The effects of caffeine on swimming performance in correlation with respiratory function.

By Caitlin Rejman

Advisor: Dr. Laura Malloy

Department of Biology
Hartwick College
Oneonta, NY 13820

This thesis is submitted in partial satisfaction of the requirements for the degree of Bachelor of Arts or Bachelor of Sciences from the Department of Biology, Hartwick College.

________________________________________  _________________
Thesis Advisor                                    Date

________________________________________  _________________
Chair, Biology Department                        Date
ABSTRACT

Caffeine is often used by athletes to enhance performance, however the magnitude of its effects varies. The effects of caffeine on heart rates, blood flow, blood vessels and skeletal muscles have all been evaluated. However, little has been done to correlate the effects of caffeine on respiratory function with its effects on performance. In competitive swimming, respiratory parameters play a major role. Thus the effects of caffeine on swimmers' respiratory functions may play an important part in performance enhancement. I hypothesized that caffeine improves swimming performance and that its effects can be explained by the effects of caffeine on both metabolism and ventilation. To evaluate this hypothesis within the methodological constraints imposed by swimming, I measured metabolism and ventilation during exercise recovery using Excess Post-Exercise Oxygen Consumption (EPOC) as an index of metabolism and using tidal volume and respiratory rate to calculate ventilation. With IRB approval, trained competitive swimmers completed a standard pool workout following treatment with caffeinated or decaffeinated coffee prior to exercise. Performance time, heart rate, VO₂, VCO₂, respiration rate, tidal volume and EPOC were measured before and directly after swimming using iWorks Lab scribe software, an SP-304 spirometer, and a GA-300 gas analyzer. Mean data were compared using a paired t-test with Dunn’s correction for multiple comparisons. I observed a decrease in performance times, and time to recovery, with an increase in heart rate, respiration rate, and tidal lung volume. These results conclude that caffeine does increase performance in competitive swimming.

INTRODUCTION

In athletics, athletes are always trying to find ways to give themselves a competitive edge. One way is through the use of ergogenic aids. In 2004 the ban of caffeine as a stimulant was lifted by the World Anti-Doping Agency because of its widespread availability and use (Astorino et al. 2010). Since then, many studies have been conducted to determine caffeine's effects on an athlete's body and performance. In a 2010 review Goldstein, et. al. concluded that during times of sleep deprivation, caffeine
can enhance alertness and vigilance, thereby aiding athletes during exercise that is exhaustive and requires more intense focus. Further, caffeine helped to enhance glycogen resynthesis during recovery after exercise, and was found to be beneficial for high intensity team sports that have a prolonged duration or are endurance in nature (Goldstein et al. 2010).

In a 2005 survey of 140 Hawaiian Ironman Triathlon athletes, 64% of the athletes indicated previous caffeine use and 89% were using it for that event (Desbrow et al. 2007). Because so many athletes try and take advantage of caffeine as an ergogenic aid, some studies have been done to see how it affects the trained athlete in different exercise conditions. A review of studies concerned with caffeine and short term exercise by Astorino et al (2010) concluded that team sports performance is enhanced with high doses of caffeine ingested pre exercise, that trained athletes are more apt to take caffeine than non-trained athletes, and that differences in magnitude of the effects of caffeine are due to metabolic differences between individuals.

The affects of caffeine have been evaluated in a variety of specific sports, with mixed results. In a study conducted by Glaister et al (2010), caffeine and sprint cycling performance were analyzed. A double blind placebo controlled design was run in which participants completed 7 submaximal 10-second sprints each trial. The results concluded that caffeine had no effect on the sprints of such short duration (Glaister et al. 2012). Another study by Gwacham and Wagner also looked at the effects on caffeine in sprinting but with college football players. In this study, the participants completed 6 35-m maximal effort sprints with ten seconds of recovery between each. This study also yielded the results that caffeine did not improve sprint time or anaerobic strength (Gwacham et al. 2012). One study, also pertaining to cycling, looked at the effects of caffeine on heart rate during submaximal cycling, and concluded that caffeine did in fact lower heart rate (McClaran et al. 2007). However, swimming is one sport where the effects of caffeine have been often overlooked because of the challenges of recording physiological data from the water.
Further, while many studies analyze the cardiovascular and metabolic responses to caffeine, little research has been done on the effects of caffeine on respiratory parameters. In the sport of competitive swimming, breathing is a critical part of any race. Breathing patterns have to be established and swimmers train themselves to breathe a particular way before, during, and after a race.

