the control and experimental groups for grip strength reported a p-value of 0.002601. This value indicates that the results are statistically significant and the research group fail to reject the second hypothesis, which states that an exercise warm-up, defined by an increase in heart rate and respiratory rate, will induce a significant increase in grip strength.

Graphs indicating the best individual change for all variables for both the experimental and control subjects are shown below, along with graphs indicating the summary of the mean percent change for all individuals for both the experimental and control subjects.

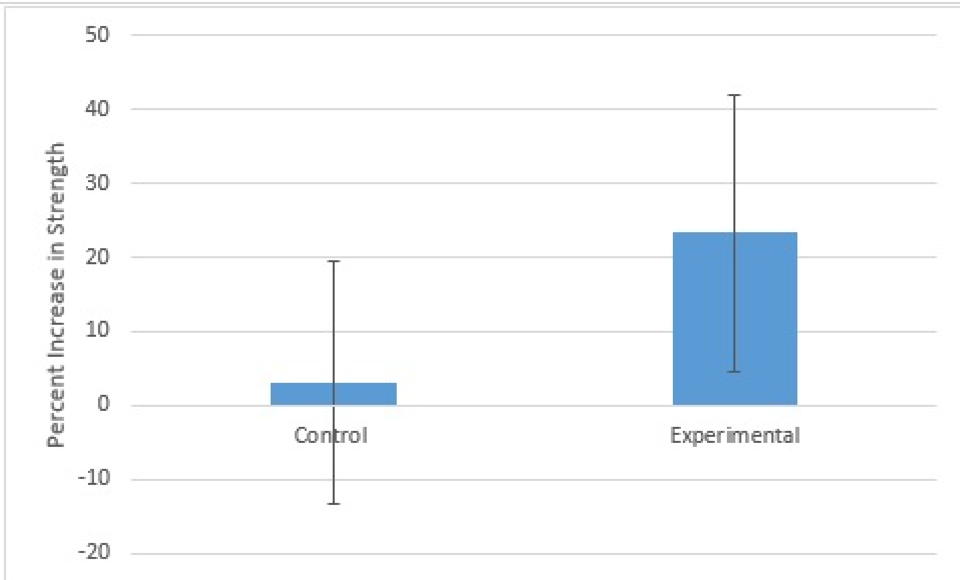


**Figure 3 –** Twenty eight students in Physiology 435 were separated into control and experimental groups and tested in a series of weeks from February to April 2014. The percent increase in strength was calculated as the mean of individual changes in strength from week one to week two. The experimental and control group were shown to be significantly different (t-test, pcalc>0.05). Error bars are +/- one standard deviation.

