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Effect of In-water SCUBA Diving Activities on Response Time in Recreational Divers

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Abstract

The purpose of this study was to examine the relationship between the performance of in-water scuba diving training activities and simple motor response time. Twenty-four students enrolled in a scuba course had their motor response times measured before and after a one hour training session. Pre- and post-dive response times were measured using an iPad application. Additionally, students were asked to complete a dive history questionnaire to determine their diving experience and health history. Statistical analysis indicated a significant training effect on response time in the recreational scuba divers F (1.00, 23.00) p =.033. The results of this study suggest that basic in-water scuba training activities may improve one's ability to elicit quicker movement responses and lead to faster cognitive processing.

Keywords: SCUBA, response time, swimming, physical activity, cognitive processing

Introduction

Over the last several decades, scuba diving has increased in popularity throughout the world, for both recreational and professional divers (Sports and Fitness Industry Association, 2015). This increase in popularity has resulted in a rapid expansion of recreational, technical, professional, and military diving opportunities. Although diving is a relatively safe activity, significant injury or death can occur with a fatality rate of 3-6 deaths per 100,000 divers (Denoble, Marroni, & Vann, 2010). The most common problems associated with diving injuries and fatalities are those factors that are influenced by human error and panic such as emergency swimming ascents and improper equipment usage during duress, along with serious and debilitating cardiac events that may be related to the physical stress that may occur during a dive. These types of incidents are often the result of errors associated with slow and/or incorrect movements during unexpected situations that require rapid decision making and motor responses. With more and more divers entering a potentially dangerous marine environment, it is imperative that motor-related research is conducted to better understand how the human body reacts and functions under scuba-specific environmental conditions. Unexpected situational changes, potentially hazardous creatures, rapid currents, and malfunctioning equipment are only a few of the potential hazards associated with open-water diving. Situational awareness and quick motor responses are necessary for survival when complications arise. Therefore, it is important to understand the mechanisms that control how divers react to situational stressors and how the body controls those responses.

The ability to respond quickly is important for any motor tasks that require rapid decision-making and movements for successful task completion. Divers, in particular, are often faced with stressful situations that necessitate accurate, rapid movements, particularly when dealing with an equipment failure that might compromise the safety of the diver. Simply turning off a malfunctioning valve or removing oneself from an entanglement might change from a minor incident into a life-threatening situation if movements are not performed quickly, automatically, and accurately. These situations require the diver to perceive the problem or threat quickly, consciously determine the appropriate responses to that threat, and execute appropriate movements within a time frame that limits their potential exposure to that problem or situation. Successful dive management is based on the ability to perform fluid movements quickly and efficiently with minimal time for detailed processing of environmental changes. Adjusting one's mask, buoyancy control, and manipulation of gas cylinder valves are all examples of movements that must occur quickly and the safety of the diver is often dependent on rapid and accurate performance of motor skills. Thus, response time is a critical safety factor for any scuba diver.

Motor response time is an important measure of a scuba diver's abilities under water as it may have a direct effect on how quickly and safely one can react under stressful conditions and challenging situations. Despite being a relatively safe activity, research reveals that many underwater deaths occur as a result of panic and one's inability to react quickly and appropriately to a stressful event (Denoble, Marroni, & Vann, 2010, Egstrom & Bachrach, 1971). Simply stated, response time is the sum of one's reaction time and subsequent movement time required to complete a task. Response time can serve as a measure of overall movement time production and provides a measure of overall speed of motor function. Factors that can affect reaction time (and therefore overall response time) include arousal levels, age, fatigue, an environmental distraction, and overall skill practice time.

In one of the few investigations examining neuropsychological effects among divers, researchers demonstrated that repeated diving activities elicited a slower reaction time (Bast-Petterson, 1998). Similarly, Alliman and Ragot (2001) examined diving and its effects on cognitive performance at a simulated depth using a pressure chamber. These researchers hypothesized that simple automatic tasks requiring rapid reaction time would be minimally affected by depth changes, while tasks requiring conscious attention and awareness would be more significantly affected. The results of this study confirmed that there were no significant changes in the simple reaction time measures but there were in the more complex tasks.

