

Examining the Triggers of the Diving Reflex in Human Subjects

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Abstract

This study examined the eliciting conditions of the diving reflex in humans. Sixteen subjects underwent four experimental trials each: breath holding (apnea), diving position, face immersion in water without breath holding (using a snorkel), and experimental dive conditions (water, position and apnea “WPA”). Heart rate, blood pressure, and ECG measurements were used to determine that only face immersion in water elicited the diving reflex, evident by the statistically significant (p -value= 0.03) decrease in heart rate (mean= 14% reduction, mean=66 bpm). Mean arterial blood pressure was also found to be statistically significant in the water, position, apnea manipulation with a p -value of 0.03, an increase from 86 mmHg to 93 mmHg.

Introduction

The diving reflex is a physiological mechanism that allows animals, including humans, to prolong their excursions underwater. We hypothesize this mechanism, the diving reflex, to be enacted by the combination of water touching the face, position of the body in relation to a horizontal plane, and apnea (holding one’s breath).

Purposefully, this is an adapted trait that has allowed for increased survival when animals suddenly dive into water. In all air-breathing animals tested thus far, this diving reflex has been physiologically significant, as it has adapted over time in structure and function (Elsner, 1983). However, the degree of response is relative among species, and a human’s response is less intense when compared to other mammals. This difference in the degree of response may be due to humans evolving as primarily terrestrial beings.

The diving reflex is characterized by bradycardia (slowing of heart rate to less than 60 bpm), apnea, vasoconstriction (a decrease in blood vessel diameter), and hypertension (increased arterial blood pressure due to vasoconstriction). The purpose of these combined reflexes is to conserve oxygen and to redirect blood to the brain and heart.

The major studied effects of the diving reflex are cardiac and vascular changes, which are controlled by nerves originating in the brainstem. The parasympathetic (“rest and digest”) nervous system can induce bradycardia via the vagus nerve. The sympathetic (“fight or flight”) nervous system has a number of effects, including limb vasoconstriction, which shunts blood away from the limbs and re-directs it to the brain and heart. Furthermore, the cardiac pacemaker cells, which control heart rate, are inhibited by sympathetic input via the

vagus nerve. In previous studies, such as those performed by Elsner (1971), Gooden (1994) and Leuenberger (2001), it was found that when the diving reflex was induced, peripheral limb blood flow decreased dramatically at the same time that arterial blood pressure rose. This reflects the elicited limb vasoconstriction response.

Primarily, apnea is essential to the diving reflex so that water is not inhaled into the lungs, but it additionally contributes to energy saving. In response to apnea, nerve stimuli decrease in the diaphragm and intercostal muscles, thus decreasing consumption of ATP. In the same way that bradycardia reduces energy expenditure in the heart, apnea allows the body to expend less energy in moving the diaphragm to breathe. Researchers, such as Gooden, have described apnea as essential for the diving reflex for this reason (Gooden, 1994).

Sheehan's study showed that total immersion of the body in water had the same effect as facial immersion. The high receptor density in the human face may

explain this effect. The most important parts of the face to submerge are the areas around the forehead, nose, and eyes because of the high receptor density in these areas. This is likely due to the ophthalmic division of the trigeminal nerve, which is very sensitive to cold water (Sheehan, 1975).

Gooden also discussed that bradycardia was significantly less dramatic when cold water in plastic bags were applied to subjects' faces, instead of direct facial immersion of water. The best explanation for the reduced response is that less facial receptors were activated, due to the barrier of the plastic bag (Parfrey, 1975).

Again, upon review of prior studies, we believe that submersion of the face in water, apnea, and position of the body in relation to a horizontal plane are the primary triggers of the diving reflex in humans, and predict the combination of all three provoke the strongest physiological response.

Materials: see Figure 1

- Portable ECG
- Electrodes
- Pulse Oximeter
- Sphygmomanometer
- Stethoscope
- 13 Game-Craft®, blue safety mats
- Rectangular tub of water
- Thermometer
- Ice, water
- Velcro bands
- Towel
- Snorkel/nose clips
- Bleach



Figure 1. Materials used in experiment.

Methods:

Subjects included 6 males and 11 females, 20-22 years of age. They participated voluntarily after signing a consent form that outlined the tasks to be performed, and potential risks of participation.

Additionally, the subjects completed a pre-experimental survey, which queried basic background information. Questions addressed the subjects' swimming experience, general fitness as measured by the number of workouts completed per week, the subjects perceived comfort level in water, and the subjects' sex and age.

Three variables were suspected as potential triggers for the diving reflex: apnea, body position, and submersion of the face in cold water. The experiment was designed to monitor effects of these variables.

Electrocardiogram (ECG), pulse oximeter (used for heart rate), and blood pressure measurements were taken during each of five manipulations performed in the experiment.



