The Effects of Exercise Induced Increases in Heart Rate and Decreases in Blood Oxygen Saturation on Reaction-Time in Young Adults

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Abstract

Exercise has been proven to be beneficial to not only physical health, but also cognitive function. Few studies have looked at the effects of increased heart rate on cognitive function in young adults. In this experiment, reaction time tests were used as a measure of cognitive function, which were administered at rest, after maintaining 60% of maximum heart rate for 45 seconds, and after maintaining 80% of maximum heart rate for 45 seconds on 20 participants (mean = 21.45 years). The relationship between reaction time and blood oxygen saturation (%SpO_2) were also analyzed. Results indicated that overall, reaction time improved (decreased) after the heart rate was increased to 60% of maximum heart rate but did not show significant improvements from 60% to 80% of maximum heart rate. There was no significant relationship between %SpO_2 and reaction time. Findings suggest that as heart rate increases, %SpO_2 slowly decreases. A positive relationship between increased heart rate and reaction time is suggested. These results could potentially have implications for advising young adults to engage in warm up exercises before sporting events for an increase in reaction time.

Introduction

A strong positive relationship between aerobic exercise and cognitive function has been regularly established by the scientific community. For example, elderly individuals who have a history of aerobic activity exhibited a higher degree of motor learning, which helped to delay the effects of dementia (Colcombe & Kramer 2003). Currently, research suggests that the increased cognitive function could be the result of increased vascularity of the brain tissue induced by activity (McDonnell *et al.,* 2013). Likewise, research in monkey models indicated that exercise induced faster completion of simple tasks (Rhyu *et al.*, 2010). There are few studies showing that cognitive function is directly affected by aerobic exercise. A study performed by Jakobsen *et al*., in 2011, effectively demonstrates that simple and complex reaction time tests can serve as a measure of cognitive function. Therefore, administration of a reaction time test immediately following aerobic exercise should show this direct relationship.

At high levels of physical activity over a prolonged period of time, oxygen levels decrease in the blood (Rowell *et al.,* 1964). Cognitive function has been shown to be significantly reduced under oxygen deprived conditions, such as high altitudes (Asmaro *et al.*, 2014). However, physical activities under these oxygen deprived conditions have shown no effect on cognitive function (Ando *et al.,* 2014). A study showing that low levels of oxygen in the blood negatively affects cognitive function should be performed. An effective way to measure the levels of oxygen in the blood is by using a Nonin pulse oximeter, which uses a finger clip sensor to project light through the index finger in order to determine the percentage of oxygen (%SpO_2) present in the blood.

Pre-performance exercise (warm-up) has been shown to increase performance. A study conducted on pre-race warm-up regimes in human sprinters showed a strong correlation to longer warm-ups and increased performance in the 100-meter sprint (Anderson *et al.,* 2014). Additionally, studies conducted on elite volleyball players have also shown that reaction time decreased as a match progressed. Indicating reaction time had improved in a strong correlation with increases in blood lactate level, an indicator of exercise intensity (Mroczek *et al.*, 2011). Blood lactate levels and increased heart rate stimulated by exercise, have been shown to improve (decrease) reaction time for moderate activity (Chmura and Nazar, 2010). Likewise, decreases in heart rate have been shown to worsen (increase) reaction time in fatigued drivers (Zhang *et al.,* 2014).

Based on this previous research, further experimentation was sought out to test the physiological effects on reaction time. The first objective is to investigate the changes in reaction time after maintaining a target heart rate for 45 seconds. Individuals are able to process information faster and more accurately when their brains are benefited with increased circulation, which is known to occur as a result of increased heart rate. Therefore, it is suggested that subjects will have an improved (decreased) reaction time, as a result of a maintained target heart rate increased from resting heart rate.

Another objective is to elucidate the effects of %SpO_2 levels on reaction time. A previous study showed that there is a significant improvement (decrease) in reaction time in the presence of 43.2% oxygen compared with 22.1% oxygen (Chung *et al*., 2009). This supports the idea that an increase in the oxygen saturation levels, resulting in more oxygen available to the brain, increases the ability of cognitive function (Duncker and Bache, 2008). Therefore, we expect that higher %SpO_2 levels will correlate with improved (decreased) reaction time.For these reasons, this study was performed to determine the direct effects of increased heart rate, caused by physical activity, on reaction time.

Methods

Subjects (n = 20: 10 Females, 10 Males) were recruited from a convenience sample within the University of Wisconsin-Madison campus. Eligible participants were of at least 20 years of age (mean = 21.45 years, range = 20-26years). Informed consent was obtained in written form prior to all measurements.

