Cardiovascular Changes in Human Diving Reflex Based on Student-Collected Data in a Physiology Lab Course

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Abstract
In this study, we analyzed data of heart rate and pulse amplitude collected by undergraduate students in a physiology lab course during and after the diving reflex. On average, heart rate was reduced 21% at 15 seconds and 29% at 30 seconds during diving. Pulse amplitude generally decreased but with greater individual variation. There is no difference in the heart rate decrease seen between male and female subjects. Athletes started with slightly lower heart rate but showed the same response as non-athletes during diving. This study provides some variations on the typical diving reflex laboratory activity that could be used with students studying the physiological regulation of cardiac function. https://doi.org/10.21692/haps.2021.006

Key words: diving reflex, heart rate, pulse amplitude, athlete, laboratory activity

Introduction

The diving reflex, characterized by bradycardia, peripheral vasoconstriction, a reduction in cardiac output, and a rise in mean arterial blood pressure, is an innate physiological response present in all air-breathing vertebrates to conserve oxygen and heat. It is sometimes referred to as the mammalian diving reflex. In humans, the reflex may be elicited by face immersion into cold water. Knowledge of the diving reflex has been well established since it was first described in 1786 by Edmund Goodwyn (Godek and Freeman 2020). In recent years, the diving reflex has been used clinically to treat paroxysmal supraventricular tachycardia (PSVT) (Smith et al. 2012).

The mechanism of the diving reflex in humans has been well studied (Foster and Sheel 2005). Diving in cold water (< 21° C/70° F) stimulates facial thermoreceptors, carotid chemoreceptors, baroreceptors, pulmonary stretch receptors, and atrial receptors. The nucleus tractus solitarius (NTS) branch collects these inputs through the trigeminal nerve and projects them to central nervous system centers responsible for respiration and cardiovascular functions, which in turn activates the vagus nerve and other nerves in the autonomic nervous system to produce the cardiovascular responses (the diving reflex) that adapt to the new environment.

Individual variation has been observed in previous studies. The decrease in heart rate generally ranges from 12% to 40% (Alboni et al. 2011; Sterba and Lundgren 1988). Recent studies also suggest the polymorphisms in certain genes like the ACE, REN, and ADBR2 gene may contribute to the variation in the diving response (Baranova et al. 2017). For example, individuals with a polymorphism in the gene ACE and ADBR2 showed the strongest peripheral vasoconstriction in response to diving.

In Physiology teaching, the human diving reflex is widely used as a lab activity for its simplicity and reliable results. Students learn both reflex and cardiovascular functions by observation of the changes in heart rate and pulse amplitude. It is also an activity suitable for the start of the course due to the straightforward experimental setup and data recording process. In this study, we asked two questions: 1) How much individual variation is observed in a typical group of young undergraduates, particularly in a lab course setting? 2) Are common factors such as sex and athletic background correlated with the cardiovascular changes? Overall, our analysis showed that the student-collected data is consistent with the established conclusions, however with greater variation. We hope our results provide insights and a reference for physiology lab instructors to guide students to compare and interpret their experimental data.

Materials and Methods

Data were collected by students enrolled in an undergraduate Human Physiology Lab in 2019. Fourty-two student volunteers, 24 males and 18 females, 18-22 years of age, participated in the diving response experiment. This project was approved by the Institutional Review Board of Gannon University (GUIRB-2019-2-200), and all subjects gave their informed consent and filled out a survey about their age, physical condition, and athletic status. A finger pulse transducer (AD Instruments) connected with PowerLab (AD Instruments, containing an amplifier and a digitizer) was used to capture the subject's pulse. While sitting and after a deep breath, the subjects immersed their face up to the cheeks in a washbasin filled with cold water at 10 – 14° C. Pulses were recorded for 30 seconds at rest, up to 30 seconds during diving, and 30 seconds when the subject came out of the water after diving. Breath-holding above water and after a

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deep breath, was used as the control for comparison. Students measured the real-time heart rate and pulse amplitude using LabChart software and filled in the datasheet for this study. In their lab reports, they compared the heart rate and pulse amplitude observed under the diving reflex and breath-holding conditions.

Experimental data were collected from subjects' lab reports with the consent form and analyzed with ANOVA using a post-hoc Tukey HSD test (Figure 1) or pairwise t-test between two groups (Figure 2). Data are presented as mean ± SEM.

