ISSN 2250-3153

A Study of Cardiovascular Function in Diving Reflex Response

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Abstract- Humans like most other air-breathing vertebrates exhibit a syndrome known as diving reflex. In man, facial immersion has shown to be sufficient stimulus for onset of reflex. During immersion there is significant slowing of heart rate, and at the periphery, blood vessels undergo constriction. In all animal, diving reflex is triggered specifically by cold water contacting the face. Water that is warmer than 21 °C (70 °F) does not cause the reflex, and neither does submersion of body parts other than the face. The precise mechanism for this effect has been debated. The heart rate and blood pressure is compared here in this study to determine the difference in autonomic changes during breath holding and diving reflex. In this study, 80 healthy subjects (38 males and 42 females) from 18 to25 years were examined to evaluate the effect of facial cooling and apnea in development of diving reflex. Facial immersion was accomplished through the voluntary action of subject into a shallow water bath. The subject was told to remain submerged as long as it was comfortably possible to do so. Throughout experiment, water temperature was maintained. Mean of heart rate and standard deviation was calculated for each of the experimental conditions. At rest, mean heart rate was 77.7±10.95, mean heart rate during hands submersion with breath hold was 70.5±13.63. Mean heart rate with face submersion was found to be 61.46±14.32. Diastolic blood pressure is compared at rest and facial submersion, while breath holding. There is increase in diastolic blood pressure during facial submersion while breath holding (84.85±16.98) than that at rest (74.04±9.78). The result obtained shows heart rate decreases during facial submersion with breath holding compared to that at rest and blood pressure increases during facial submersion with breath holding.

Index Terms- Heart rate, Diving reflex, Breath holding, Submersion, Blood pressure

I. Introduction

In man, facial immersion has shown to be sufficient stimulus for onset of diving reflex.[1] During immersion there is significant slowing of heart rate as well as peripheral vasoconstriction. These adjustments are thought to occur as a result of medullary reflexes.[2] A reflexive response to diving in many aquatic mammals and birds, characterized by physiological changes that decrease oxygen consumption, such as slowed heart rate and decreased blood flow to the abdominal organs and muscles, until breathing resumes. Though less pronounced, the reflex also occurs in certain non-aquatic animals, including humans, upon submersion in water.

Upon initiation of the reflex, three changes happen to a body. Bradycardia is the first response to submersion.[3] It is suggested that cardiovascular adjustments occurs immediately upon facial contact with cold water with human heart rate slowing down ten to twenty-five percent.[4] Slowing the heart rate lessens; the need for bloodstream oxygen, leaving more to be used by other organs. When under high pressure induced by deep diving, capillaries in the extremities start closing off, stopping blood circulation to those areas. Toes and fingers close off first, then hands and feet, as well as gastrointestinal tract and ultimately arms and legs stop allowing blood circulation, leaving more blood for use by the heart and brain. Lastly, the lungs alveoli fill up with blood plasma, which is reabsorbed when the animal leaves the pressurized environment.[5]

It has been postulated that receptor systems for the reflex are sensitive to cold stimuli, apnea and input from facial mechanoreceptor.[6,7] When the face is submerged, receptors that are sensitive to cold within the nasal cavity and other areas of the face supplied by cranial nerve V (trigeminal) relay the information to the brain and then innervate cranial nerve X (the vagus nerve), which is part of the autonomic nervous system.[8] In this study, the effects of diving reflex and breath holding in heart rate (HR) and blood pressure (BP) in healthy adults are compared. Objective of the study was to compare the effects of diving reflex and breath holding in HR and BP in healthy adults, for which different experimental conditions were performed in the subjects, which are comparison of heart rate at rest and facial submersion with breath holding, comparison of heart rate at rest and hands submersion with breath holding, comparison of heart rate while hands submersion and face submersion with breath holding, comparison of heart rate while hands submersion without breath holding and face submersion with breath holding, and lastly, comparison of blood pressure at rest and facial submersion with breath holding.

II. Materials and Methods

Eighty students (38 males & 42 females) aged between 18-25 years were randomly selected for the study among those enrolled in Kathmandu University. Individuals taking medication and those having pulmonary, cardiovascular and other illnesses were excluded from the study. After elaborate explanation of the procedure to the subjects and obtaining consent from these individuals' heart rate and blood pressure were recorded simultaneously. Facial immersion was accomplished through the voluntary action of subject into a shallow water bath. Each subject was instructed to immerse his or her face whenever ready without previous hyperventilation. The subject was told to remain submerged as long as was comfortably possible. Throughout experiment, water temperature was maintained. The experiment was conducted in each individual in the illustrated steps. Subject was given time for stabilizing their normal respiratory rate and to ease with surrounding. Then, heart rate and blood pressure was measured which accounts as normal heart rate and blood pressure. The subject was instructed to hold his breath as long as possible after a normal inspiration. Then, measurement of blood pressure and heart rate during breath holding was taken. Subject was allowed to rest for 2 minutes so that he/she regain his/her normal composure. Measurement of blood pressure and heart rate was taken while submersion of hands in cold water without breath holding (< 21°C). Subject was asked again to submerge hands in cold water but this time asked to hold his breath too and measurement of blood pressure and heart rate in this condition was noted. Subject was allowed to rest for 5 minutes. Measurement of Blood pressure and Heart rate during submersion of face (not other body parts) was noted while breathe holding in cold water. Measurement of blood pressure and heart rate immediately after submersion of face without breath holding (within 15 seconds) was noted. Two vessels, towel, tap water, ice, ice box, thermometer, stopwatch and sphygmomanometer were materials required to perform the procedure.