Figure 2. Subject during experiment that tested water, position and apnea combined.

The first set of measurements (ECG, heart rate, and blood pressure) established baseline data. This initial set of data was taken while the subject was seated, breathing normally.

Next, the subject was instructed to hold his or her breath for as long as he or she felt comfortable, without hyperventilating beforehand. The subject remained seated as in the initial measurement. This was the “apnea” manipulation. The same measurements were taken as in the initial data set, in the same order.



Figure 3. Incline made of Game Craft mats in a 5x4x3 configuration with one mat extended across the top for smoothing.

The third manipulation isolated the effects of body position. The experimental set-up was intended to mimic a diving position by having the subject lay on an incline as shown in Figures 2 and 3. Towers of five, four, and three folded mats were placed adjacently, with an additional mat opened and extended across the top, smoothing the incline. This set-up provided a seventeen-degree incline (Figure 3). The subject's dorsal side faced up, with his or her head at the lower end of the incline. The subject's hands were placed at his or her side with the palms facing up, rather than above the head (Figure 2). This manipulation was referred to as “position.”

The fourth set of data measured the combined effects of position, apnea, and submersion of the face in cold water. The subject remained in the position described

above for the position manipulation, while submerging his or her face up to his or her temples in a rectangular tub of cold water (Figure 2). The subjects were asked to hold their breath for as long as possible, with a gentle reminder that longer was better. As in the apnea manipulation, the subject was instructed to hold his or her breath for as long as he or she felt comfortable and to not hyperventilate beforehand. The tub of water was placed at the end of the incline so it could easily be reached as the subject leaned over the incline. This manipulation was referred to as “water, position, apnea” or the abbreviated, WPA. Water temperature was measured before each subject submerged his or her face into the water.

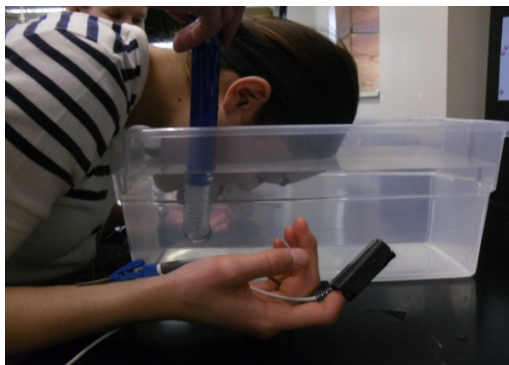


Figure 4. Subject during experiment that isolated the face submerged in water.

The final manipulation isolated the effects of water on the face. After being seated in the chair used for the initial and apnea measurements, the subject was instructed to lean forward to submerge his or her face into the tub of water on the lab bench (Figure 4). In order to control for apnea, the subject was given a snorkel and a nose plug (optional) so they could continue breathing during the submersion. The experimenter ensured that the subject was comfortable using a snorkel, and if not, he or she was provided time to

practice. The subject was informed that the measurement would continue as long as he or she was comfortable, or upon reaching their lowest, stable heart rate for 5 seconds. This manipulation was referred to as “water.” Once again, the water temperature was measured before each subject submerged his or her face.

Care was taken to ensure consistency of measurements across all trials and subjects. This included the order in which readings were taken from each machine, and the way in which the machines were set up.

First, each experimenter was assigned to a particular piece of equipment. This ensured that the measurements were being taken the same way each time, which was especially important for blood pressure measurements.

Additionally, measurements were taken in the same order for each subject. Initial and position manipulations were intended to be steady states, whereas changes were expected over the course of the apnea, WPA, and water manipulations. Therefore separate protocols were used for steady state and variable conditions, but each was consistently applied across subjects. For instance, for steady state trials, blood pressure was taken first, followed by an ECG reading, and heart rate from the pulse oximeter was monitored throughout. For apnea, WPA, and water manipulations, ECG and heart rates from the pulse oximeter were both monitored throughout the duration of the apnea and/or submersion in water. Heart rate was recorded as a range of values, while blood pressure was taken immediately following apnea/submersion period.

The set-up for the ECG, pulse oximeter, and blood pressure cuff remained consistent as well. The placement of the ECG electrodes was especially important. These were placed on the forearms and dorsal sides of the lower legs, using caution so that they would be positioned over a fleshy, muscular area, rather than over bone. Additionally, it was important that the electrodes remained fully in contact with the skin throughout the course of the experiment so that the ECG

could take accurate readings. The forearm electrodes were secured with tape, while the leg electrodes were secured by wrapping Velcro bands around the electrodes. The pulse oximeter was always placed on the right index finger, while the blood pressure cuff was placed on the left arm.

Results were analyzed using ANOVA.