Results

The data showed the average heart rate was reduced from 81.0 ± 2.0 BPM at rest to 68.9 ± 2.8 BPM at 15 seconds into diving, and further to 56.5 ± 2.1 BPM at 30 seconds into diving (Figure 1A). Both reductions are statistically significant ($p < 0.01$). After 30 seconds of recovery, the heart rate returned to 76.0 ± 2.5 BPM, not significantly different from the resting heart rate. The percentage reduction was also examined to eliminate the baseline variation in heart rate. The average heart rate was reduced from 13.7 ± 3.7% at 15 seconds into diving, and further to 28.9 ± 2.5% at 30 seconds into diving. After 30 seconds of recovery, the heart rate recovered to 5.9 ± 2.3% below the resting heart rate (Figure 1C). Breath-holding also caused a decreasing trend in both heart rate and percentage change, but the changes were not statistically significant (Figure 1A and 1C). The percentage reduction at 30 seconds of diving was statistically significantly lower than 15 seconds and recovery ($p < 0.001$).

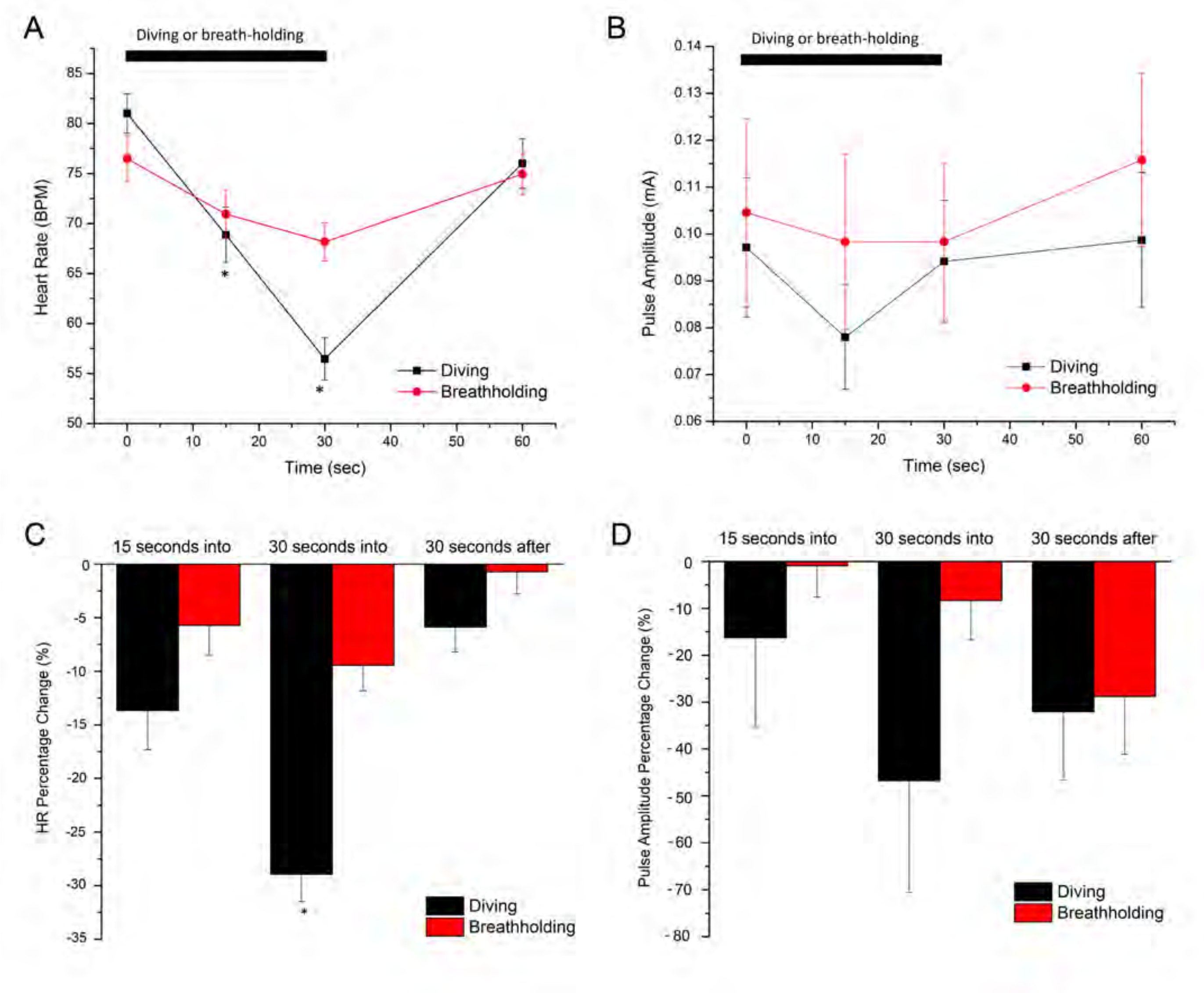

Figure 1. *Changes of heart rate and pulse amplitude during diving and breath-holding. Heart rate decreased in both BPM and percentage in diving and recovered after diving (A, C). Pulse amplitude showed a decreasing trend in diving (B, D).*

