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ORIGINAL ARTICLE

EFFECTS OF RECREATIONAL DIVING ON HEART RATE VARIABILITY IN HEALTHY AND PARAPLEGIC INDIVIDUALS

Dominik GRACZYK[1], Bartosz MOLIK[2], Jan GAJEWSKI[2], Krzysztof MAZUREK[3]
1 Armed Forces General Command, Physical Education and Sport Division, Warsaw, Poland
2 Józef Piłsudski University of Physical Education in Warsaw, Poland
3 Military Institute of Aviation Medicine, Warsaw, Poland

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Author's address: K. Mazurek, Military Institute of Aviation Medicine; Krasińskiego 54/56 Street, 01-755 Warsaw, Poland, email: kmazurek46@wp.pl

Introduction: The aim of the study was to evaluate cardiac autonomic activity during recreational scuba diving by analyzing heart rate variability (HRV) in individuals with paraplegia following spinal cord injury (SCI) compared to healthy controls (C).

Methods: The study was conducted in 38 men, comprising 19 able-bodied individuals serving as controls and 19 participants with paraplegia. Heart rate variability was assessed using a Polar Vantage heart rate recording system during three phases: rest, self-contained underwater breathing apparatus (SCUBA) diving and recovery.

Results: Increased modulation of the cardiac parasympathetic nervous system was found before diving in SCI divers compared to the able-bodied group. As expected during diving, both groups were demonstrated increased cardiac sympathetic activity. However, during SCUBA diving activity, higher cardiac sympathetic modulation was observed in the SCI group compared to the C group. The recovery of HRV indices to baseline values was similar for both groups.

Conclusions: Heart rate variability spectral and time domain analysis proved to be a useful tool for monitoring changes in cardiac autonomic system balance during recreational SCUBA diving for those with paraplegia. This study demonstrates that HRV analysis can be a helpful indirect indicator for the evaluation of the efficiency of recovery and progression of rehabilitation.

Keywords: scuba, cardiac autonomic modulation, paraplegia

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INTRODUCTION

During diving, the diver is affected by various physical and emotional factors. The most important of these include: the hydrostatic pressure of the water column, which increases with depth; breathing a gas mixture under elevated pressure; and the influence of the aquatic environment, associated with reduced temperature, limited visibility, and altered voice communication.

Variable environmental conditions lead to an increased level of stress and various adaptive physiological responses, controlled primarily by the autonomic nervous system (ANS) [27,35]. The autonomic nervous system fulfills an important function in regulation cardiovascular homeostasis in health as well as in people with various diseases. HRV is the tool often used for evaluation of cardiac autonomic function. Analyzing HRV at rest, during exercise, and under different environmental conditions allows for an indirect assessment of cardiac autonomic modulation in maintaining homeostasis.

Individuals with physical disability who participate in SCUBA diving together with friends and family members are becoming increasingly popular. SCUBA diving can be a safe and beneficial form of physical activity for those with spinal cord injuries similar to their able-bodied counterparts [7,40]. The ease of movement in water creates a feeling of independence, reveals hitherto unknown capabilities, fosters self-efficacy, and allows the individual with SCI to overcome some of the perceived barriers of their physical disability [39].

Traumatic injuries to the spinal cord at the lumbar level can result in incomplete or complete paraplegia. A complete lesion results in a predictable level of motor and sensory impairments. Whereas, incomplete paraplegia is characterized by an infinite variation of motor and sensory impairments, ranging from minimal to severe dysfunctions of motor-sensory function. The impairments found in both complete and incomplete lesions include potential dysfunction of the autonomic nervous system provoking functional changes in many organs, including the heart [18]. Overall, decreased sympathetic activity is a well-documented observation for those with paraplegia [2,17]. Grimm et al. emphasized that total sympathetic-parasympathetic ANS activity is lower in individuals with paraplegia compared to those with an intact spinal cord [14]. These authors also note that decreased functional ability of one aspect of the ANS will result in the limited function of the other.

In the able-bodied population, SCUBA diving provides a strong stimulant for both parasympathetic and sympathetic components of the ANS [12,31,35]. Lund et al. [20,21] have shown that SCUBA diving resulted in an increase in parasympathetic activity. Given the disturbances in cardiac function caused by the ANS dysfunction resulting from a SCI, the responses to SCUBA diving of the parasympathetic and sympathetic systems could differ from those found in the able-bodied [26]. In fact, Graczyk et al. demonstrated altered activity of cardiac ANS modulation in those with SCI as compared to the able-bodied controls during SCUBA diving [13].