Results:

Subjects' Time in Water and Water Temperature (during WPA) and Initial Heart Rate and Blood Pressure				
Subject #	Heart Rate (BPM)	Blood Pressure (mm Hg)	Time in Water (Sec)	Water Temperature (°C)
1	75	108/75	29	14
2	85	110/85	18	24
3	52	112/52	18	8
4	65	114/65	15	9
5	65	122/65	16	7
6	81	104/81	14	8
7	83	110/83	29	9
8	80	114/80	48	9
9	74	108/74	5	9
10	66	108/66	26	13
11	90	102/90	29	14
12	85	130/84	26	15
13	106	106/82	45	15
14	84	118/84	19	15
15	73	73/112	24	17
16	94	130/94	20	17
17	54	112/85	14	18

Table 1. Summary chart including each subject's initial heart rate and blood pressure, and WPA water temperature and time subjects remained submerged in water, the corresponding water temperatures during WPA manipulation, and initial heart rate and blood pressure measurements.

Heart Rate (Beats per Minute) and Mean Arterial Blood Pressure (mmHg) Experiments		
Measurement (X vs Y)	Averages (X, Y)	P Value
Initial HR vs Apnea HR	77, 77	0.98
Initial HR vs Position HR	77, 75	0.67
Initial HR vs WPA HR	77, 68	0.12
Initial HR vs H2O HR	77, 66	0.03
WPA HR vs H2O HR	68, 66	0.76
Initial MABP vs Apnea MABP	86, 87	0.77
Initial MABP vs Position MABP	86, 82	0.09
Initial MABP vs WPA MABP	86, 93	0.03
Initial MABP vs H2O MABP	86, 88	0.43
WPA MABP vs H2O MABP	93, 88	0.11

Table 2. ANOVA analysis was used to determine whether changes in heart rate and mean arterial blood pressure (MABP) were statistically significant. Heart Rate vs. H2O Heart rate and Initial MABP vs WPA MABP were statistically significant indicated by red ($p < 0.05$). Initial MABP vs Position MABP has an observable trend indicated by green ($p < 0.10$).

Adjusted Heart Rate (Beats per Minute)		
Measurement (X vs Y)	Averages (X, Y)	P Value
Initial HR vs WPA HR	77, 63	0.03
WPA HR vs H2O HR	63, 65	0.81

Table 3. Heart rates were reanalyzed in ANOVA after removing skewed data from subjects whose physical or emotional stress made them unable to complete the tasks at the same level as the rest of the participants. After adjustment, Initial Heart Rate vs WPA Heart Rate was found to be statistically significant ($p < 0.05$), as indicated in red.

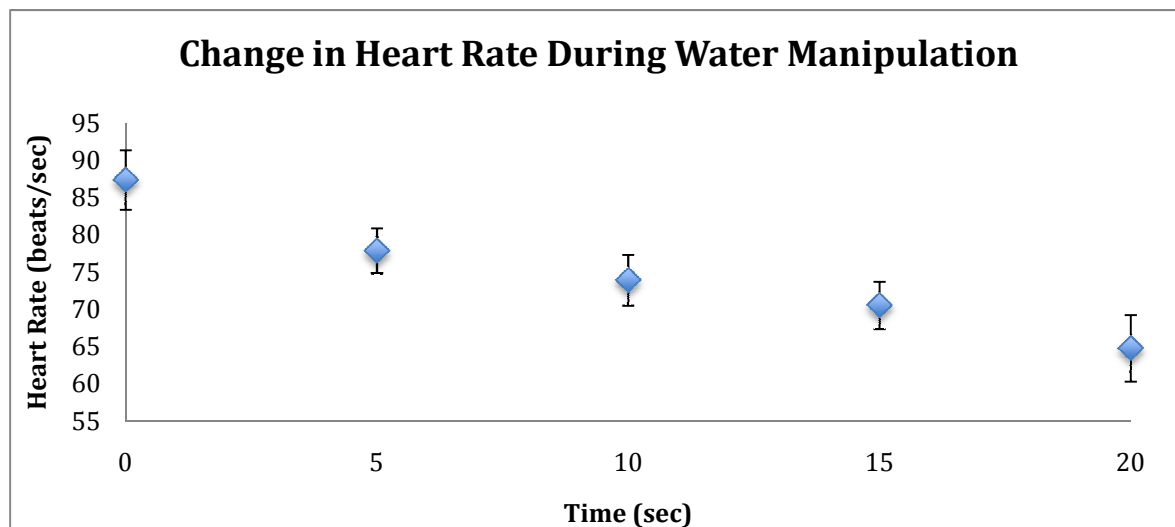


Figure 5. Displayed are the mean heart rate in beats per minute at time intervals 0 sec, 5 sec, 10 sec, 15 sec, and 20 sec during the face immersion in water variable. Error bars indicate subject variability.