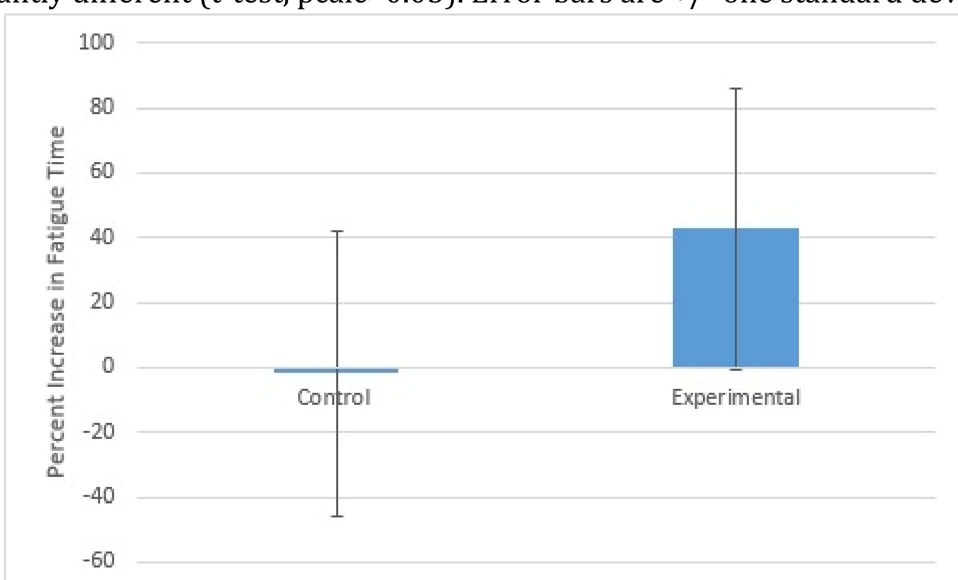


**Figure 4 –** Twenty eight students in Physiology 435 were separated into control and experimental groups and tested in a series of weeks from February to April 2014. The percent increase in fatigue time was calculated as the mean of individual changes in fatigue time from week one to week two. The experimental and control group were shown to be significantly different (t-test, pcalc>0.05). Error bars are +/- one standard deviation.