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The changes in pulse amplitude showed much greater variation. Percentage-wise, the pulse amplitude decreased 16.3 ± 18.9% at 15 seconds into diving, then 46.8 ± 23.8% at 30 seconds. After 30 seconds of recovery, the pulse amplitude returned to 32.0 ± 14.5% below the resting level (Figure 1D). The pulse amplitude changes were much less in the breath-holding control. Due to the larger variation, these percentage changes in pulse amplitude were not statistically significant. Since finger pulse amplitude is an external measurement, as it may vary by the tightness of the pulse transducer on the subject's finger, the absolute values cannot be compared across individuals. Nevertheless, we still saw a decreasing trend in pulse amplitude values during diving, and not statistically significant either (Figure 1B).

To further investigate the individual variation, we summarized the data in Table 1. In all 42 subjects, reduction of heart rate was observed at 15 seconds and 30 seconds into diving with individual variation. At 15 seconds, 33 subjects showed a decrease in heart rate, two had no change, while seven subjects showed higher heart rate. At 30 seconds, all 40 subjects showed lower heart rates (two subjects could not hold breath under water for 30 seconds). The heart rate decrease showed a wide range, between 5% and 75%, but averaged 21% at 15 seconds and 29% at 30 seconds.

In comparison, data recorded from breath-holding are also summarized in Table 1. At 15 seconds, 28 subjects showed a decrease in heart rate while 11 subjects showed higher heart rates. At 30 seconds, 29 subjects had lower heart rates, while eight had higher heart rates. Throughout the breath-holding, the average percentage of heart rate reduction was only 9%.

We also examined factors that may possibly contribute to the variation of cardiovascular changes and listed the data in Table 2. Between males and females (Figure 2A), we observed no difference between the heart rate before (80.8 ± 2.3 BPM in males and 81.3 ± 3.5 BPM in females) and during diving (at 30 seconds, 55.8 ± 2.7 BPM in males and 57.3 ± 3.5 BPM in females). Both sexes also showed about the same amount of decrease in heart rate.

Interestingly, we observed a baseline lower heart rate in student-athletes (73.0 ± 3.7 BPM), compared to non-athletes (82.9 ± 2.2 BPM, $p<0.05$, Figure 2B). Though this difference diminished in diving (athletes 55.3 ± 4.0 BPM, non-athletes 56.8 ± 2.5 BPM), the percent change in heart rate in athletes was less (24.2%) compared to non-athletes (31.5%). Since the student group was randomly chosen by the enrollment of the lab course, the types of sports these athletes participated were not controlled, including lacrosse, volleyball, wrestling, soccer, dance, competitive cheer, and cross-country running.

		Change	Percentage Range	Average	Overall Average
Diving	Diving at 15 secs	Increase (7/42)	+5% to +71%	+24%	-14%
		No change (2/42)	0%	0%	
		Decrease (33/42)	-5% to -74%	-21%	
	Diving at 30 secs*	Increase (0/42)	n/a	n/a	-29%
		Decrease (40/42)	-5% to -75%	-29%	
	Recovery	Increase (12/42)	+2% to +30%	+11%	-6%
		No change (6/42)	0%	0%	
		Decrease (24/42)	-3% to -36%	-16%	
Breath-holding	Breath-holding at 15 secs	Increase (11/42)	+3% to +36%	+14%	-6%
		No change (3/42)	0%	0%	
		Decrease (28/42)	-2% to -77%	-14%	
	Breath-holding at 30 secs	Increase (8/42)	+1% to +40%	+12%	-9%
		No change (3/42)	0%	0%	
		Decrease (29/42)	-4% to -53%	-16%	
	Recovery	Increase (19/42)	+2% to +30%	+9%	-1%
		No change (5/42)	0%	0%	
		Decrease (18/42)	-2% to -50%	-11%	

* Two subjects were able to sustain 15 seconds but not 30 seconds in water.

