SCUBA-Dive-Related Changes in Heart Rate in Children

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The purpose of this study was to monitor heart rate (HR) and rhythm during open water SCUBA dives. Nine children performed 25-min open water SCUBA dives to 8 m depth. Before, during and after these dives, ECG was recorded. Compared with predive heart rate, heart rate declined by -24 ± 8% (range -36%; -15%) during the dive. In some children a further decline in HR was observed within the last minutes of the dive. Older and taller subjects and those with a high initial HR showed a more pronounced decline in HR. Furthermore singular supraventricular and ventricular extrasystoles were observed in some children. Immersion as well as facial and skin cooling presumably account for the initial decline in heart rate. A further drop in HR within the last minutes of the dive might be related to mild hypothermia. Single supraventricular and ventricular extrasystoles might occur in healthy children during dives.

Diving with self-contained underwater breathing apparatus (SCUBA) has become very popular in children within the last ten years. More than 110,000 children and adolescents aged twelve to seventeen years dive regularly in the United States.
States (26). Professional sports diving organizations worldwide offer SCUBA diving for children aged eight years and older (9, 27, 35). However, only few data exist with regard to the safety of children who engage themselves in SCUBA diving (19, 34). The latter recreational activity is associated with environmental stresses that include raised ambient and partial pressure of oxygen in the blood, increased resistance to movement, added weight of diving equipment outside the water, cold stress, and a higher breathing resistance. These stresses all may elicit (patho-) physiological responses in humans and thereby could affect the subject’s safety in the underwater environment. Decompression sickness (DCS) however is not expected to be a major problem as no circulating venous bubbles predisposing for DCS were detected after pediatric scuba dives within the recommended depth and time limits (18).

The cardiovascular responses to SCUBA diving have been well characterized in adults only (11). Heart rate and circulation are known to be affected by numerous factors during SCUBA dives. The diving response itself is reported to cause cardiovascular effects including bradycardia, vasoconstriction, and reduced cardiac output (11) following parasympathetic reflex activation of facial receptors by immersion and/or cold exposure. Heart rate (HR) of children and adolescents as opposed to adults is expected to be more affected by factors which increase parasympathetic and decrease sympathetic activity like the diving response (4), facial cooling, and hypothermia (16). On the other hand, some excitatory stimuli like psychological stress (12) and physical workload might result in a higher increase in HR compared with adults. Furthermore hyperoxia which can induce bradycardia (32, 33) is likely to be less pronounced in children compared with adults due to shallow water dives. In consequence, at this point it is unclear in how far children’s HR is affected by SCUBA diving.

To obtain data on heart rate and rhythm during SCUBA diving in children, we conducted a field study of children aged eight to twelve years who performed an open-water SCUBA dive to a depth of eight meters in a cold Austrian lake. The study aimed at evaluating the electrocardiogram (ECG) during SCUBA diving for the presence of possible arrhythmias and changes in heart rate and analyzing factors that may be associated with the occurrence of these changes.

Subjects and Methods

Subjects

Eight male and one female pediatric SCUBA divers aged eight to twelve years participated in this study. All subjects had a valid SCUBA diving license and had been certified as fit to dive by a medical examination. Before the study, 2 children had performed 1–5 dives, 2 children 6–10, 1 child 21–30 and 4 children more than 30 SCUBA dives. SCUBA diving experience ranged from 4 weeks to 3 years, snorkeling experience from 1 to 8 years. Informed consent was signed by all participants and their parents. The study was approved by the ethics committee of the medical faculty of the University of Wuerzburg.
Experimental Protocol

Body height and weight were measured and Tanner pubertal stage was assessed using a self assessment questionnaire (36). All subjects performed SCUBA dives to a depth of 8 m in an Austrian lake. During the dives, all children used special equipment suitable for their age group and wore well-fitting wet dive suits. Breathing air was supplied by a regulator with a mouthpiece fitting for children. The subjects and their dive buddies were instructed to descent to 8m within two minutes, remain at 8 m for 20 min and ascent to surface within 3 min. The subjects were to move continuously but not to perform exhausting exercise. All children were accompanied by experienced adult divers responsible for the adherence to the diving profile. Mean duration of the dive was 25.4 ± 1.3 min. Before, during, and after the dive, heart rate was measured and recorded continuously by a redundant one-lead ECG.