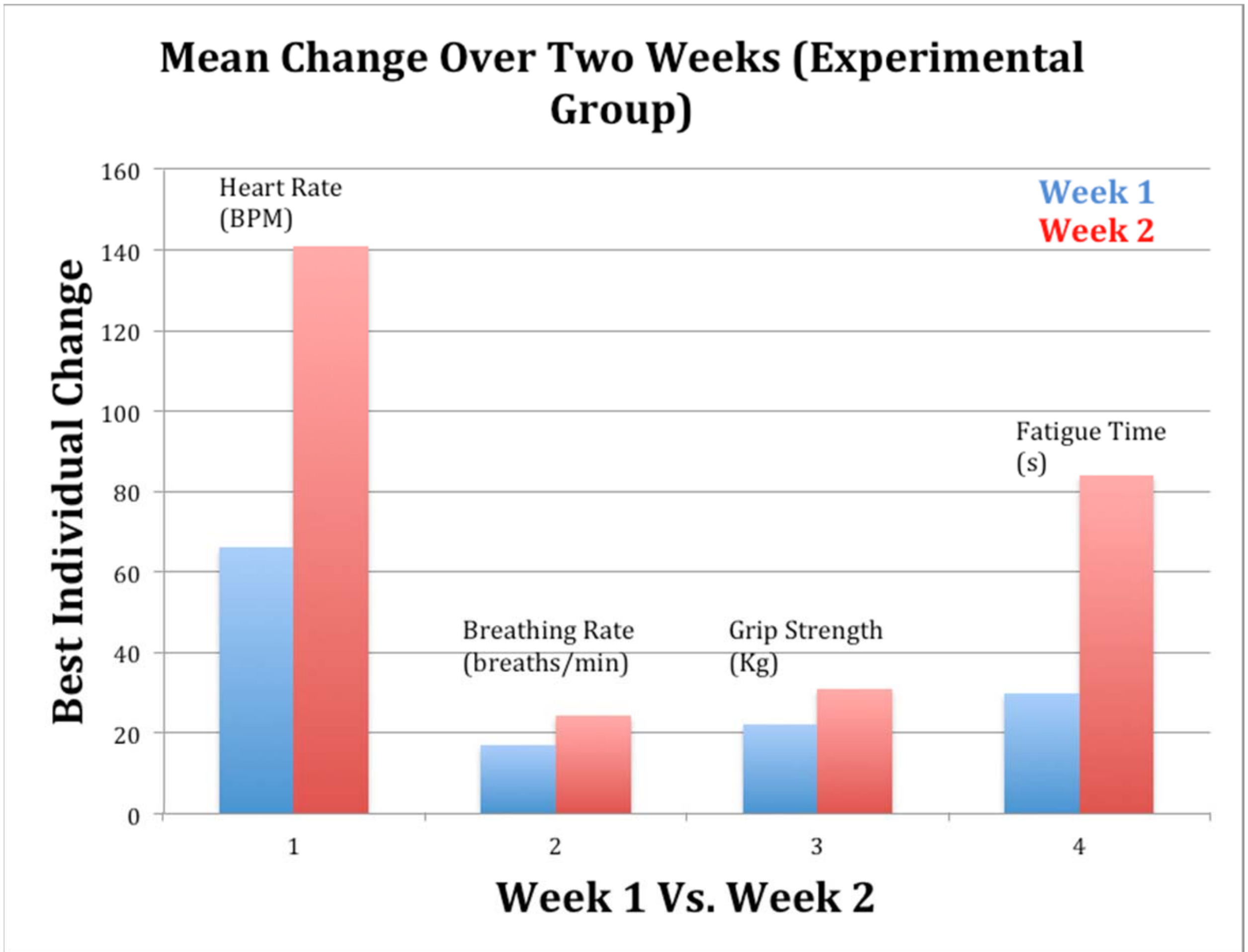


**Figure 5 –** Values of weekly measurements of an experimental individual's heart rate, breathing rate, grip strength, and fatigue time.