Table 1. *Percentage Heart Rate Changes during Diving and Breath-holding*

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	Sex		Athlete Status	
	Male	**Female**	**Athletes**	**Non-athletes**
n	23	17	8	32
Rest	80.8 ± 2.3	81.3 ± 3.5	73.0 ± 3.7	82.9 ± 2.2
Diving at 30 secs	55.8 ± 2.7	57.3 ± 3.5	55.3 ± 4.0	56.8 ± 2.5
% Change in Diving	30.9%	29.5%	24.2%	31.5%
Recovery	76.0 ± 3.1	76.0 ± 4.2	67.6 ± 5.1	78.0± 2.7

Table 2. *Comparison of Heart Rates by Sex and Athlete Status*

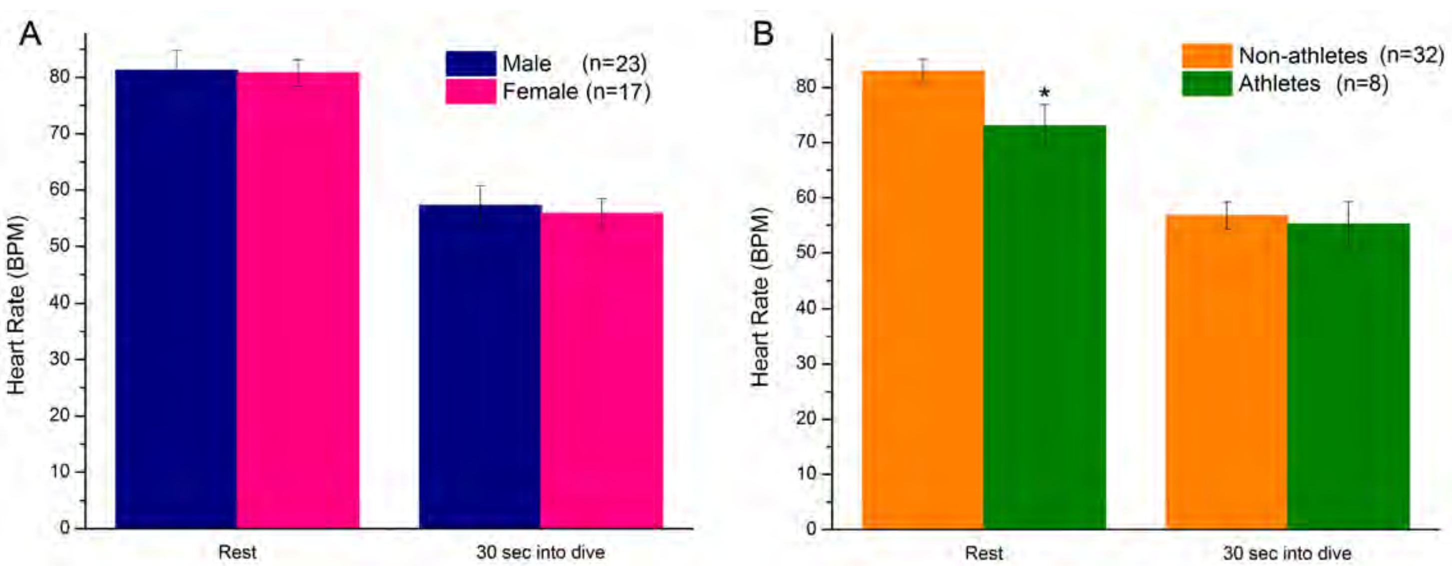

Figure 2. *Comparison of heart rate change between sexes and athletic statuses. Male and female subjects showed similar bradycardia during diving (A). Athletes showed slower heart rate at rest compared to non-athletes but similar responses and heart rates during diving (B).*

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Discussion

In this study, we analyzed student-collected data in a lab course. Overall, the cardiovascular changes we observed are consistent with the observations in published studies in past years (Alboni et al. 2011; Sterba and Lundgren 1988). The heart reduced on average 20% at 30 seconds into diving, and pulse amplitude showed a decreasing trend as well. We did observe greater variation in the sample, particularly with the pulse amplitude data. There might be two causes. First, pulse amplitude may change even without the subject doing diving or breath-holding, at least with our experimental setup. Occasionally, we observed pulse amplitude change at rest, although usually it was stable (Figure 3).

We also examined whether sex and athletic status affect the subject's response in the diving reflex. Our data showed that both males and females responded in a similar magnitude. Although student-athletes started with a lower heart rate on average, the difference diminished in diving. We wonder if the type of sports a student participates in plays a role. We did not have enough racial diversity in the subjects, thus the contribution by any racial and genetic background remains a question. These questions may be answered by future studies with larger sample sizes.