The cognitive performance of scuba divers and its relationship to safe diving skills has been examined in the research literature (Phillips, 1984). Results suggest that cognitive impairments can occur under even the mildest of environmental conditions. Additionally, researchers have investigated the effect of psychological pressure on cognitive processing speed and movement production (Tanaka, Funase, Sekiya, & Tanaka, 2014). It has been shown that as psychological pressure increases, such as under stressful diving situations and conditions, reaction time is negatively affected, thus potentially leading to inefficient and slower movements. Diving, whether in a confined training pool or in an open water environment, often increases these feelings of pressure or threat, even under the most benign conditions. According to the Yerkes-Dodson Law, performance is related to arousal levels according to the inverted-U function. Arousal levels that are too low or too high have a negative effect on performance (Yerkes & Dodson, 1908). Such a powerful impact associated with arousal can be of particular concern for individuals who engage in high-risk activities. These arousal levels may be influenced by several factors, including the introduction of new and unfamiliar skills or events (Griffiths, Steel, & Vaccaro, 1978), which in turn can slow response times. Cold water temperatures, a condition often faced by open-water divers, may dramatically slow response time and reduce manual dexterity (Stang & Wiener, 1970). Other research has shown that anxiety is often the result of not only a perceived danger often associated with diving activities, but also from none-threatening situations, like participation in safe training activities and even perceived social evaluation from other participating individuals (Griffiths, Steel, & Vaccaro, 1982).

Several studies have shown that physical activity, such as those motor activities required to scuba dive, can affect cognitive performance (Audiffren, Tomporowski & Zagrodnik, 2008; Collardeau, Brisswalter & Audiffren, 2001; Peyrin, Pequignot, Lacour & Fourcade, 1987). It is well known that the human body can adapt and compensate for a variety of inhibitors. When the inhibitor is initially removed there is a brief period of time where the level of performance increases drastically as the body continues to compensate for a resistance which is no longer there. Therefore, the researchers involved in this investigation hypothesized that scuba diving would significantly alter movement response times in college-aged scuba students.

Assessing neurological processing speed in an actual real-world diving environment is difficult due the problems associated with electronic equipment in the water and the resistive properties associated with movement in an aquatic medium. Thus, the ability to assess response time while actually submerged has not been addressed in the research literature. Most research examining changes due to hyperbaric conditions have relied on the use of hydrostatic pressure chambers. Although the effects of pressure change can be simulated in these types of chambers, the actual effects of the aquatic environment, which includes temperature differentials and heat loss due to conduction as well as movement resistance due to water density, cannot be assessed in simulated situations. These physical conditions may have a direct effect on response time due to thermoregulatory changes occurring in a pool or especially in an open-water environment. A secondary goal of this preliminary investigation was to assess the efficacy of using an electronic response timer application to acquire response times as closely as possible to what would occur in the water, immediately following water-based practice activities. An assessment of this type of data collection procedure may ease the difficulty of collecting real-world measurements in an aquatic environment by demonstrating that the use of simple tools like iPads and their applications may allow for portable equipment that is better suited for these types of situations and conditions.

Method

Participants

Upon receiving Institutional Review Board (IRB) approval, forty-eight, apparently healthy, college students (29 males, 19 females) agreed to participate in this preliminary investigation following word-of-mouth recruitment measures. The participants ranged in age from 18-26 years of age (mean = 20.9 years). Following initial recruitment procedures, twenty-four students currently participating in a scuba diving course within an academic Kinesiology Department were assigned to the experimental diving group. Additionally, another twenty-four students were recruited from a lecture-based academic kinesiology course and assigned to a non-diving control group. Regardless of group assignment, all participants had no previous experience with scuba diving activities outside of the skills performed in their individual course. Furthermore, twenty-one members of the experimental group had no previous diving experience. Forty of the participants self-identified as being right-handed, while seven participants self-identified as being left-handed, and one participant self-identified as ambidextrous. (Table 1).