Water temperature was 22.6 ± 0.8 °C at the surface and 19.5 ± 0.4 °C at 8m depth, mean air temperature was 18.2 ± 1.4 °C.

ECG

All children were equipped with a special underwater ECG-recorder (PicoMed, Ueberlingen, Germany). Five electrodes were placed on the children’s chest. One neutral electrode and two pairs consisting of two electrodes each for redundant Eindhoven II lead were used. Special clips were used to protect the electrode pads’ connections to the wires from water. All ECG data were recorded onto a SD memory card inside the device and analyzed using the “Cardioexplorer” software (PicoMed, Ueberlingen, Germany). A blue tooth interface was used for transfer between the recorder and the evaluation notebook.

ECG recordings were analyzed for heart rate at distinct periods of time before dressing the neoprene suit on land (“initial”), inside the water before descent (“pre dive”), one minute after descent (“1min dive”), ten minutes after descent (“10min dive”), 20min after descent (“20min dive”), and inside the water three minutes after the end of the dive (“3min post”). Analysis of arrhythmias was performed during the entire dive. Measurements for initial were performed in sitting, pre dive, 1min dive, 10min dive and 20min dive and 3min post in horizontal dive position. Based on the analysis software, RR-intervals of fifty heart beats were measured and converted into heart rates for each time period of interest. All analyses for heart rate and arrhythmias were performed by the same experienced physician. The mean heart rate of these fifty beats was used as the heart rate of the interval of interest. Furthermore, the mean heart rate across all time periods during the dive at 1min dive, 10min dive, and 20min dive, was calculated as the “submerged mean”.

In addition, the ECG was analyzed for the presence of arrhythmias.

Statistics

Microsoft Excel 2007, Microsoft Inc, Redmond, Washington, USA and SPSS 15, SPSS Inc, Chicago, Illinois, USA were used for statistical analysis.

All variables were tested for normal distribution using a Kolmogorrov-Smirnov test. Mean heart rates at the predefined periods of interest were compared using a
Wilcoxon test. Heart rates one, ten and twenty minutes after descent were tested for reliability by an ANOVA for repeated measures. To determine factors influencing changes in heart rate, Spearman’s correlation coefficients were calculated for anthropometric data, initial heart rate, predive heart rate and relative changes in submerged mean heart rate. The association between number of SCUBA dives, years of diving experience, years of snorkeling experience and the heart rate variables listed above was assessed by Spearman’s coefficients as well. Heart rate 20 min after descent and mean submerged heart rate were of special interest.

Results

Mean duration of the dive was 25.4 ± 1.3 min. All heart rates, changes in heart rate and anthropometric parameters were normally distributed ($p > .65$). Age, height, weight, body mass index (BMI) and the associated percentiles are presented in Table 1. The heart rates measured before dive suit dressing, directly before the dive, during and after the dive are presented in Table 2. A mean increase in heart rate of 23% could be observed before the dive. During the dive, the mean change in heart rate amounted to ±0%, -8%, and -12% at one, ten, and twenty minutes after the descent, respectively. After surfacing, heart rate inclined by 29% on average. ECG samples at the different points of measurements are presented in Figure 1. When dive and post dive heart rates were compared with pre dive heart rate, there was a mean decline of 19% at one, 25% at ten, and 28% at twenty minutes after the descent of the dive. There was a 24% decline in submerged mean heart rate (Table 2).