Positive Control

We conducted a positive control test using one subject to demonstrate the above hypothesis. As predicted, the subject's heart rate increased as more exercise was performed (Figure 1). Not surprisingly, this increase in heart rate corresponded to a decrease in reaction time (Figure 2). The relationship between heart rate and %SpO_2, however, differed than the expected hypothesis. As the subject's heart rate increased from resting to 60% of maximum, %SpO_2 linearly decreased, whereas when heart rate increased from 60% to 80% of maximum, %SpO_2 levels increased to just below the resting level (Figure 3).

Reaction-Time Test

Subject rested wrist of dominant hand on the stationary bicycle handle. One experimenter held the meterstick vertically in the air between the subject's thumb and index finger, about one inch apart (width of meterstick). This distance was measured, by another experimenter, before every trial to ensure consistency in the finger gap. The top of subject's fingers was aligned with the zero mark. Without warning, the experimenter released the meterstick and let it drop. The subjects were instructed to grab it as soon as he/she could after seeing it fall. The distance between the zero mark and where the top of the subject's thumb on the ruler after catching was recorded, by a third experimenter, in centimeters to the nearest half centimeter and repeated five times at random intervals, for each of the three pre-determined heart rates.

Calculations

To find the actual reaction times in seconds, the average distance from the five reaction-time trials was calculated. That calculated measurement was used in the equation t = sqrt (2d/g), where d = distance, in meters, that the meterstick fell, and g = the acceleration of gravity (9.8 m/s^2), and t = the time the ruler was falling (seconds).

It is difficult to define low, moderate, and high intensity exercise for experiments. This is due to differences in age, gender, and physical fitness, which affect intensity for each individual. Thus, this study focused on using three heart rate intervals (resting, 60%max and 80%max) to provide a reasonable variable useful for determining exertion. For men, maximum heart rate can be easily predicted by subtracting the age of the individual from 220 beats per minute. Women's maximum heart rate predictions have been recently shown to be most accurate by subtracting 80% of their age from 206 bpm (Paul, 2006). The maximum heart rate is then multiplied by 0.60 and 0.80 to calculate the 60%max and 80%max, respectively, of their heart rate that the subjects targeted. Therefore, these variables can easily be tested during different levels of exercise.

Physiological Measurements

The following physiological variables were measured: heart rate, blood oxygen saturation ($\%SpO_2$), and reaction time.

Heart rate and blood oxygen saturation were both measured using a Nonin pulse oximeter from Nonin Medical Incorporated (Model 9843). The finger clip sensor was worn directly on the skin of subjects index fingers of their submissive hands, while heart rate and $\%SpO_2$ were monitored by experimenters. The oximeter remained on subject throughout the entirety of the experiment. To avoid oximeter malfunction, subjects were required to hold their submissive hand to their chest during the entire experiment.

Reaction time was measured using the meterstick-reaction-time test, explained above. This data allowed for a equation to be generated to calculate reaction times (seconds).

Process

While subjects sat on a stationary bicycle, the finger clip sensor of the Nonin pulse oximeter was connected to the index finger of each subject's submissive hand. The subjects were instructed to breath deeply and clear their minds for two minutes, prior to pedaling. Following the relaxation, resting pulse and %SpO_2 were recorded.

The reaction-time test was then administered, as outlined above, with five trials at random intervals, so the subject's performance was not altered by expectation of the drop. Heart rate and %SpO_2 were recorded at the time of each reaction-time trial.

The next step was to bring the subject's heart rate up to 60% of their previously calculated maximum by pedaling on a stationary bicycle. The participant held the desired heart rate within ten bpm in either direction for 45 seconds. Experimenters then told the subject to stop pedaling when they had maintained the desired heart rate for 45 seconds. The reaction-time test was then administered again as outlined above; heart rates and %SpO_2 were again recorded for all five trials. After the five trials were complete, the subject had begun pedaling again to reach within ten bpm in either direction of 80%max. Following the 45 seconds of the subject maintaining the desired heart rate, the final reaction-time test trials were performed while reaction time, heart rate, and %SpO_2 were recorded. See Figure 4 for a detailed chronological, graphical presentation of the procedure used to conduct this study.

Statistical Analysis

Hypothesis tests comparing groups were performed using correlated sample t-tests and correlated sample one-way ANOVA on a MacBook Pro laptop computer using VassarStats software. The correlated sample mode of analysis was used to account for the fact that the same subject was tested at three heart rates. Microsoft Excel was used to calculate averages of collected data. These averages were used in t-test and ANOVA analyses. All information was analyzed and interpreted using statistics. Multiple trials allowed for accurate measurements and means were calculated. Graphs were created and analyzed to find relationships between heart rate, blood oxygen saturation, and reaction time.