The impact of repeated diving on the circulatory system in healthy individuals has been the subject of many studies. After a training cycle, beneficial changes in cardiac indicators have been observed, such as an increase in stroke volume and a decrease in resting blood pressure, which have been associated with positive changes in the regulation of the circulatory system by the autonomic nervous system [6,26].

No studies have been found in the literature regarding the effects of repeatedly performed diving on the circulatory system in individuals with spinal cord injury.

In the SCI population, the use of time or frequency domain analysis methods to evaluate HRV has been reported to improve cardiac autonomic modulation of athletes after the implementation of a well-designed training program [6,8]. Work with able-bodied athletes has shown that physical training increased parasympathetic modulation and reduced sympathetic modulation at rest and during submaximal efforts [1,32,38]. As with the able-bodied population, there is evidence to suggest that those with SCI will experience similar adaptations in cardiac autonomic modulation to a training program, such as an accelerated recovery to baseline values after an exercise bout [22]. The literature has demonstrated that HRV is a potential tool for quantifying the assessment of sympathovagal regulation of the cardiovascular system following SCI [27,34].

Based on the authors' own research on individuals with hemiparesis under SCUBA conditions [13] and data from the literature, the authors propose the hypothesis that SCUBA diving by individuals with hemiparesis caused by spinal cord injury is a safe form of rehabilitation that may have a beneficial effect on the emotional state and physical fitness of people with SCI. Comparative HRV analysis between healthy individuals and

those with hemiparesis may be used to track rehabilitation progress in individuals with SCI.

This study aimed to evaluate the heart rate variability in SCUBA divers with paraplegia compared to healthy divers, using HRV measurements during recreational diving.

METHODS

Subjects

Thirty-eight male, Caucasian, novice recreational SCUBA divers volunteered to participate in the study: 19 divers with traumatic injury on the level T6-L1 and paraplegia (SCI) and 19 able-bodied divers to act as a control group (C). At minimum, each study participant had undergone a basic diving course in a swimming pool according to the standards of HSA-Handicapped Scuba Association [34]. Potential participants were excluded if they presented with any other condition and/or treatment that could influence ANS function. All participants received a medical clearance and provided informed consent prior to participating in this study. The study obtained permission from the Regional Ethics Commission (no. 001/09-1/2006).

Study design

The research carried out was of an experimental nature. The study was performed during the summer in open water on Croatia's Adriatic Sea coast. The conditions for diving are presented in Table 1. All participants dived in typical diving gear consisting of: wetsuit, standard mask, snorkel, fins, buoyancy control device & weight system, a breathing regulator, and air tank. The mixture for breathing was compressed room air. Participants with SCI dived with two attendants, one of whom was a certified instructor. The able-bodied participants dived in pairs and provided the safety protocols for each other. In case of emergency, a paramedic was on duty. The dive session lasted 20 minutes at 6m of depth. Prior to the dive session, participants were required to refrain from intensive physical activity, smoking, coffee, and other stimulating beverages.

HRV analysis

Heart rate variability analysis was performed on the basis of measurements of R-R intervals from continuous registration of heart rate frequency using the heart rate monitor of the Polar Vantage recorder [26,27,33]. There were three phases of measurements:

1. Rest phase – directly before diving, at rest, sitting comfortably in a chair, while on the dive boat for 10 minutes.
2. Dive phase – during 20 minutes of recreational diving.
3. Recovery phase – immediately after the dive, at rest, sitting comfortably in a chair, while on the dive boat for 10 minutes.

The data were stored in a standard computer memory card and then analyzed using HRV Analysis Software v.1.1 developed by the Department of Applied Physics, Kuopio University, Finland, and Polar Precision Performance [10]. The HRV Analysis Software v.1.1 program scanned the tachograms for any artifacts or arrhythmias; these were identified and removed.