When compared with the initial heart rate, there were decreases in mean submerged HR of more than 10% and 20% in four subjects and one subject after 10 min and 20 min, respectively. The individual relative changes at all times of measurement are displayed in Figure 1. Changes in heart rate were observed before

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean±SD (Min-Max)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age [years]</td>
<td>11.4 ± 1.3 (8.9–12.5)</td>
</tr>
<tr>
<td>Height [cm]</td>
<td>152.8 ± 10.0 (133.5–163.0)</td>
</tr>
<tr>
<td>Height percentile</td>
<td>77.6 ± 22.1 (32–96)</td>
</tr>
<tr>
<td>Weight [kg]</td>
<td>42.9 ± 7.4 (32.0–55.0)</td>
</tr>
<tr>
<td>Weight percentile</td>
<td>68.6 ± 21.1 (29–95)</td>
</tr>
<tr>
<td>BMI [kg*m-2]</td>
<td>18.3 ± 2.0 (15.8–21.4)</td>
</tr>
<tr>
<td>BMI percentile</td>
<td>55.3 ± 29.2 (14–88)</td>
</tr>
<tr>
<td>Body surface [m2] (Mosteller formula (24))</td>
<td>1.35 ± 0.15 (1.09–1.58)</td>
</tr>
<tr>
<td>Tanner stage: genitals / breasts</td>
<td>2.3 ± 0.7 (1–3)</td>
</tr>
<tr>
<td>Tanner stage: pubic hair</td>
<td>1.6 ± 0.7 (1–3)</td>
</tr>
</tbody>
</table>

Parameters for all variables are presented as mean±SD (range).
descent and three minutes after ascent. The changes at ten and twenty minutes after
descent showed a trend toward a decrease in HR (\(p = .086\) and \(p = .086\), respectively).

The relative change in mean heart rate (mean submerged heart rate vs. initial
heart rate) was negatively associated with age (Spearman’s coefficient \(r = -0.883\; \(p = .002\)), height (\(r = -0.770; \; p = .015\)) and initial resting heart rate (\(r = -0.733; \; p =
.025\)). ANOVA revealed a further decrease in heart rate during the dive (\(p = .015\)).

At 20 min the mean dive heart rate had declined by more than 12% (mean
decline) in four children. Decline in heart rate 20 min after descent compared
with initial heart rate negatively correlated with age (\(r = -0.917, \; p = .01\)), height
(\(r = -0.678, \; p = .045\)), body surface (\(r = -0.733, \; p = .025\)), Tanner pubertal stage for
pubic hair (\(r = -0.794, \; p = .011\)) and pre dive heart rate (\(r = -0.750, \; p = .020\)). Further
anthropometric parameters did not correlate with changes in heart rate significantly.
There was no significant correlation between number of SCUBA dives, years of
SCUBA diving experience, years of snorkeling experience and heart rates as well
as changes in heart rates.

Analysis of heart rhythm in the nine subjects showed single supraventricular
extrasystoles \((N = 3.0 \pm 8.3 \; (0–25))\) in three children and single uniform ventricular
extrasystoles \((N = 0.6 \pm 1.3 \; (0–4))\) in two children [Number of extrasystoles \(\pm SD\]