Table 1. Descriptive demographic data comparing divers vs. non-divers

	Experimental group			**Control group**		
Gender	19 (79.2%) Males		5 (20.8%) Females	9 (37.5%) Males		15 (62.5%) Females
Age (Yrs.)	18-26 (Range)		20.9 (Mean)	18-23 (Range)		20.2 (Mean)
Handedness	19 (79.2%) Right	4 (16.7%) Left	1 (4.2%) Ambidextrous	21 (87.5%) Right	3 (12.5%) Left	0 (0%) Ambidextrous

Instrumentation and Experimental Procedures

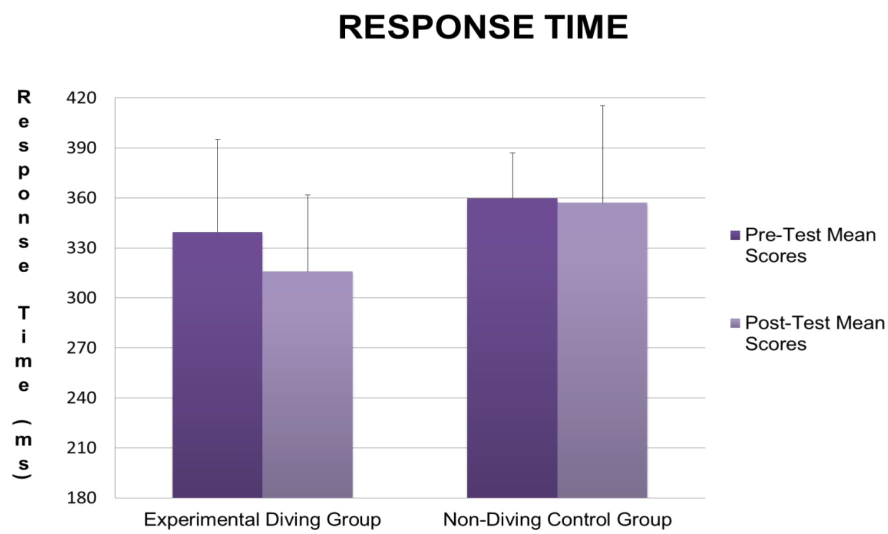
Following a description of the proposed research procedures, all participants signed an IRB-approved consent form and completed a demographic health and dive history questionnaire designed to assess their experience with dive-related activities. Prior to data collection, each participant received written documentation about the purpose of the study. All participants watched a brief demonstration of an iPad based response time test and then completed five pretest trials on the iPad, using their preferred upper extremity, and a mean score of response times was subsequently calculated. All measurements of response times were assessed using the iReaction response time iPad Application (Nathan Roys, 2011) which required the participant to actively touch the screen as quickly as possible following the presentation of a visual stimulus. This visual stimulus was in the form of a standard traffic signal in which the colored lights change on the screen. After the presentation of a warning stimulus prior to each trial, the color on the screen randomly changed from the color red to green, at which time the participant was required to touch the screen. To standardize the test, a ¼ inch foam pad was placed at the bottom of the iPad and subjects were instructed to place their forearm on the foam pad, hovering one-half inch above the touch-screen. All tests were performed while in a seated, upright position, their upper extremity flexed at 90 degrees while resting comfortably on a table positioned over the iPad.