It should be noted that the data analysis for this study was carried out by the investigators with the students being involved in only provision and collection of the experimental data. However, this study could lay the groundwork for laboratory exercises involving both data collection and its analysis by students studying cardiac physiology in the laboratory as they evaluate the influence of various parameters on individual responses during the diving reflex. This in-class activity addresses **HAPS Learning Objectives:**

- **11.10: Describe the influence of positive and negative chronotropic agents on HR**
- **11.12: Describe the role of the autonomic nervous system in the regulation of cardiac output**.

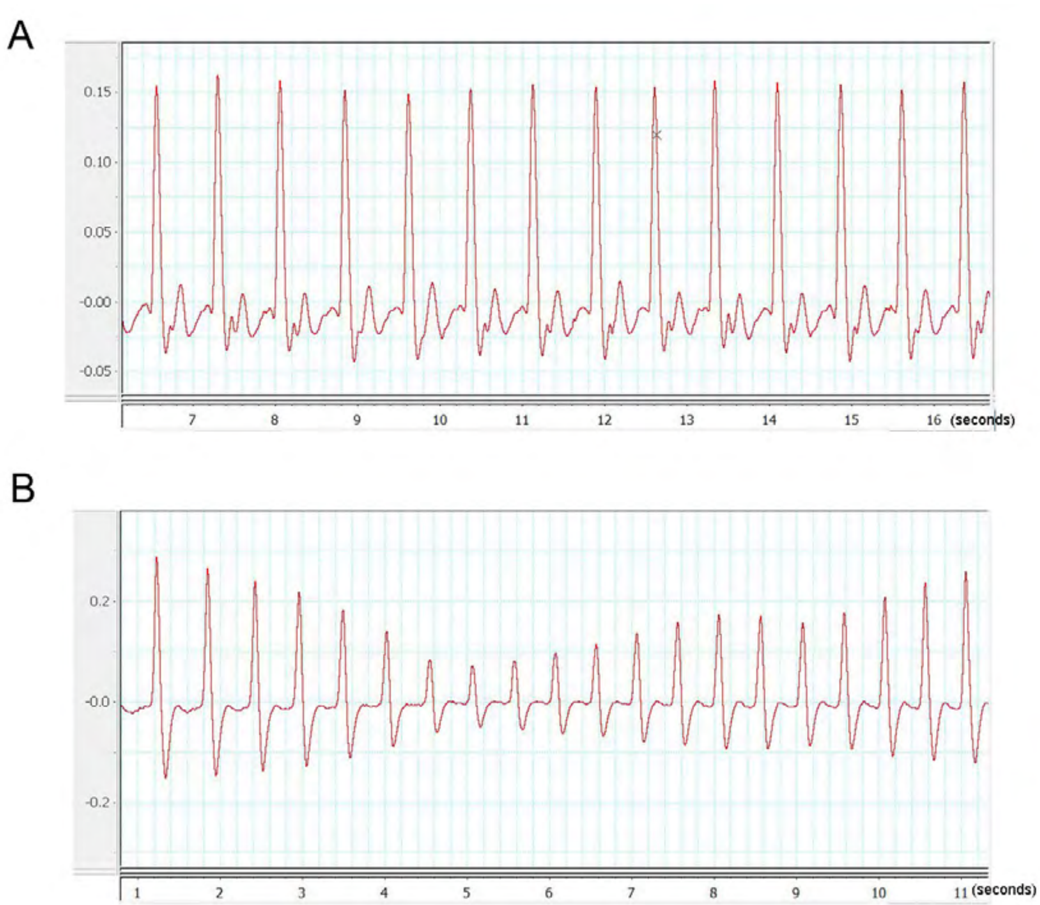

Figure 3. *Variation in pulse amplitude recordings. Both stable (A) and unstable (B) pulse amplitudes were recorded from the same subject at rest.*

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Conclusions

On average, heart rate was reduced from 81.0 + 2.0 BPM at rest to 68.9 + 2.8 BPM (-21%) at 15 seconds into diving, and further to 56.5 + 2.1 BPM (-29%) at 30 seconds into diving. Pulse amplitude generally decreased but with greater individual variation. Male and female subjects showed no difference in their diving reflexes. With a limited sample, athletes started with slightly lower heart rates but showed similar heart rates as non-athletes during diving. We hope our results provide insights and a reference for physiology lab instructors to guide students to compare and interpret their experimental data.

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Both authors are faculty members at Gannon University, Erie, PA. He Liu, PhD, is an Associate Professor and the Chairperson of the Biology Department. Mary Vagula, PhD, is a Professor of Biology. The authors teach multiple sections of Human Physiology and Human Physiology Lab, as well as other courses.

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