Results

Total Cohort

One-tailed correlated t-tests between both the resting heart rate and 60%max groups, as well as between resting heart rate and 80%max groups were significant for differences in reaction time, with $p = 0.002$ and $p = 0.002$, respectively. There was not a significant difference in reaction time between 60%max and 80%max groups; $p = 0.349$. A one-way correlated ANOVA comparing all three heart rate groups yielded a significant difference in reaction time; $p = 0.001$.

Comparing differences in %SpO_2, one-tailed correlated t-tests resulted in significant differences between the resting heart rate and 80%max groups, as well as the 60%max and 80%max groups; $p = 0.013$ and $p = 0.017$, respectively. Interestingly, there was no significant difference in %SpO_2 between the resting heart rate and 60%max groups. A one-way correlated ANOVA between all three groups also yielded a significant difference, with $p = 0.011$.

Male Cohort

Within the male cohort, one-tailed correlated t-tests followed the same trends as the total cohort, with significant differences in reaction time between the resting and 60%max groups, and the resting and 80%max groups, with $p = 0.007$ and $p = 0.034$ respectively. However, there was not a significant difference in reaction time was observed between the 60%max and 80%max groups, with $p = 0.397$. When comparing all three heart rate groups, an ANOVA produced a significant difference of $p = 0.019$.

One-tailed t-tests yielded no significant differences in $\%SpO_2$ levels between any of the groups. However, an ANOVA did produce a significant difference in $\%SpO_2$, with $p = 0.016$.

Female Cohort

Significant differences in reaction time within the female cohort were observed between each group. One-tailed t-tests produced values of $p = 0.015$, $p = 0.003$, and $p = 0.008$ for the resting versus 60%max, resting versus 80%max, and 60%max versus 80%max groups, respectively. An ANOVA likewise resulted in a significant difference in reaction time, with $p = 0.001$.

There were no significant differences in $\%SpO_2$ levels observed between any groups for any applied statistical test. With that being stated, an ANOVA did approach a significant result, with $p = 0.066$.

Discussion

One limitation of this study is the assessment of reaction time by using only the meter stick reaction time test. It is hard to tell if the improved (decreased) reaction times were due to increase brain function after exercise or a learned response to the test. Even though five different reaction time tests were administered at random intervals to minimize the effects of memory, participants could have become familiarized with the conventions of the tests. A learned response to the reaction test would explain why participants improved after each trial. There were two methods used to reduce the possibility of a learned response: teaching the subject how to do the reaction test immediately before the experiment as simplistically as possible and by the use of random intervals for dropping the meter stick in the reaction time test.

It is possible that the periods in which the target heart rates were maintained were too short (just 45 seconds). This may not be a long enough time for a change in blood oxygen saturation to have an effect on reaction time. Blood oxygen saturation may take prolonged activity to have a significant change.

Another source of error was that the population size was relatively small (n = 20). This caused potential outliers to have a greater effect on results and statistical significance than in a large population size.

Additionally, the placement of the thumb near the meter stick, the distance between the thumb and index finger, and the time that it takes to measure the reaction time was important. In order to keep this process effective and accurate the meterstick was marked with masking tape where the subjects fingers should be. The width of the meterstick was used as a way to keep the subject's thumb and index finger at a consistent distance. After the subjects stopped pedaling and held their heart rate for 45 seconds, these measurements were taken as quickly as possible.

Varying the bicycles used throughout the duration of the experiment, along with having different resistance settings, might have influenced the results. Too low of a resistance could have made it more difficult for the subjects to increase their heart rate, thus requiring more time to complete the required biking exercise. Whereas, a higher resistance may have caused the subjects to work too strenuously, which would have increased the heart rate and lowered the $\%SpO_2$ at a faster rate. To combat this issue, the same bike was used and an experimenter tested the resistance before the test to insure that it was at an appropriate level. We found it most helpful to allow the subjects to adjust the resistance for their own comfort.

During test trials the oximeter was not working, which caused fluctuations in the measurements obtained. This made it more difficult to determine whether or not the heart rate was kept steady at both 60%max and 80%max. The conclusion was that the underlying issue with the Nonin pulse oximeter was a result of dying batteries and a clenched hand that was connected to the finger clip sensor. Solutions were found to both of these problems before the experiment began. New batteries were installed into the Nonin pulse oximeter and the subjects were asked to keep their non-dominant hand (attached to the Nonin pulse oximeter) lightly held to their chest during the experiment. This allowed for accurate readings to be obtained.