The average initial heart rate at rest for all subjects was 77 beats per minute. When the subject's face was submerged in water while breathing through a snorkel, their heart rate dropped on average to 66 beats per minute. This was a 14% decrease in heart rate, suggesting that the heart may have been approaching bradycardia. When the data was analyzed using ANOVA, the difference between initial heart rate and face submersion in water without apnea ("Water") was found to be statistically significant with a p-value of 0.03 (Table 2 and Figure 5).

The average initial mean arterial blood pressure (MABP) was 86 mmHg, whereas the average MABP for the WPA manipulation was 93 mmHg. This yielded a 7.9% increase in MABP. The increase in MABP was found to be statistically significant with a p-value of 0.03 when analyzed using ANOVA (Table 2).

A trend was observed ($p=0.09$) when comparing initial MABP and position MABP. The average initial MABP for subjects was 86 mmHg, while the average MABP for the combined WPA manipulation was 82. This yielded a decrease of 5.1% (Table 2).

ECG Results:

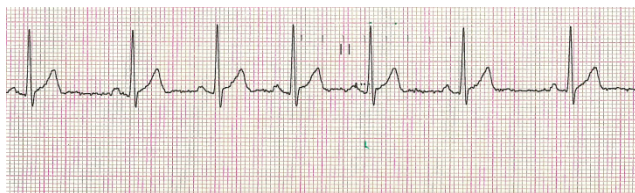


Figure 6. Subject 16's ECG recording during rest.

The average initial heart rate, when compared to the average heart rates for both the apnea and position manipulations, was found to be insignificant. The average apnea heart rate and average position heart rate were found to be 77 and 75 beats per minute, respectively. P-values comparing these manipulations to initial measurements were 0.98 and 0.67, respectively (Table 2).

When comparing initial MABP measurements to apnea and water MABP measurements, insignificant p-values of 0.77 and 0.43 respectively were found. In addition, an insignificant p-value of 0.76 was found when comparing heart rate for the WPA manipulation to the heart rate for the water only manipulation. WPA MABP compared to water MABP yielded an insignificant p-value of 0.11.

Upon initial analysis, possible erroneous data was observed for the WPA experiment. After removing these skewed data points, new p-values were obtained. Initial heart rate compared to WPA heart rate yielded a P value of 0.03, and WPA heart rate compared to water heart rate yielded a p-value of 0.81 (Table 3). The p-value of 0.03 for adjusted heart rate data indicates that the water WPA manipulation was significant ($p<0.05$).

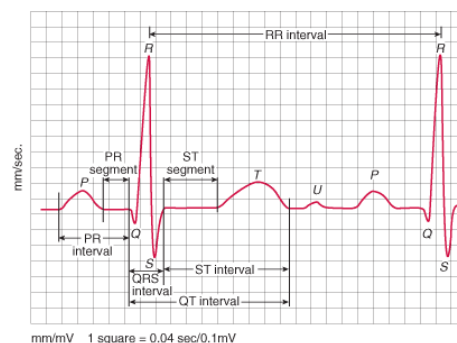


Figure 7. A sample ECG recording, which describes the segments of the waves and intervals. In our analysis we measured the amplitude of the R wave, the P-R interval and the R-T interval (12 Lead ECG Explained).