Following completion of the five pretest response time measurements, participants in the experimental diving group (n = 24) actively participated in one hour of in-water scuba training activities requiring rapid and complex upper body and limb movements that included: equipment removal and retrieval, shared buddy breathing, partner-assisted towing, water entries, and mask clearing tasks (Table 2). All motor tasks were performed in an indoor pool at a maximum depth of twelve feet. Participants in the non-diving control group sat quietly reading for one hour in a standardized controlled laboratory setting. Following the completion of diving activities, participants in the experimental diving group immediately exited the pool and within sixty seconds, performed five trials of post-test response time measurements using the iPad application protocol. Participants in the non-diving control group (n = 24) were assessed following the sixty minute period of quiet reading.

Results

A two-way (group x time) analysis of variance (SPSS, v.23, Chicago, IL) was conducted examining the effect in-water motor skills on response time in recreational scuba divers. There was no statistically significant interaction between the effects of group and time on response time, F (1, 23) = 3.414, p = .078, η_p^2 =.129. The main effects indicated that response time was significantly faster after in-water skills training (p = .033) and group response times were significantly different (p = .023). The mean pre-test response time decreased from 339.49 milliseconds to 315.84 milliseconds for the experimental diving group. The mean pre-test response time decreased from 362.34 milliseconds to 357.08 milliseconds in the non-diving group. These results suggest that performing in-water motor skill training may decrease the response times of scuba diving participants.

Figure 1 - Motor response times



Discussion

The results of this exploratory study supported our hypothesis that in-water training activities would have a significant effect on simple motor response time in divers. Previous research has found that acute aerobic exercise activities, such as that which would occur from in-water training activities, appear to increase arousal levels to a point that facilitates improvement in reaction time performance (Collardeau et al., 2001). Aerobic exercise has been shown to increase central nervous system activation that may potentially facilitate improved cognitive and neural functioning (Peyrin et al., 1987). Non-fatiguing physical activity should at the very least cause an improvement in movement time resulting in faster overall response time. In this investigation the tasks completed by participants in the diving group were simple motor tasks and were not aerobically fatiguing. However, the process of gear configuration prior to the dives and the necessity of maintaining neutral buoyancy in the water during the motor tasks may have elicited an increase in the cardiovascular workload, thus resulting in moderate aerobic exercise.

Interestingly the results of this study suggest that motor task performance may be improved with practice. Previous research has suggested that reaction time slows with an increase in real-world diving activities (Bast-Petterson, 1998) and simulated dives in a hyperbaric chamber (Alliman & Ragot, 2001); this current investigation suggests that an increase in the performance of in-water motor tasks may benefit the diver beyond the simple learning of the necessary skills needed to dive safely. Additionally, researchers have suggested that significant psychological stress can severely limit one's ability to process information and produce accurate movements (Tanaka, et. al., 2014). While under stressful conditions, the inability of a diver to quickly produce the necessary movement, whether replacing a lost mask or sharing air during an out-of-air emergency, may lead to a rapid escalation of the problem and severely increase the psychological demands on the individual. An improvement in response time may result in less psychological stress and prevent a panic response and resultant out-of-control situation from occurring. The results of this study suggest that response time may improve with training and the safety and performance of the diver may be enhanced through proper practice design and training protocols. Improvements in response time will allow for quicker and more efficient responses under stress and may allow the diver to respond more "instinctively," thus allowing for attention to be better directed to any external stressors.

Table 2. Dive-related motor tasks

Equipment removal and retrieval skills Upper extremity movements required for quick and efficient removal and replacement of necessary scuba equipment to simulate an emergency situation in which any removal of gear is necessary.
Shared buddy breathing skills Upper extremity movements used to simulate the motor skills necessary to share gas between two divers in an out-of-air emergency. These skills require divers to share air from one primary scuba regulator while submerged.
Partner-assisted towing skills Upper and lower extremity movements used to simulate the in-water assist and tow of an injured or incapacitated diver. This requires a diver to initiate and maintain body contact while swimming with another fully-equipped diver for a specified distance in the water.
Water entries Upper extremity movements used to practice the entry of the diver into the water from a standing position (giant stride). Diver will stride vertically into the water from a position outside the body of water in which they are entering.
Mask clearing skills Upper extremity movements used to assist the diver in clearing any water from the mask during diving. These skills may be performed on the surface or while submerged. They require the diver to adjust the mask with one or two hands while exhaling into the mask to displace the water.