This study looked at effects of $\%SpO_2$ and heart rate on reaction time. An improvement (decrease) in reaction time with the increase of heart rate and $\%SpO_2$ were the expected results. The decrease in reaction time that was observed in the total cohort between the resting heart rate and 60%max groups, as well as resting heart rate and 80%max implies that increasing one's heart rate, for even a short period of time, does lead to decrease in reaction time. It was not surprising that there was a weak correlation seen between raising the heart rate from 60%max to 80%max since this is the smallest change in heart rate that was measured. However, the ANOVA test did show significant results when it compared all three heart rates indicating that there is some correlation to a decreased reaction time as heart rate increases.

In regards to the $\%SpO_2$ as measured in the entire cohort, there was not a significant difference between the reaction time at the resting heart rate and 60%max. The hypothesis of this experiment was incorrect when it stated that the $\%SpO_2$ would be higher with a higher heart rate and improved reaction time. The results showed that as reaction time improved, the $\%SpO_2$ decreased. Research suggests the reasoning behind this is a sudden onset of exercise without warm-up, causing a decrease in oxygen circulation (Anderson *et al.*, 2014). This would cause the brain to go into survival mode, cutting off oxygen to other parts of the body in order to save the limited oxygen supply for itself. Meanwhile, it was much more of a challenge for the subjects to reach and maintain their heart rates at 80%max for 45 seconds than 60%max. The more intense exertion explains why there was a significant difference in %SpO_2 between both the reaction times seen in 60%max and 80%max as well as in resting heart rate and 80%max.

When separately analyzing male and female cohorts, it was shown that the male cohort followed the trend of the total cohort by not having a significant difference between the heart rate and reaction time when compared to 60%max group to the 80%max group. The female cohort showed these same trends but also had a significant difference in reaction time between the 60%max and 80%max. Intriguingly, for both the male and female cohorts there were no significant results between reaction time and %SpO_2 when just two different heart rates were compared. However, the total cohort had significant differences in reaction time in both the comparison of 60%max versus 80%max and resting heart rate versus 80%max. It would be interesting to run this experiment with many more subjects to see if this trend would continue or if the total cohort would fall out of significance with the additional subjects. Although the %SpO_2 data was not significant when just two different heart rates and reaction times were compared, the male cohort had significant results when the data from all three heart rates were compared and the female cohort had near significant results in the same instances. Despite the fact that there is less evidence in support of the lower levels of %SpO_2 having an effect on decreasing reaction time, there is still enough evidence to warrant further testing to see how closely these two criteria are related.

Based on the results, the blood oxygen saturation decreased in correlation with the improvement (decrease) in reaction time (Figure 5). Duncker and Bache found the opposite in their experiment concerning blood flow during exercise in 2008. This could be because the body takes time to circulate oxygen throughout the body. It isn't clear if the results would be more similar to Duncker and Bache if the exercise time was longer.

Based on the results in Figure 6 for women, it is shown that as heart rate increased from resting to 60%max, reaction time improved (decreased) at a slower rate than between 60% and 80% of the maximum. However, the results for men were different. It was shown that when the mens' heart rates increased (between resting and 60%max), the reaction time largely improved (decreased), and then plateaued between 60%max and 80%max. The calculated average resting heart rate for female participants was 87.3 bpm, which was approximately 14 bpm higher than the average resting heart rate for male participants, which was 73.8 bpm. The higher resting bpm for a woman could mean that she would not have to work as hard to increase her heart rate to 60%max as a man would to do the same task. The presumptive reason for females having a higher resting heart rate in our studies is that females have smaller hearts than males and would therefore have to raise their heart rate to account for the lower stroke volume (Reed *et al.*, 2014).

Conclusion

It was concluded that increased heart rate does increase cognitive function. However, there is not enough evidence to support the notion that blood oxygen saturation levels have direct effects on reaction time.

