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Effects of a Demand-Valve SCUBA Regulator on Cardiorespiratory Response During Submaximal Exercise Under Normobaric Conditions: A Preliminary Investigation

Christopher R. Kovacs Ph.D.
Western Illinois University, cr-kovacs@wiu.edu

Camille Dhom B.S.
Western Illinois University

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Effects of a Demand-Valve SCUBA Regulator on Cardiorespiratory Response During Submaximal Exercise Under Normobaric Conditions: A Preliminary Investigation

Cover Page Footnote

The authors would like to acknowledge Peter Buzzacott, Ph.D. for his assistance with the initial statistical analysis of the data presented in this paper.

Abstract

SCUBA diving fatalities are often related to cardiac events triggered by stress linked to equipment. The purpose of this investigation was to examine the effects of a SCUBA regulator on cardiorespiratory exercise at a submaximal workload. Ten participants (mean = 21.5 yrs; s.d. = 1.16) completed two submaximal exercise tests at 1 ATA; one while breathing normally and a second while breathing directly from a demand valve SCUBA regulator. Total time to test completion (TOT), heart rate (HR), blood pressure (BP), rating of perceived exertion (RPE), and arterial oxygen levels were all assessed. No significant differences between conditions were found for measures of TOT, heart rate, blood pressure, RPE, and arterial oxygen measures. Statistical analysis suggested that use of a SCUBA regulator itself did not affect exercise tolerance or increase cardiorespiratory stress at submaximal workloads. Several anecdotal observations in HR, BP, TOT, and RPE responses suggested further research is warranted.

Keywords: SCUBA, diving, exercise, regulator, tolerance, breathing

Introduction

SCUBA diving is a sport or activity that has been shown to be a safe activity when performed by effectively trained individuals with the necessary experience to mitigate any problems that may arise in a hyperbaric environment. Safe SCUBA (self-contained underwater breathing apparatus) diving is dependent on the ability of a diver to manage the environmental factors associated with the diving experience and the physiological factors that may affect a diver's ability to meet metabolic needs (Pendergast, et al., 2003). In addition, equipment design has been shown to have a significant effect on the energy costs associated with diving (Passmore & Rickers, 2002) and needs to be considered when developing safe diving protocols. Divers may be faced with circumstances that may increase the physiological demands on the diver and increase the associated stress on the diver, including environmental conditions that increase workload stress (Stang, & Wiener, 1970). Stress has been seen to play a significant role in diving incidents and fatalities and may be a precursor to the onset of panic (Griffiths et al., 1982; Egstrom & Bachrach, 1971). Additionally, 15% of deaths associated with SCUBA diving have been attributed to equipment issues while diving (Denoble et al., 2008) while 41% of these fatalities were due to issues that resulted in insufficient gas being delivered to the diver. The relationship between air consumption and exercise intensity has been well established (Buzzacott et al., 2014) and any limitations in air consumption during a dive can seriously affect both performance and diver safety.

Situational conditions and diver fitness often are associated with an increase in the stress response; however, diving equipment may also place increased stress

on the diver through limitations in gas delivery between equipment and the respiratory system. Although the risks involved in SCUBA diving are minimal when training meets the capability of the individual, there are risks, nonetheless. Performing activities that require one to spend a significant amount of time under water and dealing with different environmental conditions can create increases in stress and energy expenditure requirements for a diver. Additionally, the recreational diving population has been described as a largely unhealthy and sedentary population (Denoble et al., 2010) partly due to the higher mean age of active divers being 42 years of age and a significant number of divers with a higher risk for cardiac disease due to the presence of significant cardiovascular risk factors. Thus, significant research has shown that an increased number of diving fatalities are related to cardiac events that lead to loss of air while submerged with drowning being the actual cause of death (Denoble et al., 2008).