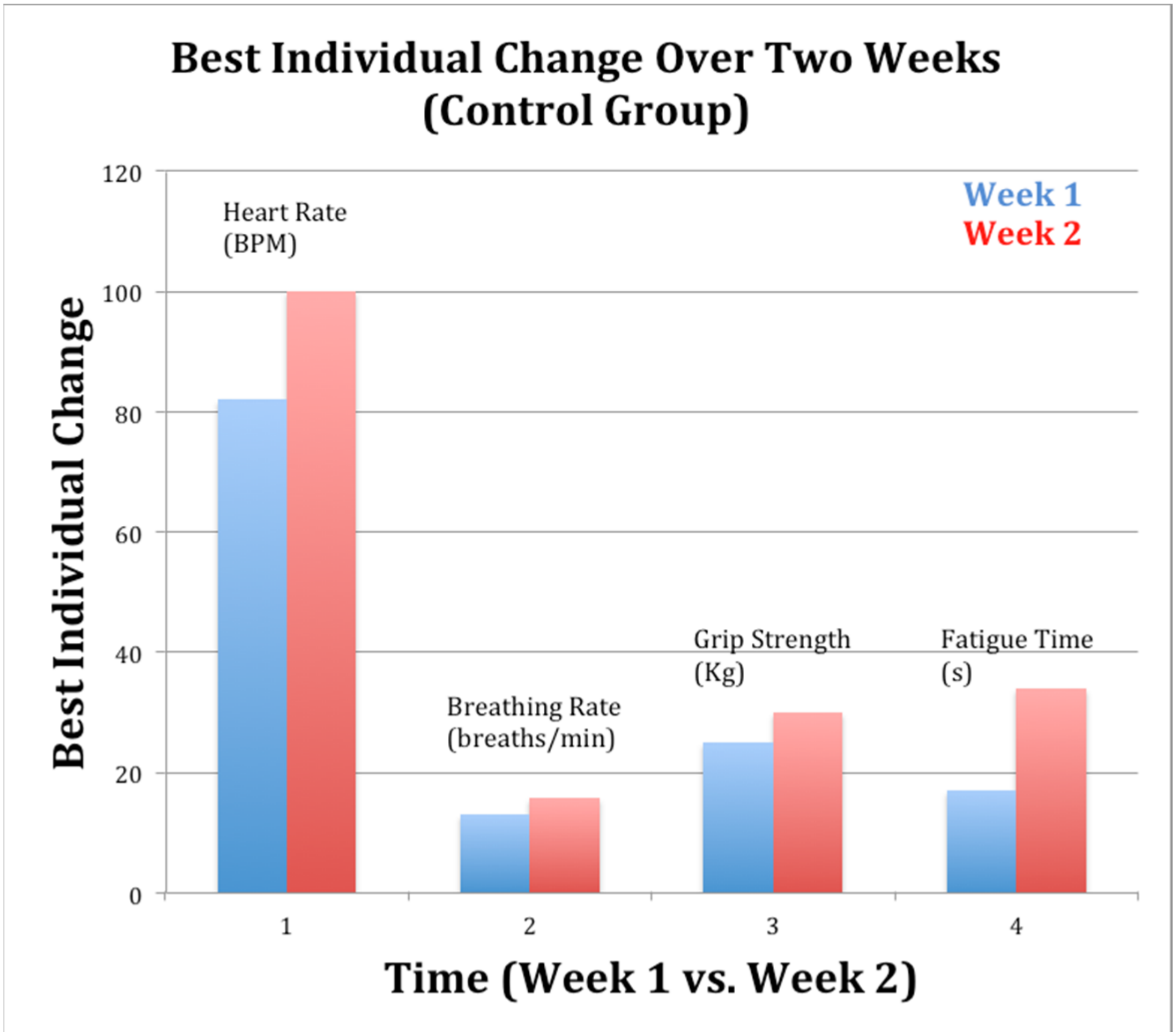

**Figure 6 –** Values of weekly measurements of a control individual's heart rate, breathing rate, grip strength, and fatigue time.

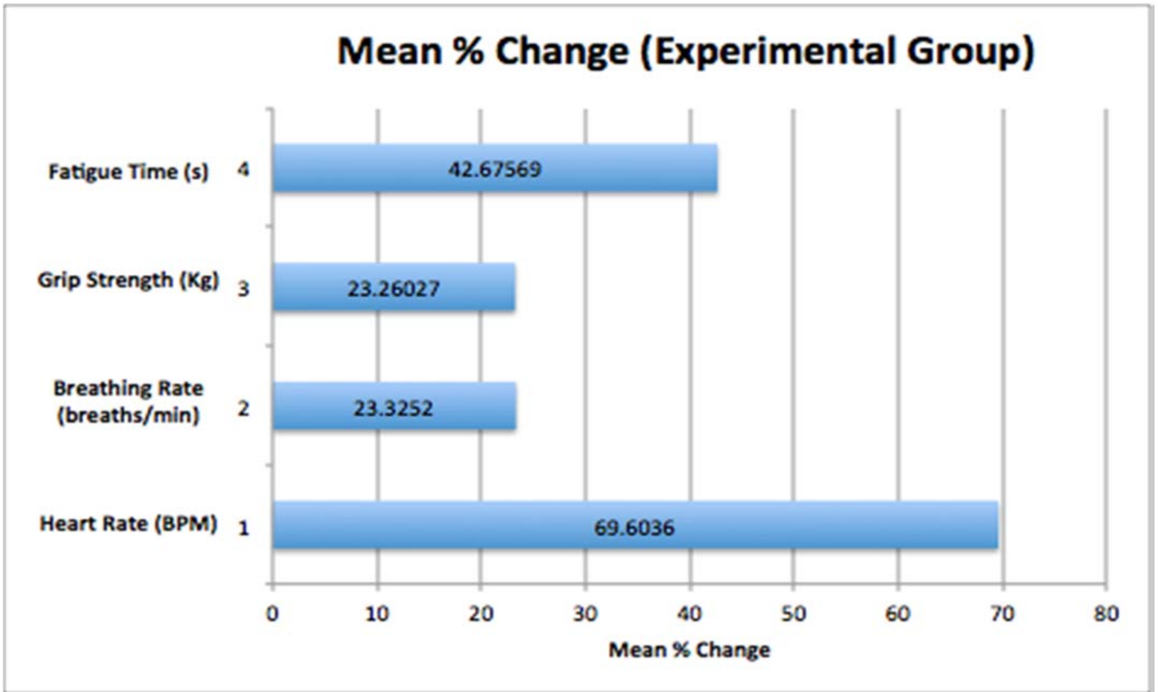


**Figure 7 –** Percent change of weekly measurements of an experimental individual's heart rate, breathing rate, grip strength, and fatigue time.