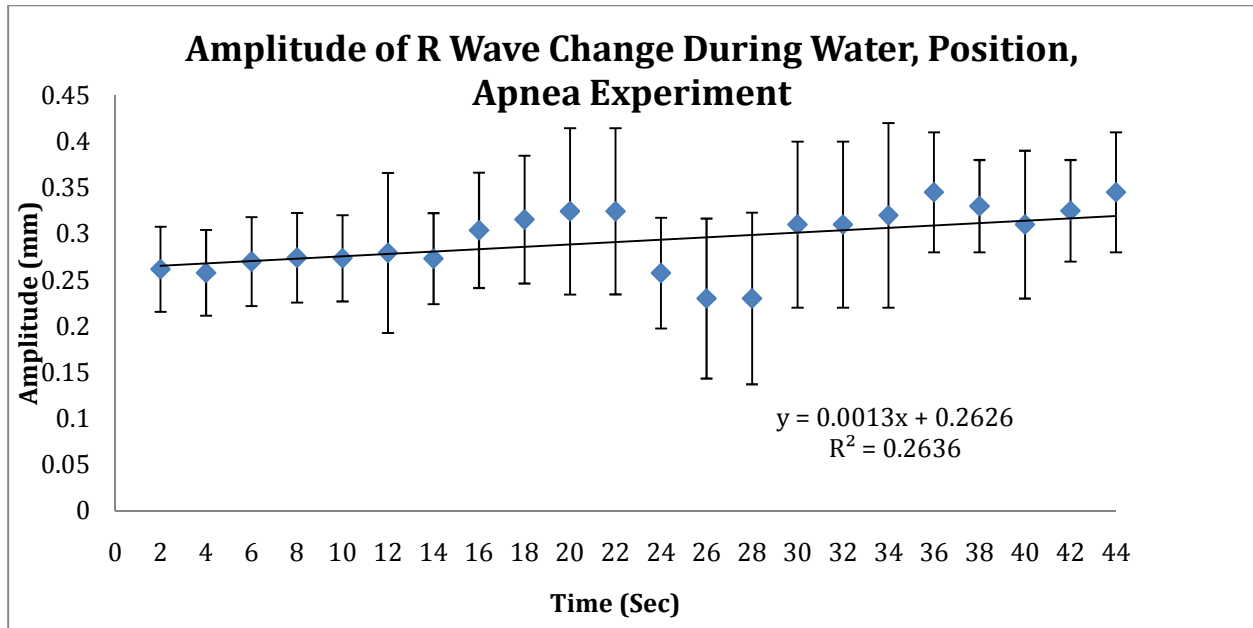


Figure 8: Electrocardiogram data from WPA. Average amplitude of the R wave is plotted against time for the duration that the subjects kept their faces submerged.

Amplitude of the R Wave (mm)		
Measurement (X vs Y)	Averages (X, Y)	P Value
Initial Amplitude vs Apnea	0.31, 0.31	0.79
Initial Amplitude vs Position	0.31, 0.28	0.64
Initial Amplitude vs WPA	0.31, 0.26	0.49
Initial Amplitude vs H2O	0.31, 0.30	0.91
WPA vs H2O	0.26, 0.30	0.56

Table 4. ANOVA statistical analysis of amplitude of the R Wave measured from the ECG. The results found all variables to be statistically insignificant.

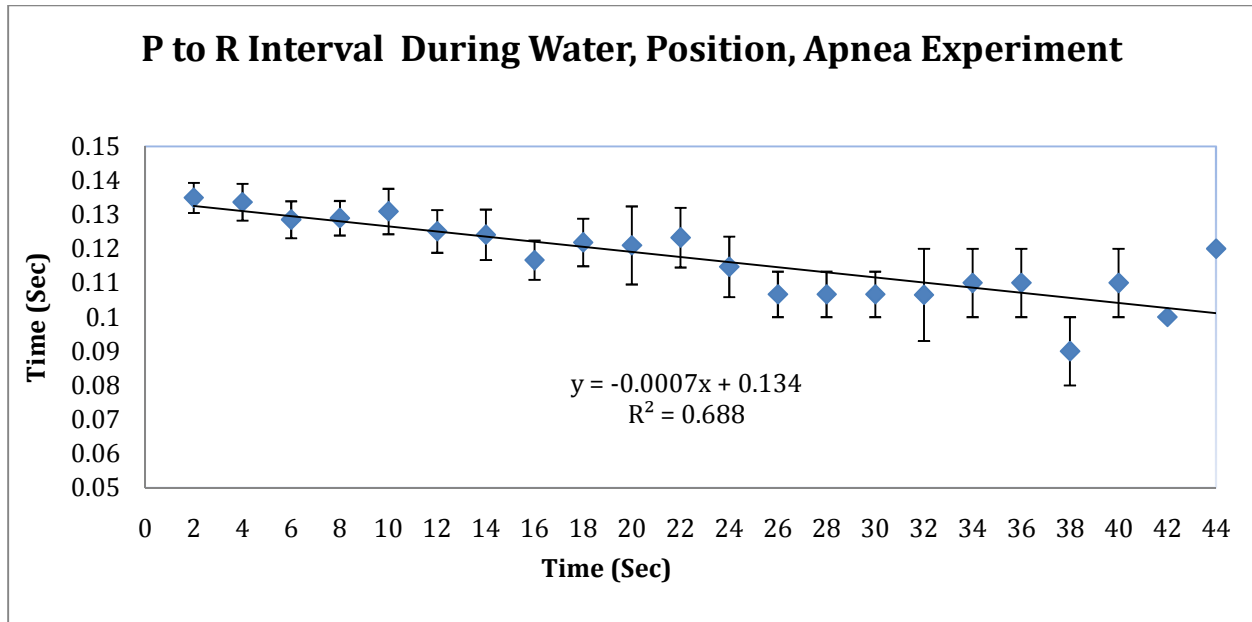


Figure 9: Electrocardiogram data from the manipulation that combined submersion in water, body position, and apnea. Average time between the P and R waves is plotted against time for the duration that subjects kept their faces submerged.