<table>
<thead>
<tr>
<th>Time of measurement</th>
<th>Mean± SD (Min-Max)</th>
<th>(\Delta)</th>
<th>(p)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Referring to initial heart rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Initial</td>
<td>106 ± 14 (85–130) min(^{-1})</td>
<td>0%</td>
<td>—</td>
</tr>
<tr>
<td>Pre dive</td>
<td>130 ± 13 (106–150) min(^{-1})</td>
<td>23 ± 7% (8–34%)</td>
<td>0.008**</td>
</tr>
<tr>
<td>1min dive</td>
<td>105 ± 10 (89–122) min(^{-1})</td>
<td>0 ± 10%(-18–9%)</td>
<td>0.859</td>
</tr>
<tr>
<td>10min dive</td>
<td>97 ± 7 (82–107) min(^{-1})</td>
<td>-8 ± 11% (-24–8%)</td>
<td>0.086</td>
</tr>
<tr>
<td>20min dive</td>
<td>93 ± 12 (71–109) min(^{-1})</td>
<td>-12 ± 15% (-36–6%)</td>
<td>0.086</td>
</tr>
<tr>
<td>Submerged mean</td>
<td>98 ± 7 (86–107) min(^{-1})</td>
<td>-6 ± 11% (-26–7%)</td>
<td>0.173</td>
</tr>
<tr>
<td>3min post</td>
<td>136 ± 13 (118–162) min(^{-1})</td>
<td>29 ± 14% (5–43%)</td>
<td>0.008**</td>
</tr>
<tr>
<td>Referring to pre dive heart rate</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pre dive</td>
<td>130 ± 13 (106–150) min(^{-1})</td>
<td>0%</td>
<td>—</td>
</tr>
<tr>
<td>Initial</td>
<td>106 ± 14 (85–130) min(^{-1})</td>
<td>-18 ± 5% (-25; -8%)</td>
<td>0.008**</td>
</tr>
<tr>
<td>1min dive</td>
<td>105 ± 10 (89–122) min(^{-1})</td>
<td>-19 ± 8% (-33; -10%)</td>
<td>0.008**</td>
</tr>
<tr>
<td>10min dive</td>
<td>97 ± 7 (82–107) min(^{-1})</td>
<td>-25 ± 7% (-35; -14%)</td>
<td>0.008**</td>
</tr>
<tr>
<td>20min dive</td>
<td>93 ± 12 (71–109) min(^{-1})</td>
<td>-28 ± 12% (-46; -16%)</td>
<td>0.008**</td>
</tr>
<tr>
<td>Submerged mean</td>
<td>98 ± 7 (86–107) min(^{-1})</td>
<td>-24 ± 8% (-36; -15%)</td>
<td>0.008**</td>
</tr>
<tr>
<td>3min post</td>
<td>136 ± 13 (118–162) min(^{-1})</td>
<td>5 ± 8% (-10± 12%)</td>
<td>0.110</td>
</tr>
</tbody>
</table>

Values are presented as mean ± SD (range). P values computed in paired-samples-T-tests are listed in column four.

Table 2 Heart Rates and Changes of Heart Rates (\(\Delta\))
Calculated from Different Baselines
No further arrhythmias were detected. ECG samples of the arrhythmias observed are presented in Figure 2a and b.

**Discussion**

For the first time, this study monitored the heart rate and rhythm in children performing open-water SCUBA dives. A decline in heart rate was observed throughout the dive that was found to be associated with the initial heart rate and anthropometric variables.

Several factors may account for heart rate changes during SCUBA diving. First, the diving response, a physiological adaptation allowing animals to endure a lack of oxygen, is known to decrease HR. In humans, the diving response is known to be less pronounced in adults compared with children (4). In an earlier study of infants aged two to twelve months, submersion alone caused an immediate fall in heart rate of 25% (range 5–51%; 13). In the current study, we obtained a statistically significant decrease in HR of 19% on average from the predive baseline after
1 min of SCUBA diving when the face had been submerged, thus, comparable to the degree of HR response reported for infants.

Being an important facilitator of the diving response, facial cooling is a stimulus for decreasing HR (3, 22), too. This effect was initially expected to be caused by direct brain cooling (8), however more recent studies found bradycardia to be linked to trigeminal stimulation (1, 3, 14). Furthermore, Heindl et al. reported that cooling of the nasal cavity results in significant bradycardia in man (15). The latter observation might explain, why SCUBA divers show a diminished response to facial cooling during immersion compared with swimmers, as dive masks cover larger parts of the face as well as the nasal cavity (29). Diving bradycardia has been shown to depend on water temperature with the highest decline in heart rate in the coldest water (30). Bradycardic responses to facial cooling have also been shown to vary with age (28). In fact, we found an association between age and the decline in HR in our subjects. However, earlier studies revealed that aerobic fitness and thereby parasympathetic tone may account for the effect of age on HR response, since there were differences between elderly aerobically fit and sedentary subjects while these differences could not be found in younger subjects. All subjects participating in the current study performed endurance sports such as swimming or athletics at least twice a week. The narrow age range and medical and sports history of our children divers rather indicated that aerobic fitness was unlikely to account for the obtained relationship. Moreover, the diving bradycardia measured in our study was more likely maintained by mechanisms other than the diving response, e.g., cold stress.