One important parameter that could be analyzed to shed more light on metabolism in swimmers exposed to caffeine is excess post-exercise oxygen consumption or EPOC. When looking at this, one also can look at VO₂, VCO₂, RER. It is known that duration, intensity, and mode of exercise as well as, athlete fitness level, split exercise sessions, and resistance verses aerobic exercise all impact EPOC(Børsheim et al. 2003). In a study by Gmada et al (2004), the effects of fitness level on EPOC after supramaximal individualized exercise were measured. Participants performed three repetitions of exercise at 120% of the maximum aerobic power, with two recovery periods of 5 minutes and following the third trial was a recovery period of 20 minutes. It was concluded that before and after repetitions, EPOC varied according to fitness level (Gmada et al. 2004).

Since little is known about how caffeine effects swimming performance, or the respiratory system, the purpose of this study is to investigate those effects. Does swimming performance increase with caffeine? How does caffeine effect the respiratory system? Or does it work only by its effects on metabolism? And do those changes made by caffeine to various respiratory or metabolic parameters help to explain the difference if any in performance? My hypothesis is that caffeine will improve swimming performance, and that its effects can be explained by the effects of caffeine on both metabolism and ventilation.

**MATERIALS AND METHODS**

Ten members, six female of the Hartwick Swimming team and four male, all highly trained competitive athletes were subjects for this experiment. The procedures of this experiment followed the
guidelines established in and approved by Hartwick College's IRB. Each participant was informed of the benefits, risks, and was asked to sign a written consent form before beginning any part of this study. The study was conducted during open swim hours at Hartwick's Moyer Pool facility with the additional supervision of a lifeguard on duty.

Each participant was given an unidentified cup of coffee, caffeinated or decaffeinated, made using a Keurig coffee maker so each cup would be identical in volume. Because peak caffeine absorption takes place between 30-75 minutes after ingestion (Sökmen et al, 2008), subjects were asked to sit at rest for 15 minutes following coffee consumption before entering the pool. Each participant then breathed into the respirometer until CO₂ and O₂ levels stabilized for a baseline measurement. Heart rate was also measured. Participants then swam a standard swim practice averaging about 30 minutes in length, beginning with a warm up period, and ending with a timed 100 yard sprint. The practice was generated by Hartwick College's head swimming coach, and coach to all participants, Dale Rothenberger. The practice is as follows:

Warm up:
- 300 Swim
- 100 Pull
- 100 Drill
- 100 Swim

Main set:
- Women: 14 x 75 yards on 1:30
- Men: 16 x 75 yards on 1:20
- Timed 100 freestyle sprint from a push off the wall, not from a starting block

Immediately upon completion of the sprint, the subjects were connected to the respirometer and CO₂ and O₂ levels were recorded until they returned to the baseline levels established prior to exercise. Heart rate, lung volumes, and air flow were also measured. The following week, the subjects came back for a second trial following the same procedure after drinking the second coffee alternative.

An SP-304 respirometer and GA-300 gas analyzer were used to measure the oxygen consumption, carbon dioxide production, lung volume, and air flow in each subject. This apparatus was
connected to a computer running a Labscribe data acquisition program via an amplifier and USB port. The respirometer was attached with plastic tubing. All of the equipment is set up on a trolley for easy mobility around the pool facility. The mask on the respirometer was cleaned with an alcohol wipe and prepared for the next subject between each measurement.

![Figure 1. A participant breathing into the respirometer.](image)

Mean swim times for the 100 yard freestyle sprint in trial 1 and 2 were compared to see if there was an increase in performance between the decaffeinated and caffeinated trials. Other important measures that were evaluated are time to recovery, tidal volume, respiratory rate, ventilation and excess post-exercise oxygen consumption, or the excess oxygen uptake above the resting level in the recovery phase. With light exercise, there is a rapid recovery to a steady state VO₂ with very small oxygen debit. However, with intense aerobic exercise, such that the subjects completed, recovery takes much longer starting with a fast component followed by a slower component. EPOC was calculated by taking the RelVO₂ and multiplying by the elapsed time until recovery was reached and the participant reached their baseline taken prior to exercise. This calculation gives mlO₂/g. Respiratory rate was calculated by looking at the air flow recording and counting three breaths. The time for those breaths was divided by 60 and multiplied by 3 to get breaths per minute. Heart rate was also compared at rest and immediately
following exercise to be compared between the two trials. Heart rate was taken manually by the participant at the beginning of the study, immediately after exercise, and again after recovery. Participants took their heart rate for 10 seconds. I then multiplied that number by 6 to get the beats per minute. T-tests were used to compare caffeinated and decaffeinated trials with a standard p value of 0.05. Heart rate results compared the three stages of the study; rest, post-exercise, and recovery. A t-test with Dunn's correction for multiple measures was used with a p value of 0.025.