A secondary purpose of this investigation was to examine the effectiveness of a simple iPad application for scuba-related data collection procedures. Due to the nature of diving activities and the need to collect real-world data at specific dive sites, the use of traditional methodological tools may be compromised due to the lack of laboratory control. Recent technological advances, such as iPad applications, allow for compact and reliable computerized software to be used in more non-traditional real-world situations, such as in an open-water environment in which more traditional tools may be limited or unavailable. Anecdotal reports from this investigation suggest that the use of iPad technology provides researchers with a powerful tool; however, the use of electronic equipment in an aquatic environment presents hazards to data collection procedures. During this study there were several instances in which the equipment was nearly compromised or destroyed due to excessive water being present during response time assessments. Fortunately, the researchers were able to prevent any loss of data or impaired equipment during this investigation.

Limitations

There were several limitations to this exploratory study on response time and scuba diving performance. Given the human body's unique ability to adapt to its surrounding environment, water immersion may have resulted in the diver's body compensating for the increased resistance offered by the water. This may have affected our results due to the measurements of response time being recorded immediately following the subjects exiting the water, which may not have allowed the motor system enough time to re-adjust to a non-aquatic environment. In addition, task learning may have occurred during the pre-testing procedures that may have had an effect on the post-test scores. This learning effect may have facilitated a change in the speed of response time by improving the efficiency of cognitive processing. This effect, however, was thought to have minimal impact on our study due to the task simplicity and the movement pattern being familiar to all participants. Additionally, the results from the non-diving control group suggest that there was no significant change in response time due to task learning.

The use of five trials for the pre-test and post-test response time measures was a minimum number of acquisition trials and future studies should expand the number of trials to provide a potentially more reliable measure of response time. The limited number of trials was due to the unique nature of the data collection procedures used in this investigation. Prior to the post-test, each diving participant was asked to exit the water quickly and was required to remove a significant amount of diving gear and any excess water on his/her body prior to being seated in front of the iPad. Due to this delay, a minimum number of trials was selected in an effort to minimize time loss between in-water activities and posttest data acquisition. Finally, the small sample size in this investigation may have impacted the results of the investigation. The use of small samples was due to the specialized skills needed for this study and the limited number of individuals who engage in scuba-related activities and tasks.

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Future Research

Further research may benefit from modifications to the current methodology, particularly testing within a real-world open water environment and measuring arousal levels and motor performance of scuba divers pre-dive, mid-dive, and post-dive. There have been recent technological advances in underwater technology (iDive iPad housing, San Diego, CA) that in the future may allow for these types of measurements to be assessed in actual diving scenarios at varied depths and under real-world conditions. The parameters of our study were confined to pool diving with water temperature and maximum dive depth comparable to the mildest of diving conditions. Future studies may benefit from an environment which more closely reflects open water diving, especially variations in water temperature and dive depth.

Conclusions

Interest in the effects of scuba diving and related hyperbaric conditions on the central nervous system is a significant area of interest for individuals interested in dive-related research (Taylor, Macdiarmid, Ross, Osman, Watt, Adie, Crawford, & Lawson, 2006). Knowledge regarding how response time is affected by certain environmental conditions is an important area of investigation, as a better understanding of these changes may allow a diver to better anticipate these effects on motor function and help a diver better prepare for sudden situational changes during diving activities. Additionally, water temperature can significantly affect a diver's central nervous system function. Therefore an understanding of how proper thermoregulatory equipment may prevent the excessive heat loss and hypothermia that causes decreased cognitive performance is necessary for safe diving practices. Awareness of these related factors may lead to the development and implementation of better training methods and protocols for the diving community to improve safety.

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