P to R Time (Sec)		
Measurement (X vs Y)	Averages (X, Y)	P Value
Initial Amplitude vs Apnea	0.13, 0.13	0.31
Initial Amplitude vs Position	0.13, 0.13	0.97
Initial Amplitude vs WPA	0.13, 0.12	0.21
Initial Amplitude vs H2O	0.13, 0.13	0.35
WPA vs H2O	0.12, 0.13	0.68

Table 5. ANOVA statistical analysis of the distance between the P and R Wave measured from the ECG. The results found all variables to be statistically insignificant.

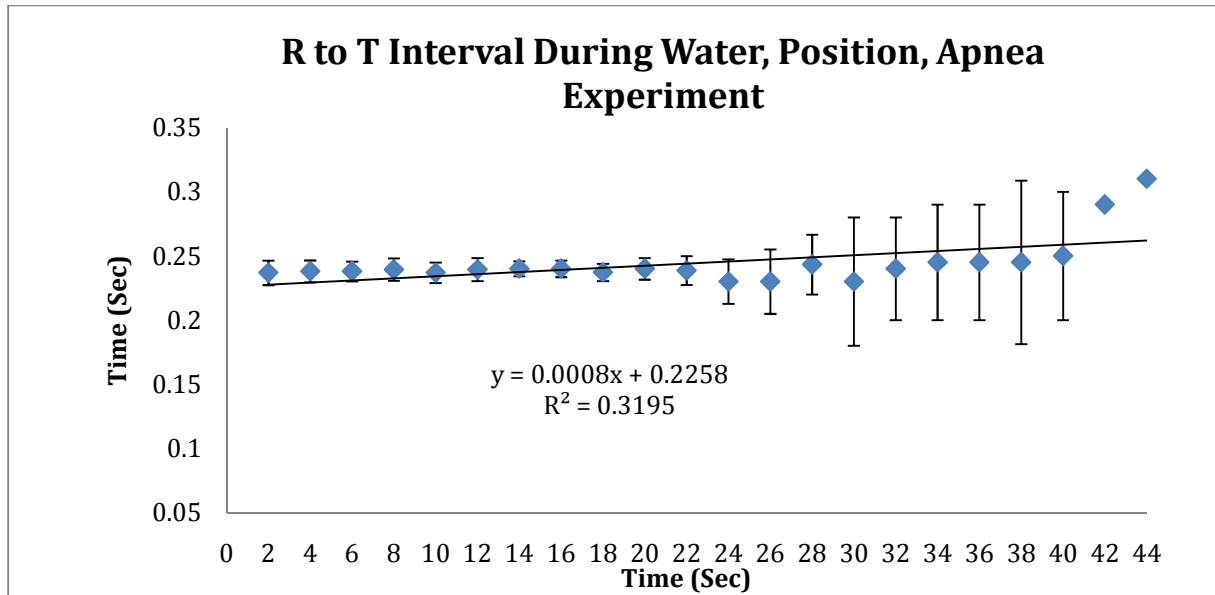


Figure 10: Electrocardiogram data from the manipulation that combined submersion in water, body position, and apnea. The average time between R and T waves is plotted against time for the duration that the subjects kept their faces submerged.

R to T Time (Sec)		
Measurement (X vs Y)	Averages (X, Y)	P Value
Initial Amplitude vs Apnea	0.25, 0.25	0.92
Initial Amplitude vs Position	0.25, 0.25	0.77
Initial Amplitude vs WPA	0.25, 0.24	0.18
Initial Amplitude vs H2O	0.25, 0.24	0.40
WPA vs H2O	0.24, 0.24	0.59

Table 6: ANOVA statistical analysis of the distance between the P and R Wave measured from the ECG. The results found all variables to be statistically insignificant.

Three measurements from the WPA electrocardiogram data were taken (figure 6). All measurements were taken every two seconds for the duration that the subject's face remained submerged.

In the first measurement, the amplitude of the R waves was measured, as shown in

Figure 8 and Table 4. High variability yielded an insignificant R^2 of 0.26 for a linear trend line. Next measured was the P to R interval, as shown in Figure 9 and Table 5. The linear trend line gave a slope of -0.01 seconds per second, meaning that the interval decreased slightly over the submersion period. The R^2 value was the

highest for this graph compared to the other electrocardiogram graphs, but nonetheless, was not significant ($R^2 = 0.69$). The next measurement was the R to T interval, as shown in Figure 10 and Table 6. While the averages seem to remain fairly constant (slope = 0.0008 seconds per second), the dramatic increase in variability after 24 seconds only allowed for a linear trend line with an R^2 value of 0.32, which is insignificant.

Discussion:

We initially hypothesized that all three variables (water, position and apnea) were required to trigger the diving reflex; however, after analyzing our results, the data suggests that water alone was the primary trigger. Due to the high p-values found in Table 1, it was determined that apnea and position did not trigger the diving reflex because the heart rate did not statistically change during manipulation. Likewise, we also found insignificant differences between the initial MABP and the MABP measurements taken in the water and apnea experiments.