Divers are often presented with situations that increase their physiological workload (e.g., emergency event, strong current) that may lead to a greater cardiorespiratory response (Passmore & Rickers, 2002). This response leads to an increased physiological need for air (or other gas). But the ability to obtain the necessary gas requirements may be limited by the actual respiratory equipment (i.e., demand valve SCUBA regulator) due to differences in air flow rates from the limited capacity of a regulator to deliver air based on its structure. Thus, an impedance to enough air or gas may have a negative physiological effect on the body's ability to respond efficiently to increased exercise demands and may result in significantly elevated measures associated with cardiorespiratory performance. Diving requires conservation of energy due to the need for the body to maintain a lower respiration rate to conserve and manage gas supply. Stress, environmental changes, aquatic creatures, and equipment malfunctions can all play a role in increasing the stress on a diver and a corresponding increased respiration rate and more rapid depletion of gas reserves.

Significant research has examined the effects of both respiratory safety equipment and experimental respiratory resistances on physiological performance (Coyne et al., 2006; Johnson et al., 1999; Louhevaara et al., 1986). No significant research has examined the effect of using a standard SCUBA diving demand valve regulator and air cylinder on the cardiorespiratory response to increased exercise demands under normobaric laboratory conditions. A SCUBA regulator is designed to deliver gas safely and efficiently to a SCUBA diver on demand (thus, demand valve regulator) under increasing water pressure. As a SCUBA diver dives deeper and is subjected to increasing water pressure, SCUBA regulators are designed to match that ambient pressure and allow the diver to breathe at a similar rate as one would breathe at sea-level. Similar research has examined the effect of a self-contained breathing apparatus (SCBA) used by emergency personnel on

cardiorespiratory exercise performance (Qiu & Wang, 2012; Louhevaara et al., 1985). This research has suggested that SCUBA-type equipment use has a significant effect on total exercise tolerance time and related physiological measures. Thus, the purpose of this preliminary investigation was to examine the effect of a standard SCUBA regulator on the cardiorespiratory exercise response in non-divers. We hypothesized that breathing air from a demand valve SCUBA regulator under sea-level conditions will result in significant differences in cardiorespiratory measures of performance, including heart rate, blood pressure response, RPE, arterial oxygen, and total time to exercise completion when compared to non-regulator conditions.

Potential benefits from this pilot investigation may include obtaining more data regarding the effect of regulators on cardiovascular function with increasing workloads in divers. An increased understanding of the role of SCUBA equipment on cardiovascular response during SCUBA diving may lead to the development of appropriate exercise programming for divers to offset these demands and may help prevent SCUBA -related accidents associated with poor health or physical fitness, ranging from in-water heart attacks and pulmonary embolisms to problems associated with increased obesity and poor physical strength.

Method

Participants

Following approval by the Institutional Review Board, ten participants (six males and four females) with a mean age of 21.5 years old were recruited for participation in this preliminary investigation; a convenience sample was obtained through word-of-mouth recruitment and an email sent to the student population of a department of kinesiology at a midwestern comprehensive university in the United States of America. None of the participants were certified SCUBA divers and/or had any familiarity with the dive equipment used in this investigation. Participants were asked to complete a medical history and activity questionnaire prior to testing and any questions regarding the study were addressed by the principal investigator. Additionally, each participant was asked to fill out a Par-Q screening instrument to assess potential cardiovascular risk. No participant indicated the presence of any cardiorespiratory disease or associated risk factors and all proceeded with testing. All participants were provided with an informed consent prior to their participation in this study.

Experimental Procedures

All participants in this study were asked to complete two separate submaximal exercise tests on a cycle ergometer (Monark, Sweden) approximately one week apart under standard sea level atmospheric pressure (1 ATA/760 mmHg). During