III. RESULTS

From the data obtained different statistical parameters were calculated. Mean of heart rate and standard deviation was calculated for each of the experimental conditions which are shown in table 1.

Table 1: Heart rates observed during various stages of experiment

Conditions	Heart rate
At rest	77.7±10.95
Hands submersion without breath hold	74.33±11.68
Hands submersion with breath hold	70.5±13.63
Face submersion	61.46±14.32

*Values are means ± S.D.

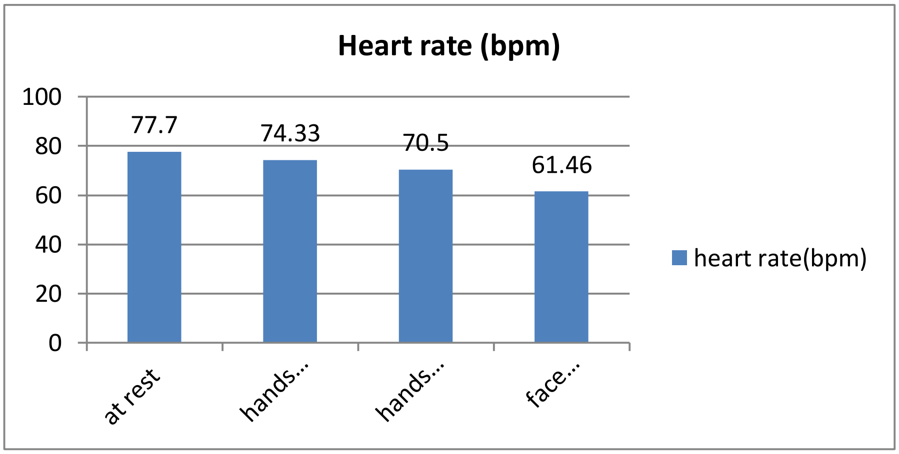

Figure1: Mean value of heart rate (in bpm) obtained at different experimental conditions

At rest, the mean heart rate of 77.7±10.95 is significantly higher than mean heart rate of 61.46±14.32 during face submersion. Hands submersion with breath hold was found to be mean rate of 70.5±13.63 which was lesser than the hands submersion without breath hold (74.33±11.68).

As shown in table 2, blood pressure obtained at rest was mean systolic 115.75±10.69 and during facial submersion while breath holding, mean systolic 125.33±14.36. Similarly, mean diastolic pressure recorded at rest and during facial submersion while breath holding were 74.04±9.78 and 84.85±16.98 respectively.

Table 2: Blood pressure obtained in two different conditions

Conditions	Systolic BP	Diastolic BP
At rest	115.75±10.69	74.04±9.78
Facial submersion while breath holding	125.33±14.36	84.85±16.98

Table 3 illustrates the significant difference in mean values obtained during different experimental conditions for heart rate and blood pressure.

Table 3: t-values calculated compared with t-tabulated value at 0.05 significant level with d.f=78

Cases	t-value	Result	p-value
1.HR compared at rest and facial submersion while breath holding	8.4551	Significant	< 0.05
2.HR compared between at rest and hands submersion while breath holding	4.1381	Significant	< 0.05
3.HR compared between hand submersion without breath holding and facial submersion while breath holding	7.2947	Significant	< 0.05
4.HR compared between hands submersion while breath holding and facial submersion without	6.1692	Significant	<0.05
5.Systolic BP compared at rest and facial submersion while breath holding	6.2592	Significant	<0.05
6.Diastolic BP compared at rest and facial submersion while breath holding	4.1381	Significant	<0.05