While apnea and position manipulations alone did not trigger a significant response, submersion of the subject's face in water did elicit a significant response. This significant data suggests that water is the primary trigger for the bradycardia response of the diving reflex. Therefore, when water is involved in any manipulation, heart rate should decrease to some extent.

Surprisingly, this result was not reflected in our initial analysis of the data from the WPA manipulation. Further thought and analysis was needed to explain this finding.

After review of our raw data and pre-experimental surveys, we realized that three subjects were exposed to environmental and internal conditions that were inconsistent with the rest of our subject pool. Subject 9 indicated an illness that made it difficult to breathe, and as a result, the subject was able to remain submerged in water for a mere 5 seconds during the WPA manipulation. This brief time (5 seconds) is likely not long enough for the diving reflex to fully develop. Therefore, we believe, the subject's heart rate did not have a chance to respond.

To further bolster this belief, we examined our data and observed that other trials of the WPA manipulation consistently resulted in a brief increase in heart rate before undergoing the full dive response (a decrease in heart rate). We hypothesize this rise in heart rate may be due to the initial physiological shock experienced when water hits the face. Because of the brief time period that subject 9 spent submerged in the water, a decrease of heart rate due to the dive reflex was not observed, only the initial increase or spike. For this reason, we decided to reanalyze our data with subject 9's data omitted (Table 3). Subject 5 also reported discomfort due to the cold temperature of the water. For this trial, we used water that was 7 °C. This affected the subject's ability to remain reasonably relaxed, resulting in possible skewed data. Again, this subject was removed during reanalysis. Our last outlier subject indicated prior to experimentation that he or she was under high levels of stress and was currently ill. For this reason, we decided to omit this subject upon reanalysis.

Even after removing these outliers, only 7 of our subjects attained a low heart rate of less than or equal to 60 beats per minute. As a physiological definition, the condition of bradycardia refers to a heart rate of 60 beats per minute or less. While not all subjects dropped to this value, we can reasonably say that our subjects were approaching bradycardia, as shown by the consistently decreasing heart rates observed in the WPA and water manipulations. Because subjects were only instructed to remain submerged for as long as they felt comfortable, rather than for a set amount of time, it is likely that some submersion times were too short to elicit a full-fledged diving reflex. Thus, while their heart rates began to decrease, they may have dropped further had the subjects remained submerged.

After reanalyzing our data without the three outlier subjects, the average heart rate for the WPA manipulation compared to the initial heart rate was significantly lower. The p-value of the data before omitting the outlier subjects was 0.11 indicating a trend, while the data omitting the outlier subjects resulted in a significant p-value of 0.03 (Table 3). This additional way of evaluating the data supports our original finding that water is the main trigger for the diving reflex.

Various conditions of the diving reflex also had an effect on the subject's blood pressure. When testing apnea's effect on the diving reflex, we observed no difference in average MABP from the initial measurement, as evidenced by the high P value of 0.77. Isolating the position variable by asking the subject to lie on the incline

resulted in a decrease in MAPB from the initial MAPB measurement. This can be explained because pumping blood in a subject's body requires less work to compete against gravity while on the incline than it did when sitting upright in a chair for the apnea and water manipulations. The opposite response (an increase in MABP) was observed during the WPA manipulation, as the blood pressure measurements were significantly higher than the initial readings. This data suggests that cold water introduced in the WPA manipulation acts as a stressful stimulus on the subject, causing his or her blood pressure to increase. The stressor introduced by water has a much stronger effect on MABP than the subject's position. Because we observed a decrease in average MABP during the position manipulation, but an increase when compared to average MABP during the WPA manipulation, we can again conclude that submerging the face in water overrides the responses produced by position.

The electrocardiogram data allowed us to search for changes in cardiac conduction velocity and the degree of ventricular depolarization. Our analysis was performed for the data in the WPA manipulation. The P to R interval indicates the time between atrial depolarization and ventricular depolarization, which is the time required for the atria to contract. Nothing significant about the P to R interval was determined in the data (Figure 9, Table 5). Like the P to R interval, the R to T interval represents conduction velocity. This interval is the time between ventricular depolarization and repolarization, indicating the time from ventricular contraction to relaxation.

Because it is primarily the sympathetic division of the nervous system that regulates ventricular contraction, ventricular contraction to relaxation time also provides insight to sympathetic activity. However, no significant changes in the R to T interval were found (Figure 10, Table 6), so we cannot conclude anything significant about sympathetic activity. Finally, the amplitude of the R wave was measured to provide information about the degree of ventricular depolarization, indicating the strength of ventricular contraction. As with the measurements of conduction velocity, no significant values were discovered (Figure 8, Table 4).