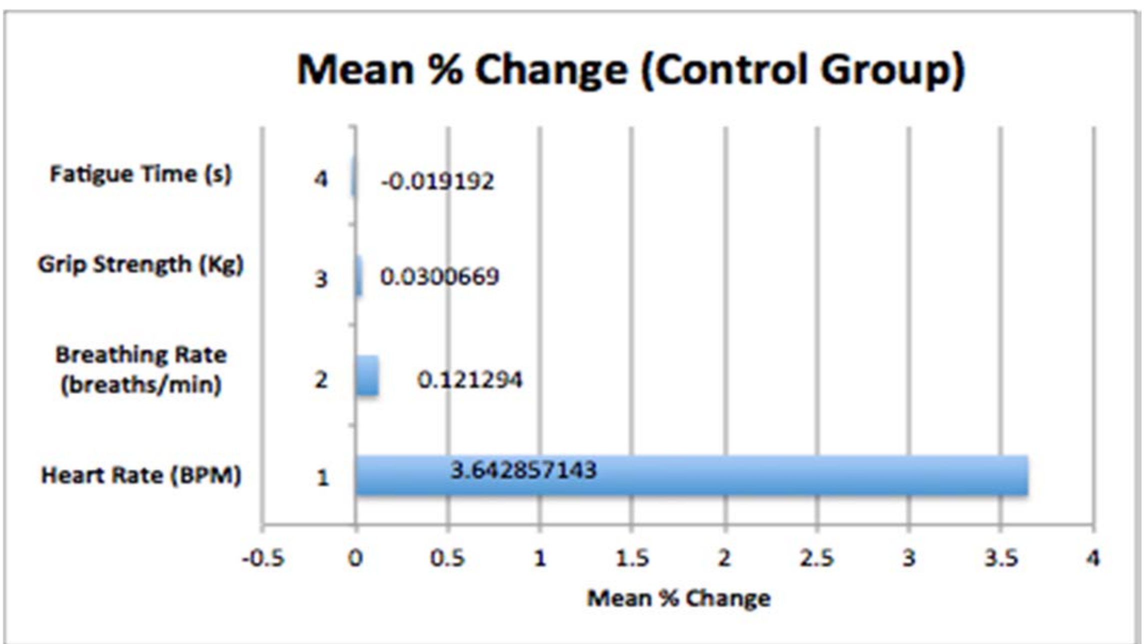


**Figure 8 –** Percent change of weekly measurements of a control individual's heart rate, breathing rate, grip strength, and fatigue time.

**Discussion**

The results failed to disprove either of the hypotheses because, as the p-values indicate, the maximum grip strength and fatigue time of the participants increased in response to the warm-up. Additionally, the collection of data was successful because of the efficiency and consistency of the research group's methods. That is, the protocol was consistent for each participant in both groups.

A number of outside influences may have caused potential changes within the experiment and the collected data. Included in these potential influences are the physical state and well being of the participants and the placement and mechanical integrity of the measuring devices. For example, factors such as the amount of sleep obtained by each participant, if the participant worked out in the recent past, general health status, and overall physical fitness of the participant prior to each test may have affected the amount of force they are able to exert on the Hand Dynamometer. In addition, mechanical factors such as the accurate placement of the electrodes for the EMG, efficiency of the measuring devices, and correct placement of the BSL Respiratory Effort could have had unprecedented effects on the data.