the initial (control) submaximal exercise test each participant was required to cycle against an increasing physical workload until they reach a submaximal level of physical effort and physiological response. Participants began each test cycling against a standardized resistance (in watts) while having their heart rate, blood pressure, rating of perceived exertion (RPE), and arterial oxygen levels (pulse O_2) assessed. Heart rate and blood pressure data were collected using a Polar heart rate monitor and standard blood pressure cuff. Rating of perceived exertion was assessed using the Borg RPE scale (6-22 index) and arterial oxygen was measured through an oxygen sensor placed on the right index finger of each participant. All submaximal exercise testing was conducted using the YMCA cycle ergometer protocol (Table 1) which consists of several three-minute stages of cycling against a specified resistance. During submaximal testing, heart rate, blood pressure, RPE, and arterial oxygen levels were assessed at the completion of each stage and the workload was adjusted based on the prescribed protocol (Figure 1). This process was repeated every three minutes until the participant reached their submaximal heart rate (85% of maximal HR) or they quit the test voluntarily. Individual heart rates for exercise test cutoff determinations were calculated using the following formula: $220 - \text{Age} \times (.85)$. Each participant was provided a five-minute cool-down period during which they continued to pedal against little resistance until their heart rate recovered (below 100 beats per minute).

Table 1.
YMCA Submaximal Exercise Protocol

1st Stage	150 kgm / min (0.5 kg)			
	HR < 80	HR 80-89	HR 90-100	HR > 100
2 nd Stage	750 kgm/min	600 kgm/min	450 kgm/min	300 kgm/min
3 rd Stage	900 kgm/min	750 kgm/min	600 kgm/min	450 kgm/min
4 th Stage	1050 kgm/min	900 kgm/min	750 kgm/min	600 kgm/min

During the experimental exercise test, each participant was assessed using the previously described protocol, while breathing compressed air (3000 psi maximum pressure) from a demand valve SCUBA regulator (Dive Rite, FL) connected to an 80 cu/ft aluminum SCUBA cylinder via a standard eight-foot braided low pressure regulator hose (Miflex, Italy). Measures of HR, blood pressure, RPE, and arterial oxygen levels were again collected at the conclusion of each stage until 85% of individual maximum heart rate was attained or the test was ended voluntarily.

Results

Descriptive means and medians were initially calculated for all participants (Table 2). An initial descriptive analysis of the data indicated all variable means for the regulator condition (except RPE) were within two standard deviations of the respective mean values for the control condition and therefore considered non-significant. Subsequently, a repeated measures analysis of variance ($p < .05$) on this limited sample size confirmed no significant differences between pre-test and post-test measures of heart rate, blood pressure, rating of perceived exertion and arterial oxygen levels (SPSS, version 27). Subsequent post-hoc analysis determined minimum sample sizes required for future research to detect if true differences between groups exist for each variable.

Discussion

Preliminary statistical analysis of the data suggested that breathing from a demand valve SCUBA regulator did not appear to affect exercise tolerance or increase cardiorespiratory stress at submaximal workloads under normobaric environmental conditions. Anecdotal analysis of time to exercise completion data does possibly suggest that breathing from a SCUBA regulator may decrease overall exercise tolerance (Figure 1). Additionally, rating of perceived exertion (RPE), a subjective measure of physical difficulty during exercise, was descriptively higher (although non-significant) for the regulator condition, suggesting that there was greater perceived stress when breathing from a SCUBA regulator when compared to breathing under non-regulator conditions. This may be due to the restrictions imposed by breathing from a SCUBA regulator and the lack of oxygen to the lungs or simply due to the “unnatural” feeling a novice may associate with breathing through a regulator mouthpiece (Figure 2). Although statistically insignificant, heart rate response was higher in the regulator condition, which is consistent with those results seen in similar research examining the effects of SCUBA-type regulators on physiological response (Louhevaara et al., 1985) (Figure 3). Finally, systolic blood pressure was higher at the 12-minute stage under regulator conditions when compared to the same time point for the control condition (Figure 4). Thus, it appears that there may be a greater cardiorespiratory response to exercise stress when breathing from a SCUBA demand valve regulator. These anecdotal observations may suggest that the use of a demand valve SCUBA regulator may act as a limiting factor for extended periods of physical exertion.

Table 2.