Like all scientific research, areas within our experiment were subject to possible experimental error. For example, blood pressure measurements are prone to variation between subjects. We attempted to keep our measurements as consistent as possible by having the same experimenter take each blood pressure reading. Some subjects also had a tendency to move while on the incline, especially after removing their faces from the water. Because the blood pressure measurement was taken immediately following facial submersion, these movements between manipulations could have introduced variation in the blood pressure readings.

Another experimental error we encountered was due to the subject's breathing. Although subjects were instructed to take a normal breath before the apnea measurement and to avoid hyperventilation, there were varying degrees of inhalation between subjects. While we tried to take each measurement at

the same time, the measurements were often inadvertently taken at different time points of the diving reflex progression. For example, because each subject was able to perform the apnea and WPA manipulations for unique amounts of time, the duration of time that the diving reflex had to develop was different. Therefore, although the heart rate and blood pressure measurements were taken in the same order for each subject, the specific progression of the diving reflex that the subject had developed was different. While interpreting data, it is important to be wary of these confounding variables.

In future experiments, the duration of the manipulations would be standardized. For instance, they would receive prior instruction as to how long to hold their breath or keep their faces submerged for the apnea and WPA manipulations. Subjects who are not able to adhere to this instruction would be excluded from the data analysis. Upon reviewing the amount of time our subjects were able to remain submerged, we suggest at least 20-25 seconds as the standard time.

Future experiments should determine if the diving reflex is a graded response that is correlated to water temperature. For example, this experiment could be performed with a group of subjects who were used in a series of five trials. In each trial, the water temperature would be set to a different temperature 5, 15, 25, 35, and 45 °C, respectively. By monitoring a subject's physiological responses to the varying temperatures, one could determine if the diving reflex is a graded or an all-or-none

response triggered at a particular threshold temperature.

Another experiment that would improve our understanding of the diving reflex may look into what makes the facial submersion of water so pertinent. One could perform an experiment with three groups of subjects. Group 1 would be tested for indications of the diving reflex by the traditional experiment in which the subject would submerge his or her face into water. Group 2 would be tested for indications of the diving reflex by applying sealed bags of water to his or her face. Finally, group 3 would be tested for indications of the diving reflex by providing a stream of cold air to the participant's face. This experimental set up would clarify if it is the direct contact of water that causes the response, or if it is the cold sensory receptors in the face that cause the diving reflex response. The stream of cold air would determine if cold air alone blowing onto one's face would be enough of a stimulus to trigger the diving reflex response.

Habituation was an additional idea we discussed for future experiments. We only performed one trial on each of the participants in our study. Participants commented after the experiment that there was an initial shock when submerging their faces in water. This verbal feedback was consistent with what was observed for the subjects' heart rate. The initial shock likely triggered the sympathetic nervous system, as observed in the initial increase in heart rate when the face was submerged. However, after this initial increase, an even more dramatic decrease in heart rate was

observed. We believe this decrease is due to parasympathetic activity resulting from the diving reflex. In a future study, it would be interesting to note whether over numerous trials the subjects would become habituated to the submersion of their faces in water, and therefore decrease or eliminate the initial sympathetic nervous system's response. This may provide more accurate data when analyzing the bradycardia observed during the diving reflex since most mammals are habituated to diving into cold waters. It may be found that the sympathetic and parasympathetic responses compete with one another during the shock of submersion. Therefore, the observed parasympathetic response may be less dramatic than what would be seen if it was not being masked by sympathetic response to shock. This proposed experiment may provide answers to the question of why aquatic animals have a much greater diving reflex response than terrestrial humans. Zbrozyna performed a variation of this proposed study in which he found that in masked divers, initial tachycardia was not elicited after habituation (Zbrozyna, 1992).

Although we administered an experimental questionnaire, we determined after the experiment that it was not very effective. The first problem we encountered with the survey was due to the subjective levels of comfort that were reported between participants. Ideally, this would have been helpful in eliminating subjects from the study by using their comfort level to determine if they would be able to withstand an adequate amount of time in the water. However, the second problem we had with the survey is that there is not a strong

correlation between reported comfort level in the water and the duration of time subjects were able to hold their breath.

We also discussed the issue of the participants' snorkel experience. Subjects who had never used a snorkel before may have been subjected to additional stress, causing some of the measurements to be partially biased. We tried to minimize this bias as much as possible by allowing the subject to take a few practice breaths before submersion in order to help them feel as comfortable as possible.

As our experiment shows, the primary trigger of the diving reflex is the

introduction of a subject's face into water. Apnea and position had little to no effect on the recorded response. Furthermore, heart rate, not blood pressure or heart conduction, was the best indicator of the natural diving reflex. More experiments should be performed, especially controlling for stress reflexes and allowing habituation. Water temperature may also have a graded effect and must be further examined. We found the diving reflex to be both simple and challenging to study; an elegant response to an age-old stimulus.

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