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Tables and Figures

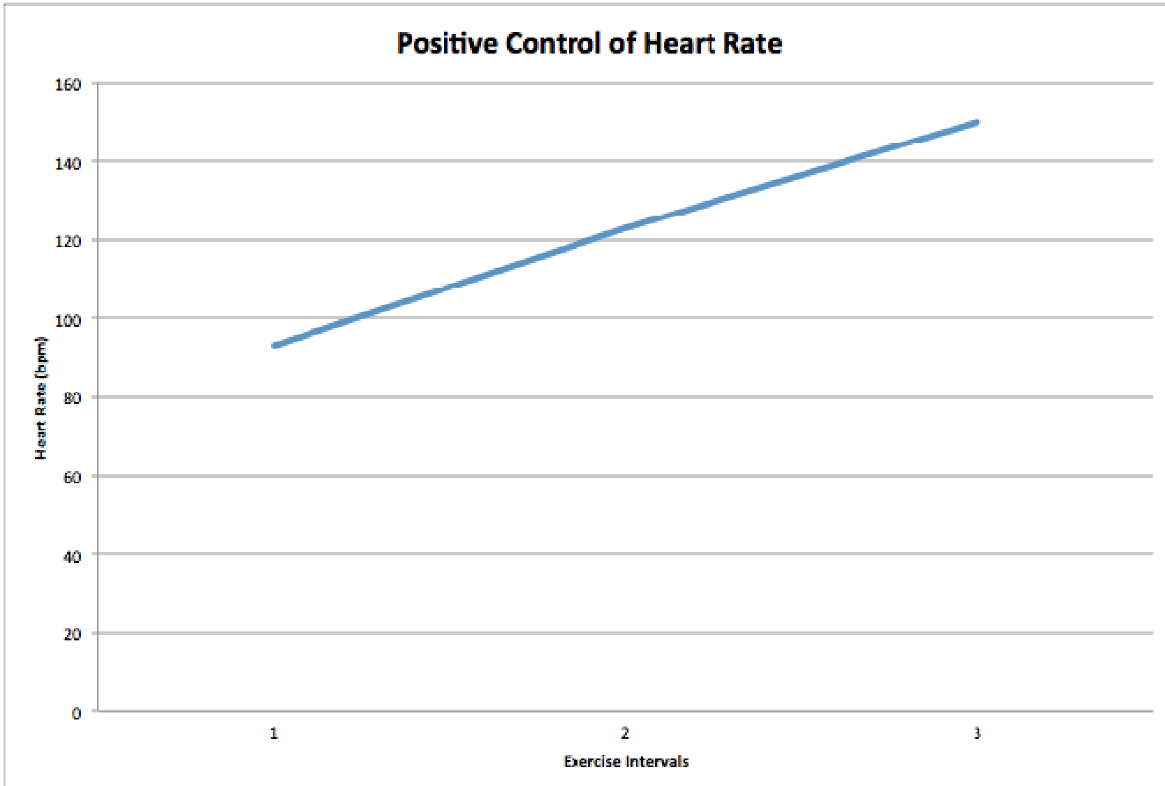

Figure 1: Heart rate increases with exercise. Exercise intervals: 1=resting heart rate, 2=60% maximum heart rate and 3=80% maximum heart rate