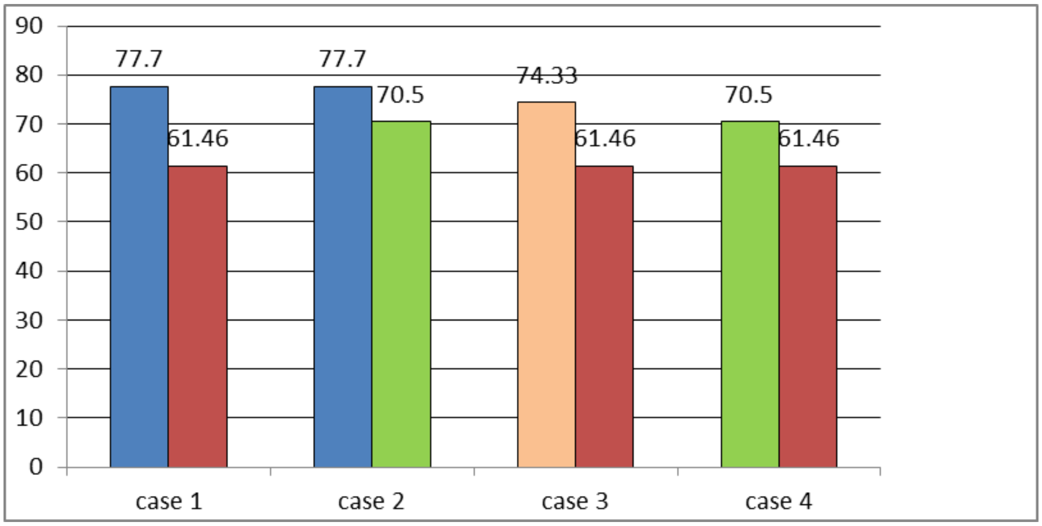

Figure 2: comparison of mean heart rate in four different cases

Case 1: heart rate at rest and during facial submersion while breath holding, Case 2: heart rate at rest and during hands submersion while breath holding, Case 3: heart rate during hands submersion without breath holding and during facial submersion while breath holding, Case 4: heart rate during hands submersion while breath holding and during facial submersion while breath holding.

IV. Discussion

The result obtained signifies that there are significant differences between two parameters in each of the cases. It would be more of value if the knowledge of increase or decrease between the two conditions be obtained which would further add significance to the hypothesis stated. Nonetheless interpretation of values obtained can be done with the graph plotted and on the basis of medical physiology.

Heart rate is compared at rest and during facial submersion while breath holding. In figure 2, case 1 graph shows that heart rate decreases during facial submersion with breath holding than that at rest. The exact mechanism of slowing of heart rate is yet not fully understood. Heart rate slows down in order to lessen the blood supply to other parts of the body.[2]

The first response to the face submersion is bradycardia.[3] It is suggested that cardiovascular adjustment occurs immediately upon facial contact with cold water with heart rate slowing.[4]

Heart rate is compared at rest and during hands submersion while breath holding. This statement observed from this experiment is in contrast to the statement given from previous study. Previous research states that submersion of body parts other than face does not elicit diving reflex.[2] Heart rate may have been decreased owing to the fact that during breath holding, apneic condition is developed i.e. decreased blood supply to the body. So, to compensate for the decreased blood supply condition heart rate slows. It is also to be noted that heart rate has fallen significantly with only peripheral skin being in contact with cold water. From this point of view, it may not be necessary that activation of trigeminal nerve through facial submersion be the only factor to trigger diving reflex but decreasing temperature in peripheral skin be also the another factor to elicit diving reflex. However, further scientific study is required to support this statement. Heart rate is compared between hands submersion without breath holding against face submersion with breath holding. Also, heart rate is compared between hands submersion with breath holding and face submersion with breath holding. There is decrease in heart rate during face submersion while breath holding than that of hand submersion with and without breath holding. It may be explained by the fact that trigeminal nerve activation found exclusively at face may be reason as to why heart rate level is more decreased in facial submersion while breath holding than that of hand submersion without breath holding and hands submersion with breath holding. Trigeminal nerve is extremely sensitive toward the cold sensation.[6] This cold sensation stimulates the afferent part of trigeminal nerve thereby may stimulate the cardiac center present in the medulla which is responsible for bradycardia. Figure 1 also shows that there is more decreased level of heart rate during hands submersion while breath holding than during hands submersion without breath holding. This could be explained by the fact that breath holding leads to oxygen deficit leading to decreased heart rate. However, further scientific study is required to support this statement. There is increase in diastolic blood pressure during facial submersion while breath holding than that at rest as depicted in table 2.

During facial submersion while breath holding there is stimulation of trigeminal nerve which will activate cardiac center and cause peripheral vasoconstriction. The peripheral vasoconstriction leads to decreased blood supply to body extremities so that more of blood is supplied to more important organs like brain and heart. This peripheral vasoconstriction raises diastolic blood pressure.[2,6] When sympathetic system is stimulated both arteries and veins are constricted. Venous constriction leads to increased venous return which increases stroke volume. This increased stroke volume may be responsible for rise in systolic blood pressure which is represented in the table 2. On the physiological basis, systolic blood pressure rises by sympathetic stimulation. It is also true that sympathetic stimulation not only increases systolic blood pressure but also increases heart rate. But, in this case there is decrease in heart rate. So, sympathetic stimulation may not be the reason to increase systolic blood pressure. Increase cardiac output is responsible for increase in systolic blood pressure. Cardiac output depends upon heart rate and stroke volume. For this case, heart rate cannot be considered as a factor responsible to increase systolic blood pressure as there is decrease in heart rate. So, the factor that may cause increase in cardiac output increasing blood pressure should be stroke volume and this increased stroke volume is due to increase in venous return.[9]

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