In accordance with the guidelines of the Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology [41], the following HRV parameters for time domain and frequency analysis were calculated: average normal R-R interval time (RR ms); standard deviation of all normal N-N intervals (SDNN ms); the square root of the mean squared differences of successive NN intervals- (RMSSD ms); low frequency component in normalized units (n.u.) - 0.05-0.15 Hz (LF), high frequency component in n.u. - 0.16-0.40 Hz (HF) using the very low frequency component (up to 0.04 Hz) for normalization, and the LF/HF ratio. According to the above-mentioned recommendation of the Task Force of the European Society [41], an increase of R-R and HF describes cardiac autonomic parasympathetic stimulation, whereas SDNN and LF are mediated both sympathetically and parasympathetically. Moreover, the LF/HF ratio was calculated as a measure of autonomic balance. Spectral analysis was performed using the nonparametric method of evaluation of power spectral density (PSD). The minimum window width for the PSD method was 256 samples.

Statistical analysis

Two-way ANOVA for repeated measures was used for means comparisons. Repeated factor (pre-diving, diving, and post-diving) as well as group effect (experimental, control) was considered for analysis. The Kolmogorov-Smirnov test was utilized in order to assess the normality of the variables. Logarithm transformation was applied to those of skewed distribution. Post-hoc comparisons were done using the Bonferroni test. ANOVA results were confirmed using non-parametric Fiedmann ANOVA (Wilcoxon test for post-hoc comparisons),

and U-Mann Whitney test was used for assessing differences between measures and groups, respectively. The significance level of α=0.05 was adopted. All analyses were carried out using the SPSS Statistical Software program.

RESULTS

The research results are presented as a comparison of the values of individual spectral and time-domain parameters before the dive, during the dive, and in the recovery period after the dive. These data were compared between the two groups of divers studied: individuals with hemiparesis resulting from spinal cord injury and a control group of healthy individuals.

Results from the able-bodied participants were treated as a point of reference in relation to the HRV values recorded for the individuals with paraplegia. In addition, the HRV responses of the C group to diving were considered to be within normal limits. Results of HRV recorded during the diving phase were analyzed independently from the rest and recovery phases. This was done due to the changes in body position between phases and alterations in breathing pattern and depth during diving, which could have an effect on HRV.

Table 1 provides the general characteristics of the participants in this study and the open water diving conditions. No adverse symptoms or complications were reported for any of the participants during their 20-minute dive. Tables 2 and 3 presented, respectively, frequency and time analysis of HRV during rest, diving, and recovery phase.

Prior to the dive, rest phase, the R-R interval values were greater for those in the SCI group as compared to the C group. Lower values of the LF/HF ratio were noted for those with paraplegia in the rest state, which could indicate higher parasympathetic modulation and a tendency for overall lower ANS stimulation.

During the dive phase, the HRV indices drifted in a similar direction in both comparison groups. It was noted that the increased sympathetic modulation (increased LF, LF/HF) and a reduction in parasympathetic modulation (decreased HF, R-R, and RMSSD), were greater in the SCI group. During

Tab. 1. General characteristics of participants and diving conditions (X±SD).

Groups	Numer of participants	Age [years]	Body heigh [cm]	Body mass [kg]	Number of diving	Air temp. [°C]	Water temp. [°C]	Water clarity [m]
SCI	19	32 ± 5.95	178 ± 5.56	78 ± 10.77	1 ± 05	25 ± 1.9	22 ±1.3	7 ± 2.89
C	19	33 ± 7.14	178 ± 7.08	82 ±14.03	13 ±10.35	23 ±2.6	21 ±0.8	15± 6.65

SCI- divers with spinal cord injuries T6-L1 with paraplegia
C - nondisabled divers, control group

Tab. 2. Indices of frequency analysis HRV in rest, diving, and recovery phases in paraplegic persons (SCI) and nondisabled controls (C) (X ± SD).

Indices	SCI			C		
	Rest	Diving	Recovery	Rest	Diving	Recovery
LF n.u.	26.63±18*	46.81±23	31.37±21	28.87±16*	39.92±18	36.45±23
HF n.u.	73.37±18*	53.19±23	68.63±21	71.13±16*	60.08±18	63.55±23
LF/HF	0.34±0.6*	0.83±1.69	0.57±0.89	0.51±0.56*	0.76±0.49	0.49±1.14

* significant statistic difference (p<0.05) between rest and diving phases
n.u. – indices in normalized units

Tab. 3. Indices of time analysis HRV in rest, diving and recovery phases in paraplegic persons (SCI) and nondisabled controls (C) (X ± SD).