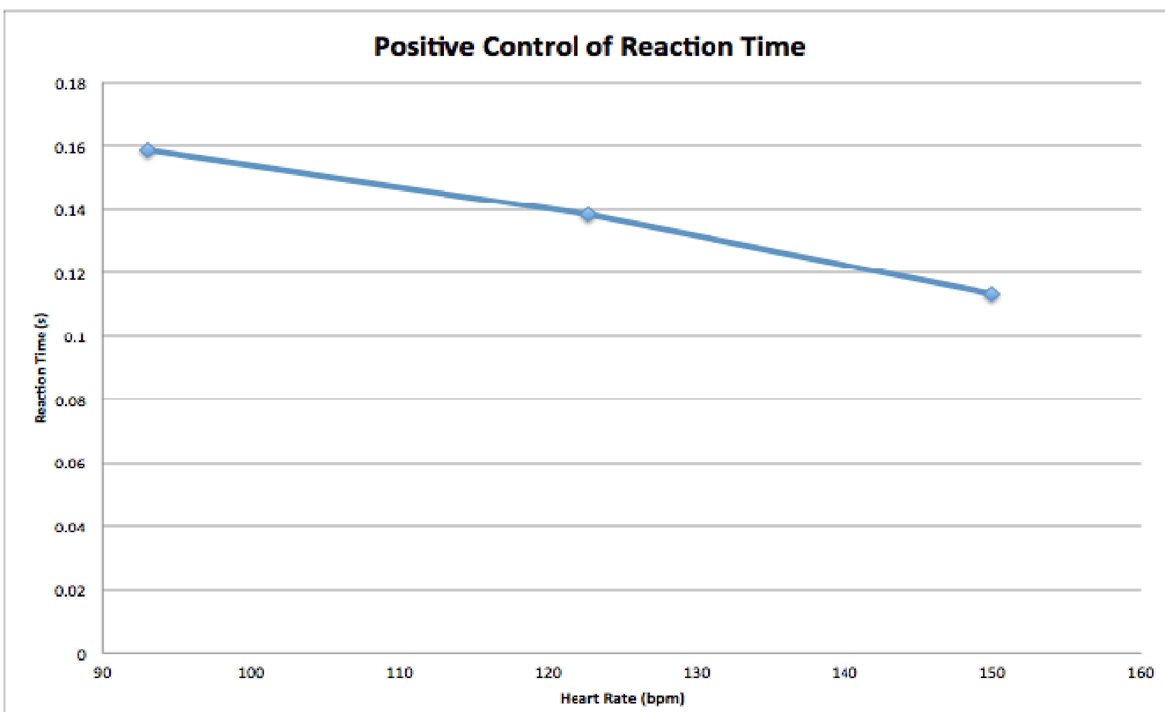

Figure 2: Reaction time improves (decreases) as heart rate rises.

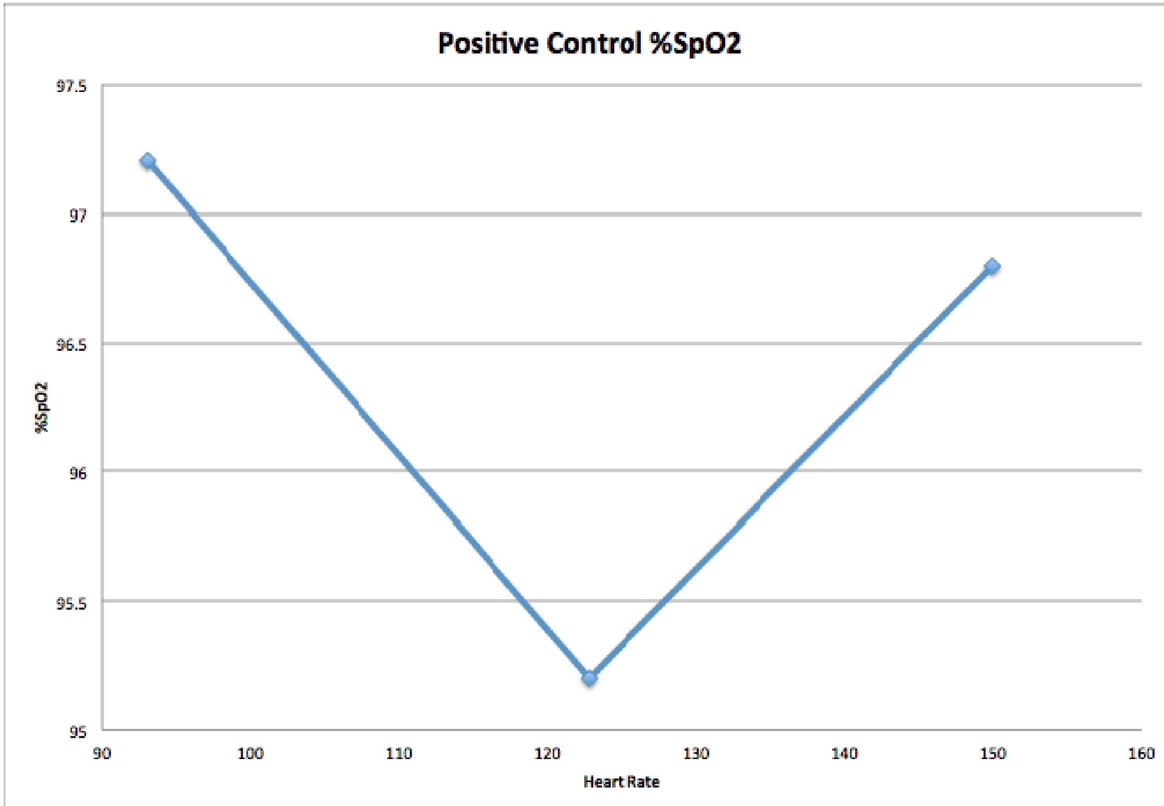

Figure 3: Blood oxygen saturation changes in as heart rate increases.