RESULTS

There was a statistically significant difference between caffeine treated and not-caffeine treated trials for each of the following measurements; timed swimming performance (p=0.001), respiratory rate (p_{rest} = 0.007, p_{postexercise} =0.005), post exercise tidal volume (p=0.003), heart rate at rest(p=0.002), heart rate at recovery (p=0.000), and time to recovery (p=0.031). Resting tidal volume (p=0.059), heart rate during immediately post exercise phase (p=0.779), and EPOC (p=0.615) did not demonstrate statistically significant differences between caffeine treated and control trials.

Figure 2 below shows the heart rate taken at rest, immediately after sprint swim and upon recovery. Predictably, in both treatments, immediately following exercise mean heart rate was higher that at rest or recovery (Paired T-test with Dunn’s correction for multiple comparisons, p_{rest} = 0.066, p_{postexercise} =0.779, p_{noncaffeinerest} =0.002, p_{caffeinerest} =0.00). There were no statistically significant differences between treatment groups (caffeine and no caffeine) in any time period. However, for each treatment group, recovery was incomplete; heart rate upon recovery were significantly higher at rest.
Figure 2. Heart Rate for swimmers with and without caffeine at rest, post exercise and upon recovery. Blue bars indicate trials in which decaffeinated coffee was administered, and red bars indicate caffeinated coffee. \(N=10\). Comparing rest and recovery values between no caffeine trials, and comparing rest and recover values in caffeine trials are the only statistically significant values. (Paired T-test with Dunn’s correction for multiple comparisons, \(p_{\text{rest}} = 0.066\), \(p_{\text{postexercise}} = 0.779\), \(p_{\text{recovery}} = 0.039\), \(p_{\text{noncaffeinerestrecovery}} = 0.002\), \(p_{\text{caffeinerestrecovery}} = 0.000\))

At both rest, and post exercise, the trials with caffeine had a significantly higher respiration rate (Paired T-test, \(p_{\text{rest}} = 0.007\), \(p_{\text{postexercise}} = 0.005\)).

Figure 3. Respiration rate for swimmers at rest before exercise and immediately post exercise with non caffeine and caffeine trials. Blue bars indicate trials in which decaffeinated coffee was administered, and
red bars indicate caffeinated coffee. N=10. Both at rest and post exercise, mean values are statistically significantly higher in caffeine treated trials. Asterisks indicate statistically significant values. (Paired T-test, Dunn's correction for multiple comparisons, \( p_{\text{rest}} = 0.007, p_{\text{postexercise}} = 0.005 \))

Mean tidal volume measurements were statistically significantly greater in caffeine trials, post exercise, but not at rest prior to exercise, and yielded different results than respiration rate. At rest, trials with caffeine had a lower but not significant mean tidal volume (Paired T-test, \( p_{\text{rest}} = 0.059, p_{\text{postexercise}} = 0.003 \)).

![Tidal Volume Graph](image)

Figure 4. Tidal volume for swimmers at rest before exercise and immediately post exercise with non caffeine and caffeine trials. Blue bars indicate trials in which decaffeinated coffee was administered, and red bars indicate caffeinated coffee. N=10. Post exercise tidal volume was statistically significantly greater in caffeine trial. Asterisks indicate statistically significant values. (Paired T-test, Dunn's correction, \( p_{\text{rest}} = 0.059, p_{\text{postexercise}} = 0.003 \))

Ventilation measurements post exercise were statistically significantly greater in caffeine trials, and ventilation measurements at rest were not. Ventilation was greater at rest without caffeine, and greater post exercise with caffeine. Ventilation is directly affected by tidal volume, which was also lower at rest without caffeine.
Figure 5. Ventilation in swimmers with non caffeine and caffeine trials. Blue bars indicate trials in which decaffeinated coffee was administered, and red bars indicate caffeinated coffee. N=10. Asterisks indicate statistically significant values. (Paired T-test, Dunn's correction, \( p_{\text{rest}} = 0.039, p_{\text{postexercise}} = 0.003 \))

Excess post exercise oxygen consumption did not yield statistically significant differences between trials. When comparing individual participants data, about half had higher EPOC with caffeine, and the other half without caffeine. There was no pattern or correlation found between caffeine use and EPOC.
Figure 6. Excess post exercise oxygen consumption in swimmers with non caffeine and caffeine trials. Blue bars indicate trials in which decaffeinated coffee was administered, and red bars indicate caffeinated coffee. N=10. No values are statistically significant. (Paired T-test, p=0.615)

Time to recovery did yield statistically significant values. Oxygen and carbon dioxide levels returned to resting levels following exercise more rapidly during trials in which participants were given caffeine.