Descriptive data of heart rate, blood pressure, rating of perceived exertion, and arterial oxygen measures during exercise performance

	Control		Regulator	
	Mean (SD)	Median	Mean (SD)	Median
Rating of perceived exertion	14.7 (1.5)	14.5	16.7 (1.9)	16.5
Total time to completion	846.7 (151.5)	870.5	792.3 (125.4)	780
Pulse oxygen levels at completion	96.6 (0.8)	97	96.4 (1.6)	96.5
Heart rate at minute 3 of exercise	102.6 (9.7)	104	103.6 (10.1)	104.5
Heart rate at minute 6 of exercise	117.1 (8.0)	114.5	121.3 (12.8)	121.5
Heart rate at minute 9 of exercise	136.9 (11.8)	133.5	139.1 (10.8)	135
Heart rate at minute 12 of exercise	147.3 (10.3)	147	154.8 (9.5)	155
Systolic BP at minute 3 of exercise	133.2 (24.2)	129	129.3 (10.7)	124
Systolic BP at minute 6 of exercise	147.9 (24.7)	143	151.4 (20.7)	142
Systolic BP at minute 9 of exercise	153.5 (20.2)	155	163.8 (21.1)	158
Systolic BP at minute 12 of exercise	164.0 (20.2)	172	171.3 (18.9)	170
Diastolic BP at minute 3 of exercise	85.1 (32.8)	78	80.1 (20.9)	74
Diastolic BP at minute 6 of exercise	80.6 (24.8)	78	81.1 (25.0)	74
Diastolic BP at minute 9 of exercise	87.2 (27.7)	80	79.2 (23.7)	70
Diastolic BP at minute 12 of exercise	94.0 (40.3)	80	80.3 (23.7)	74

Figure 1.

Condition comparison of time to completion of submaximal exercise test.

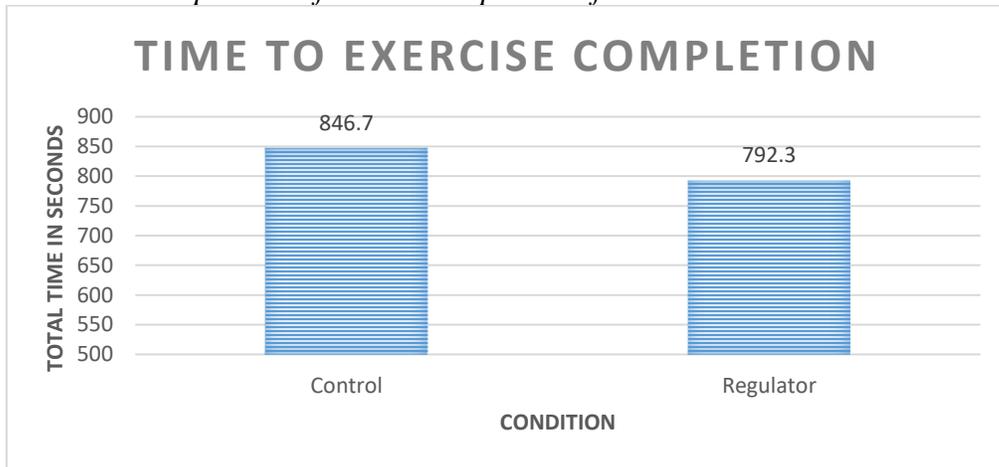


Figure 2.

Condition comparison of rating of perceived exertion during submaximal exercise (RPE).