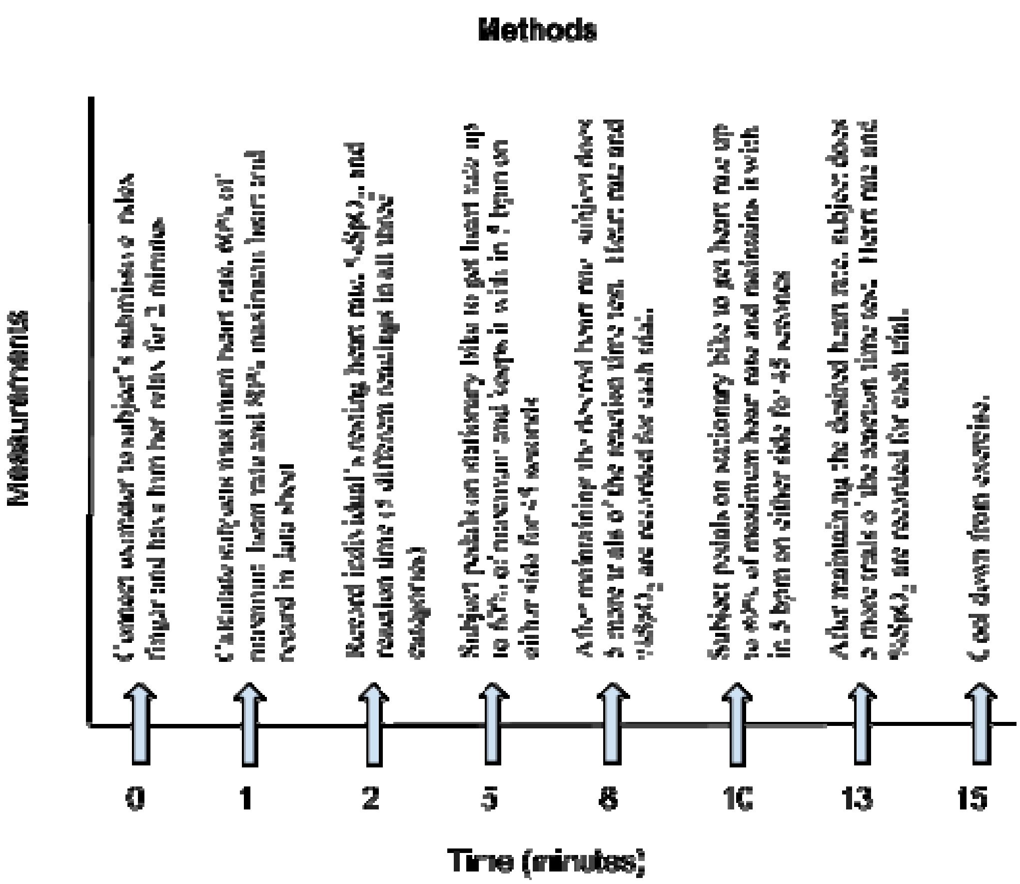

Figure 4: Sequence of experimental events including time intervals.