![Time to Recovery](image)

Figure 7. Time to recovery in swimmers reaching baseline oxygen and carbon dioxide levels with non caffeine and caffeine trials. Blue bars indicate trials in which decaffeinated coffee was administered, and red bars indicate caffeinated coffee. N=10. Caffeine treated recovery times are lower. Asterisks indicated significantly significant values. (Paired T-test, p=0.031)

100 yard freestyle sprint times were taken to test all out pace performance in swimmers treated with and without caffeine. This measurement demonstrates that caffeine treatment did decrease swim time and therefore improve performance (Fig. 8). The difference in mean between the trials is 1.562 seconds. Values for the comparison in times between trials are statistically significant (Paired T-test, p=0.001).
CONCLUSION

After comparing the results of the trials without caffeine to the trials with caffeine, we can see a clear performance increase, supporting my hypothesis. All of the respiratory measures including respiration rate, tidal volume, and ventilation were greater after exercise in the caffeine trial. These increases could contribute to performance by enhancing \( \text{O}_2 \) availability and \( \text{CO}_2 \) release especially during intense 100 yard sprints.

Recovery time decreased under the influence of caffeine. This could also be related to the increase in respiration rate and tidal volume. If the body gets what it needs faster, it is able to recover faster. Recovery time is the time to recovery of resting level oxygen consumption and indicates how quickly glucose recycling and heart and respiratory muscle recovery is taking place. Ganio et. al. (2009) brought up in his literature review that caffeine also helps improve performance by acting on 3 difference mechanisms including; increasing mobilization of intracellular calcium, an increase of fatty acid oxidation, and serving as an adenosine receptor antagonist in the central nervous system. These three metabolic changes aid the body in faster response.

Figure 8. Mean (+/- SEM) for 100 yard freestyle sprint time in seconds for swimmers with non-caffeine and caffeine trials. Blue bars indicate trials in which decaffeinated coffee was administered, and red bars indicate caffeinated coffee. N=10. Asterisks denotes mean sprint time values were statistically significantly lower in caffeine treated subjects.(Paired T-test, p=0.001)
EPOC measurements however, did significantly decrease with the influence of caffeine. This could indicate that oxygen consumption is not effected by caffeine, but only by the metabolism of the individual. The study by Gmada et al. 2004 states that fitness levels of the individuals are what effect EPOC. This study, while contradicting my hypothesis, does support that and it can be concluded that EPOC is varies and is very individualized. Finally, heart rate also gave us very little significant information when comparing caffeine to no caffeine. Many things could have also impacted heart rate in the individual including, time of day, amount of food consumed, anxiety over school, and amount of sleep the previous night.

Future research could be done to further investigate a correlation between recovery time, and other respiratory parameters including respiration rate and tidal volume with the influence of caffeine. Further research could also be done with EPOC if a more sophisticated way of measuring and analyzing data is used. The Labscribe program used for this study has many other capabilities for data analysis. Respiratory parameters could be analyzed in more depth and other measurements could be looked at. Respiratory exchange ratio, and flow index are two examples. The effects on caffeine on distance events in swimming could also be explored. A 100 yard sprint just allow the non-aerobic systems to begin. Distance events would provoke different recovery times and metabolic processes within the body.

This experiment would be interesting to run if we had equipment that was more mobile in the pool facility, and allowed us to take measurements while a swimmer was actually swimming and doing laps in addition to just the before and after, which has lag time between getting out of the pool and putting the mask on. Also with a larger subject pool, the effects of caffeine on swimmers who are regular caffeine users verses non-caffeine drinkers could yield some interesting results that could indicate tolerance or level of intensity with effects of the caffeine. The type of caffeine and dosage could have been another variable that could also have been tested. For example, caffeine pills, or gum could have been used instead of black coffee. That would eliminate the possibility that there are other factors contributing to the increase in performance.
This study had several limitations. One was the age and athletic ability of the participants. All were between the ages of 18 and 21, and are collegiate athletes. Finding older or younger athletes could have given much different results. Also, this study was conducted out of season for the swimmers. If they were in season and in better shape, respiratory measurements would have been much different as well. The environment provided a limitation as well. Moyer Pool is an indoor facility that was poor air quality. Another pool, or outdoor pool would have had better air quality.

In conclusion, caffeine does effect and improve the performance of competitive swimmers. Noticeable changes can also be seen in the respiratory system with the ingestion of caffeine such as increase in tidal volume, respiration rate, and ventilation. Some conclusions can be drawn to help explain those changes, but further research still needs to be done on the specific effects on the respiratory system.

WORKS CITED