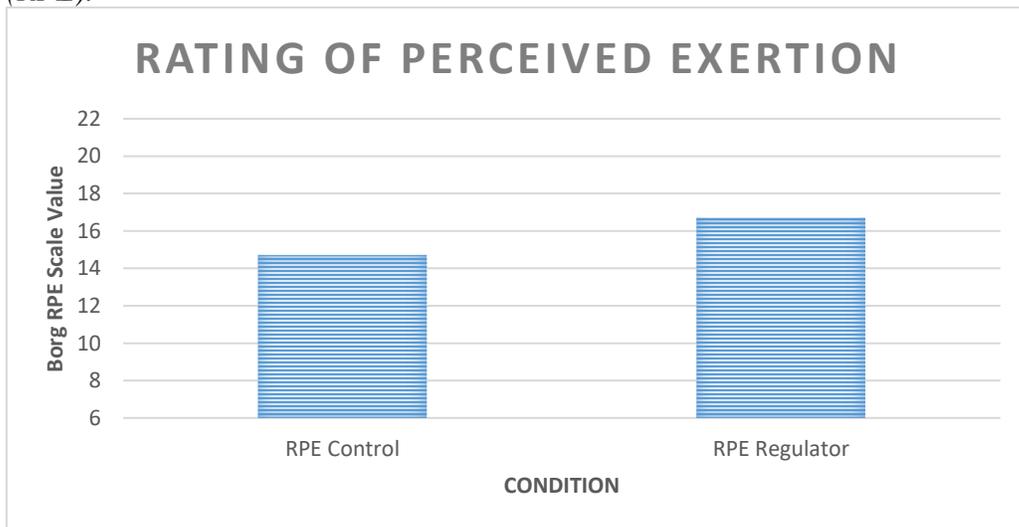


Figure 3.

Condition comparison of heart rate response during submaximal exercise.

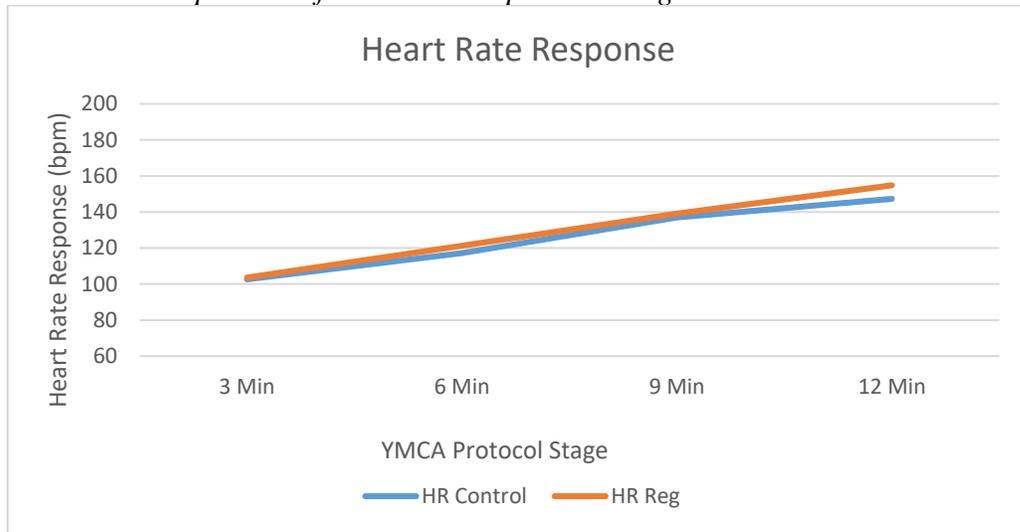
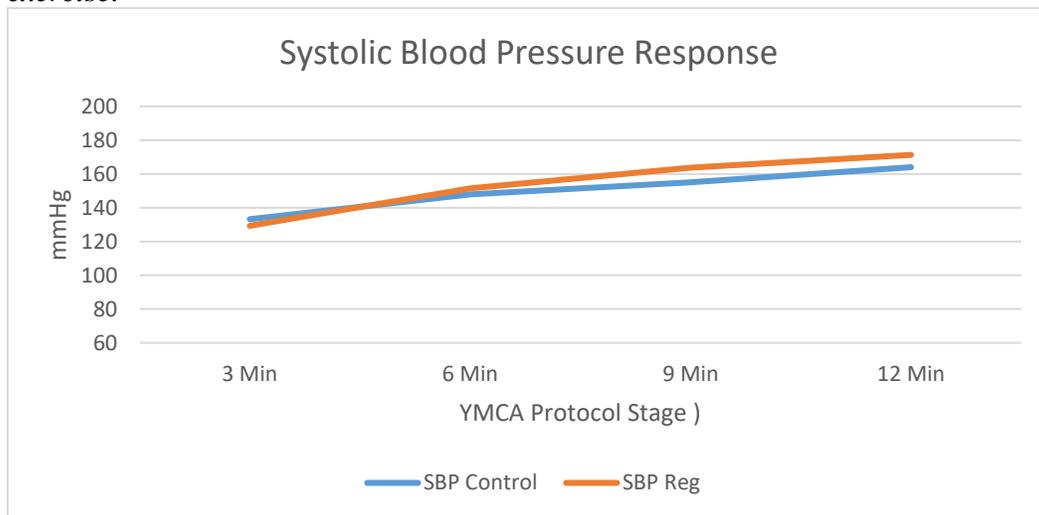