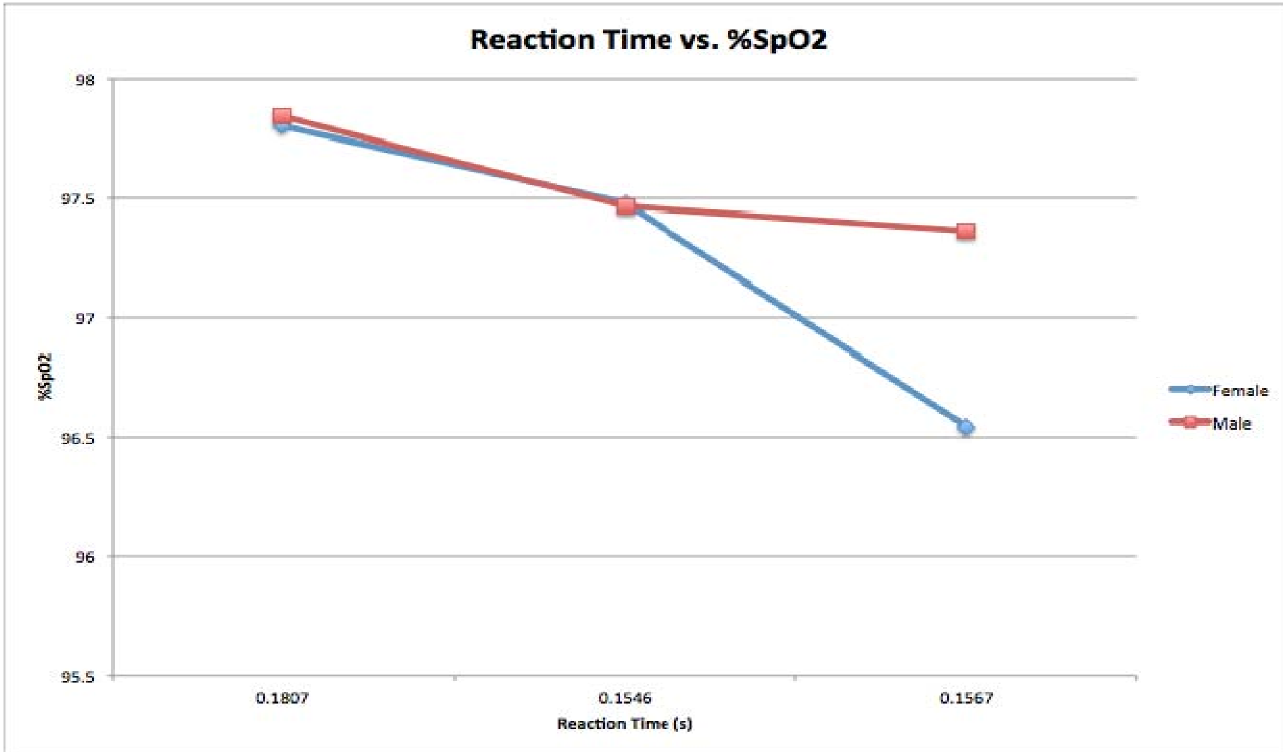

Figure 5: Change in blood oxygen saturation as reaction time improves (decreases) for females and males.

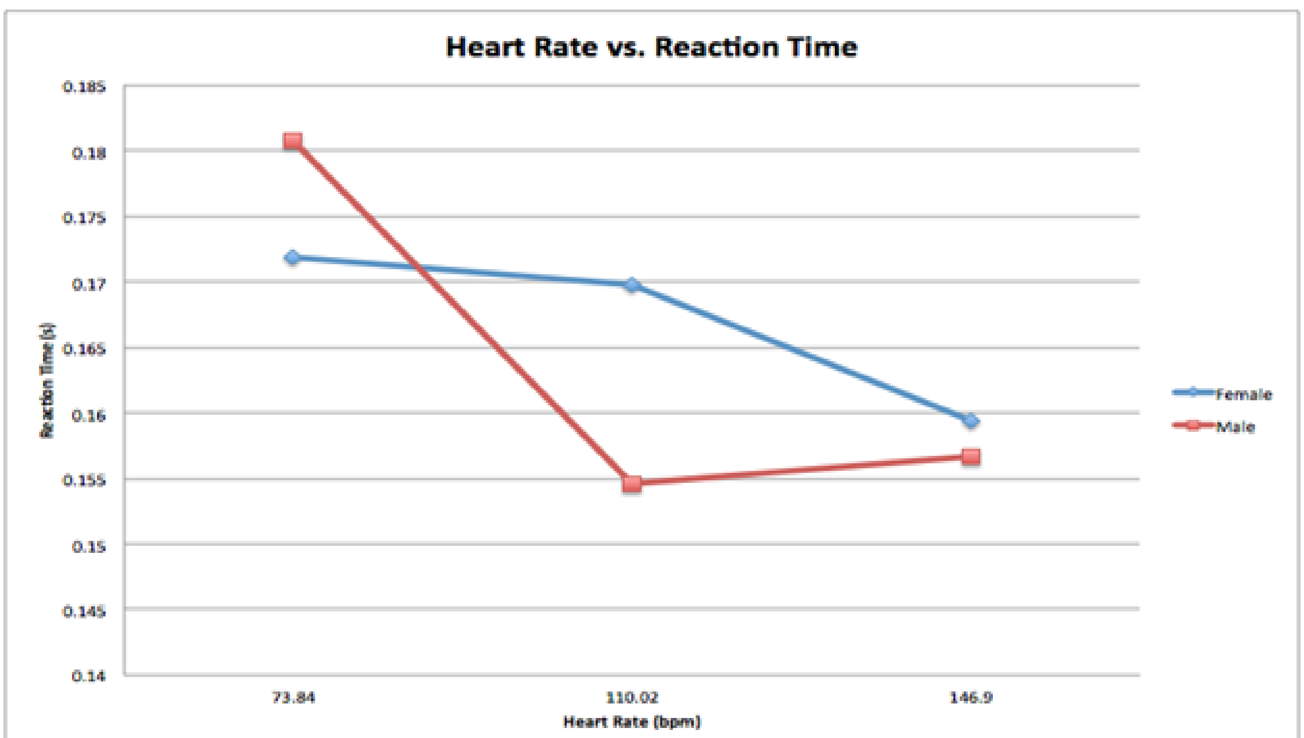

Figure 6: Changes in reaction time as heart rate increases for females and males.