Indices	SCI			C		
	Rest	Diving	Recovery	Rest	Diving	Recovery
HR	87±14*	116±19	93±12	94±10	94±10	90±12
R-R (ms)	720±126*	508±69	661±87	654±85 *	574±65	685±92
SDNN (ms)	52±43	26±8	53±58	40±25	31±13	50±29
RMSSD (ms)	14±9	7±4	23±33	12±7	8±3	13±8

* significant statistical difference (p<0.05) between rest and recovery phases

the recovery phase, the values of R-R and RMSSD were significantly increased similarly in both groups, as compared to the diving phase. This could be interpreted as an increase in parasympathetic modulation. There was also a non-significant trend noted in both groups – an increase in LF and SDNN, which could be an indication of generalized ANS stimulation.

In summary, during the dive, the values for HF and R-R interval, associated with parasympathetic modulation, were lower in the SCI group, and the values of LF/HF ratio, associated with sympathetic modulation, were higher in the SCI group than the C group.

DISCUSSION

Heart rate variability describes the cyclic variations in heart rate and can be applied as a non-invasive tool to examine the modulatory effects of the autonomic nervous system on intrinsic heart rate. Physiological changes of HRV during immersion are adaptive and a flexibility mechanism caused by a haemodynamic shift in cardiovascular system. Scuba diving is characterised by relatively high heart rates just before submersion, an individually variable but significant bradycardic dive response [27,34].

In our investigation, it was found that before recreational diving, persons with SCI were characterized by significantly greater values of R-R interval and smaller, though non-significant, values of LF/HF, which suggest a higher level of the parasympathetic part of ANS modulation as compared to the C group. Though the magnitude differed, the HRV variables measured during the dive indicated a similar direction of HRV adaptations in both groups. During the 20-minute dive, there was an increase in HRV indicators that characterize sympathetic modulation and general autonomic nervous system activity (LF, LF/HF), and a decrease in the values that characterize parasympathetic modulation (R-R, HF). The observed significant differences of R-R between the SCI and C groups while diving suggest a stronger stimulation of the part of the ANS in the SCI group during SCUBA diving.

The literature is inconsistent about the expected changes in autonomic nervous system activity during SCUBA diving, and most of the research comes from studies of able-bodied people [12,19]. As in this study, some have reported that autonomic nervous system parasympathetic modulation decreases during diving, primarily due to a decrease in the R-R interval [9]. Others have demonstrated an increase in both sympathetic and parasympathetic activity during diving (16). It has also been reported that parasympathetic modulation dominated during the dive; however, after returning to the surface, the autonomic balance shifted toward increased sympathetic activity (5).

Once the 20-minute dive was completed, the shift of HRV indices towards resting values was observed in both groups. By the end of the recovery phase, all HRV indices had returned to near resting values (no significant differences). These findings suggest that there is a similar reaction of the ANS regardless of whether or not the individual has a SCI. This result is important in supporting the justification that SCUBA diving is a safe activity for those with SCI.

Results of athletic studies showed significant differences for respective HRV markers in the early recovery period. Some HRV markers (RMSSD, LF/HF) return to rest values directly after physical effort, while others (RR, SDNN) maintain changed values up to 20 minutes after effort [5,9,22].

In our results, the observed feature of increased sympathetic modulation during diving, as determined by the HRV changes, increase of LF, LF/HF as well as an increase of HR and decrease of R-R. Those changes could be caused by different factors, including the following: greater physiological costs of work performed by persons with SCI under water, greater emotional tension following diving, and lower physical capacity of persons with SCI, as well as different ANS function as a result of spinal cord injury.

An important aspect influencing ANS balance is differences in work loading during diving in persons with SCI and able-bodied divers. Recreational diving performed by the able-bodied individuals was connected with a small load of relatively low-intensity physical work. SCI divers performed greater work than able-bodied divers because of the lack of function in their lower extremities. SCI divers mainly used their upper extremities and trunk muscles to maintain body stability and move underwater. The work performed by smaller groups of muscles in the SCI group compared to the C group was connected with greater physiological costs and probably more extensive adjustment reactions from the ventilation and circulation systems. These reactions included an increased heart rate, which was closely associated with higher ANS sympathetic modulation.

In the present study, it was assumed that changes in HRV reflect a physiological and expected direction of change, consistent with the

literature discussing HRV responses during diving in healthy individuals. In contrast, the differing HRV responses observed in the group of divers with traumatic spinal cord injury may be interpreted as a result of the higher physiological cost of effort and dysfunction of the autonomic nervous system due to the injury.