Figure 4

Condition comparison of systolic blood pressure response during submaximal exercise.



Overall, these preliminary data differed from similar research examining the effect of a demand valve regulator on exercise performance (Qiu & Wang, 2012; Louhevaara et al., 1985). Although the small sample size did not provide sufficient statistical power to discover statistically significant differences, it should be noted that the lack of differences observed between experimental and control conditions in this investigation may be favorable to the SCUBA diver. These results

may support the hypothesis that the use of a demand valve SCUBA regulator, when used correctly by an experienced SCUBA diver, may not account for increased cardiorespiratory stress on the diver. Thus, any potential increases in cardiorespiratory response to increased workload during a dive may be mitigated by decreasing the workload (when possible) and may not be the result of the necessary equipment needed for life-support during underwater operations. This would account for one less stressor for the SCUBA diver to have to manage during diving; an activity that requires constant situational awareness for its safe performance. Future research will need to increase the number of participants used to truly assess the effect of breathing from a SCUBA regulator on physiological performance by having sufficient statistical power. But this pilot investigation suggested that equipment might not be a strong factor in physiological stress and the potential cardiac issues associated with those stressors.

Limitations

As noted, this pilot investigation was initially conducted to examine the effect of a regulator on exercise tolerance. As with any preliminary investigation, several limitations should be noted in an effort to further inform a larger research study on this topic. The limited sample size made it difficult to assess whether there were any statistically significant differences between the experimental and control conditions. Future investigations will require a larger participant sample to determine any proposed differences. Future sample size requirements from this preliminary investigation have been determined through statistical power analysis (SPSS, version 27) and further research with a larger projected sample size of more than 65 participants ($p=.05$, margin of error=2.5) appears warranted. In addition, differences in both breathing depth and rate amongst the different participants during both the experimental and control submaximal exercise trials may have accounted for different levels of gas transport into and out of the lungs, thus affecting cardiorespiratory responses to the exercise conditions.

The order of the tests provided to each participant may have impacted the results because the pre-test may have provided for a familiarization period for the participants that may have impacted their performance during the regulator testing conditions. Finally, comfort with the equipment may have also accounted for the lack of differences in this pilot study. Several participants had more difficulty breathing from a regulator simply due to a lack of comfort with having a mouthpiece in their mouth during exercise. Future studies may want to utilize individuals with some level of diving experience to minimize the potential differences in comfort with breathing from a demand valve SCUBA regulator.

Research examining any potential stress on SCUBA divers is important to advance our knowledge of physiological responses under diving conditions and

improve the overall safety of SCUBA diving. With the right experience, fitness, and knowledge, divers can safely engage in SCUBA diving with minimal risk. Benefits from this study include more detailed information regarding the effect of regulators on cardiovascular function with increasing workloads in divers and improving our understanding of the role of SCUBA equipment on cardiovascular response during diving. Ultimately, expanding our knowledge of these types of factors may help lead to the development of appropriate exercise programming for SCUBA divers and may help decrease the incidence of SCUBA-related accidents associated with poor physical conditioning and fitness.

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