Implications of the results can benefit people looking to improve their athletic performance. More specifically, athletes looking to increase their maximum strength output as well as the time during which this strength is exerted should consider incorporating a similar warm-up into their workout routine. As the data suggests, increasing heart rate and breathing rate were beneficial to the participants' performance. Although the exact reasons for the participants' increases in fatigue time and force exerted are unknown, possible explanations have risen. Mechanisms such as accumulation of acidic waste products, depletion of energy, reduction of neural drive to working muscle caused by a serotonin "spillover," and the inability of a nerve to maintain a high-frequency signal were all possible causes of fatigue that the research group mentioned in the introduction. Although the inability of the nerve to maintain high-frequency signaling during maximum muscular exertion can be a cause of fatigue, it should not be the mechanism underlying the results in this study because not enough exercise was performed by the subjects to change this. It can be that, since the experimental data after the 3-minute warm-up was collected after spring break, participants may have worked out or trained more, and that was not controlled by the study.

The improvement in performance could also be due to the increased flow of oxygenated blood to muscle, due to an increase in stroke volume induced by the sympathetic nervous system which is achieved while warming up. Increase in blood temperature resulting from exercise is also crucial to the release of oxygen to the tissues as implied by the oxygen-hemoglobin dissociation curve. Increased blood flow could have cleared metabolite build-up associated with fatigue in muscle fibers. Additionally, another possible theory explaining the increase in strength and fatigue-time with warm-up can be a delayed adrenal gland influence of the sympathetic nervous system on the body. Warming up for a few minutes before the experiment could have given the subjects enough time for the epinephrine secreted into the bloodstream to reach target organs (Raff, Levitzky 2011).

Although the error produced in the experiment was as minimized as possible, it was not absent. The main source of error in this experiment was human error. The breaths per minute were calculated by hand by the experimenters because there was not a system to calculate this on the computer. This led to varying results based on how each specific breath peak was measured, although care was taken to be as precise as possible. An additional source of human error occurred while the participant was performing the experiment. If the participant spoke while their breathing rate was being measured the outcome of breath peaks on the graph generated by the BSL respiratory effort were altered. Speaking with the participants during this particular data collection was discouraged; however, the participants were sometimes spoken to. This error could easily be corrected by ensuring silence during the subject's breath measurements. To remove bias, care should be taken in the future to not let the subject know when their breathing rate is being taken, and to not alter their results by talking to them. In addition, some of the participants were already fatigued from prior experiments in the day at other lab stations, thus, potentially skewing the data. This was out of the control of the participants and the experimenters.

The final source of human error was the placement of the electrodes of the EMG Device. Even though electrodes were placed as close as possible to the designated positions as indicated by the machine, human error could have played a role in putting them in less than ideal places. Equipment inaccuracies also occurred throughout the experiment. The equipment that was used (the exercise bike, the BSL Respiratory Effort, Pulse Oximeter, and EMG Device) was usually accurate, but did show some signs of being inaccurate. Ideally, more precise equipment could be used if there is a means to attain it.

**Future Direction**

Experimenters looking to conduct a similar study should incorporate the same sequence of events for the control and experimental procedures. The order in which the data was collected allowed for minimal influence from outside sources. Additionally, the variables that constituted the pre-workout warm-up should be kept the same, as these are in accordance with the literature.

Future experiments could include more explicit pre-workout warm-up. For example, instead of having participants bike for three minutes, future experiments can have participants bike for three minutes at a pace that will increase their heart rate by 50%. This allows stronger comparisons to be made between individuals and the correlation between their increased blood flow and maximum strength output. Future experiments could also measure the effects of increased oxygen intake, as this would separate the effects of the warm-up on the heart and on respiration. Additionally, a more precise control would be to have the participants sit on the bike for three minutes. This would take into account the effects of sitting on the bike, holding the handle bars, etc. on their heart rate and breathing rate.

Finally, experimenters looking to repeat this study could measure the heart rate and breathing rate of the experimental group ten minutes after they do the warm-up in addition to before the warm-up. Presumably, the participant's heart rate and breathing rate would return to their baseline values ten minutes after the warm-up. This allows for confirmation of the effects of the warm-up on the experimental results by ensuring that the grip strength and fatigue time were measured while the participant had an elevated heart rate and breathing rate.

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