The profile of HRV changes reported by other authors is often qualitatively and quantitatively varied, which may be explained by the heterogeneous conditions of the studies conducted, the varying degrees of spinal cord injury, as well as individual variability in HRV parameters [8,17].

A comparison of the training effects in individuals with SCI and healthy subjects indicates that post-exercise recovery is prolonged in individuals with SCI [14]. The time needed for exercise recovery reflects an organism's overall ability to tolerate various activities. The similarity in time and magnitude of recovery between the two experimental groups in terms of returning cardiac autonomic system balance to resting values could indirectly indicate good functional fitness and proper cardiorespiratory capacity in persons with spinal cord injury compared to controls.

It should be considered that the parasympathetic part of the reaction to environmental stimulation is generally faster than the sympathetic part. It is related to the regulation of the ANS by the central nervous system, which primarily influences vasomotor and ventilation centers. The CNS also influences peripheral receptors that initiate changes in blood pressure and ventilation variability [28,32]. Longer monitoring of recovery after diving would be useful for defining the reversion time of HRV markers to rest values.

Future studies on this topic are recommended for divers with spinal cord injuries after a complete training cycle. These studies could provide additional information that would be helpful in evaluating the influence of diving training on the efficiency of cardiac autonomic activity in paraplegic divers, as well as on improvements in functional fitness and physical capacity. Our observations, connected with many years of cooperation with disabled persons, revealed the positive influences of diving training and underwater expeditions on persons with SCI. Persons with high lesion level SCI engaged in diving quite often modify their position from participants of diving courses to leaders and organizers of diving activity. Persons with spinal cord injuries who practice diving reap many benefits, such as improved functional fitness, better socialization, increased activity, and enhanced self-evaluation [33]. Diving training results in a reduction of pathological muscle tone, a decrease in muscle pain, and an increase in vital lung capacity [4,15]. Therefore diving should be recommended for disabled persons as a beneficial part of social rehabilitation. We did not observe symptoms or disorders limiting participation of persons with SCI in diving, and we found that all participants completed the research program. The results suggest that SCUBA diving is a safe activity for people with SCI in terms of physiological adaptation, as well as emotional and social benefits. HRV monitoring, as a marker of changes in the autonomic nervous system (ANS), has found applications in various professional groups, including aviation personnel. In pilots, HRV analysis has been used to assess health status, stress load, and physical effort during flight-related activities — for example, during parachute jumps [23], training on flight simulators, and actual flights [3,20].

The limitations in interpreting the results of the present study stem primarily from the relatively small number of divers included. A review of the literature on diving among people with disabilities indicates that it is extremely difficult to recruit more than a few to a dozen individuals for such studies.

Another limitation was the variability in the time elapsed since spinal cord injury and the differences in psychomotor rehabilitation among individuals with SCI. As a result, the participants differed in their general physical condition and psychosomatic status.

The emotional state of the participants, which could have influenced their responses—also within the scope of ANS reactions to diving—was not analyzed in this study. Such an assessment exceeded the objectives set for the present work.

SUMMARY

In persons with spinal cord injury on the level T6-L1, in rest condition, HRV markers indicated a higher level of parasympathetic ANS modulation in relation to able-bodied participants. During diving, both the able-bodied and persons with SCI, HRV markers indicated a shift of autonomic balance to predominance of the sympathetic part. The divers with a SCI were characterized by greater total ANS activity, greater modulation of the sympathetic part, and smaller modulation of the parasympathetic part during diving in relation to able-bodied divers. In terms of recovery, after the 20-minute dive, there was no difference between the groups in the ability of the measured HRV indices to return to resting levels.

CONCLUSIONS

Qualitative and quantitative analyses of HRV are a useful tool for monitoring cardiac autonomic activity in paraplegic divers with posttraumatic injury of the spinal cord. HRV analyses could be used as an indirect marker for the evaluation of the efficiency of recovery after diving and the progress of rehabilitation. Recreational diving could be recommended as a safe form of rehabilitation for persons with posttraumatic spinal cord injury and has profitable influences on their psychological well-being and self-evaluation.

AUTHORS' DECLARATION

Study Design: Dominik Graczyk, Krzysztof Mazurek. **Data Collection:** Dominik Graczyk. **Manuscript preparation:** Dominik Graczyk, Krzysztof Mazurek, Bartosz Molik. **Statistic analysis:** Jan Gajewski. The Authors declare that there is no conflict of interest.

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