A second factor accounting for bradycardia during SCUBA diving is a loss in body heat. Boussuges et al. (5) exposed healthy subjects to dry and immersed hyperbaric hyperoxia. While heart rate remained constant in the dry environment after five hours, it declined significantly between the beginning and after 5 hr in the

Figure 2 — a) Single supraventricular extrasystole during the SCUBA dive. b) Single ventricular extrasystole during the dive.
immersed state. As a decline in rectal temperature was measured during immersion, the loss of body temperature likely explained the bradycardia. Hyperoxia, that is known to be the most important contributor to hyperbaric bradycardia, was negligible in the study by Boussuges et al. (5). In the current study of children diving to a depth of eight meters, hyperoxia may have theoretically been a contributing factor to bradycardia. However, for a couple of reasons the role of hyperoxia can be considered negligible in our study. The subjects performed a shallow water dive only and therefore the elevation in \( \text{pO}_2 \) (38 kPa) was rather mild. Furthermore, some subjects showed a pronounced HR decline that was associated with anthropometric factors, while the ambient oxygen pressure was not different from subjects who showed mild bradycardia only.

During SCUBA dives, children are exposed to (cold) water which can result in skin and body cooling. After twenty minutes of immersion a decrease in heart rate greater than 20% could be observed in three children. Due to their lower body weight and body mass index, their increased surface area and reduced subcutaneous fat tissue (37), children are more susceptible for heat loss than adults. In addition, children often use wet dive suits only, whereas adult SCUBA divers use semidy or dry suits for diving in cold water that give better thermal insulation. Moreover, children’s suits do not fit perfectly quite often, as parents buy larger suits to use them longer and save costs. All these factors may have contributed to a faster and higher heat loss and, thus, a more pronounced and maintained bradycardia compared with adults. In our study, body mass index, body weight and the according percentiles were not significantly different between children with a higher (>12%) and a lower (<12%) decline in heart rate. In contrast, children with a greater fall in HR 20 min after the descent were significantly older and taller than subjects who showed a less pronounced fall. In some studies, tall subjects have been reported to suffer from orthostatic syncope earlier than smaller subjects (21). A higher heart rate might consequently be required in the upright position. Autonomic dysregulation following loss of gravidity during submersion might therefore explain a higher downregulation of HR during diving. However, it is likely, that height plays an important indirect role as higher height results in higher body surface area. As high body surface area fosters heat loss (31), tall children might be more at risk for heart deceleration due to thermal mechanisms.

Autonomic regulation is expected to play a central role in control of heart rate during SCUBA dives. Children with a history of fainting or neurocardiogenic syncope might be more sensitive to environmental stimuli like facial cooling or hypothermia. For this reason, these children might be at increased risk for severe bradycardic reactions during SCUBA dives or even loss of consciousness. Additional provocations like tilt test might identify children at risk during medical fitness to dive examination.

In contrast to the conditions during the dives, children are exposed to different stimuli outside the water before and after the dives. An increase in heart rate could be observed before descent and after surfacing though immersion is actually associated with a decline in heart rate (20). This increase might be explained by several mechanisms: First, mechanical workload due to the diving gear required physical effort when walking with equipment to the lake and entering the water. Second, nervousness and fear might have been present (6). Especially in unexperienced pediatric divers, fear and nervousness before the dive might lead to an increased
heart rate. However, there are no previous studies that investigated the effect of diving experience on heart rate and changes in heart rate. Spearman’s correlations did not indicate an association between heart rate, changes in heart rate and diving experience in the current study. However limited sample size has to be taken into account. Third, neoprene suits consist of an excellently insulating fabric and, thus, temperature can increase inside the suit. In contrast to under-water conditions, divers are at risk to suffer hyperthermia outside the water. As cooling by vaporization is very limited because of the air-tight suit, an increase in body temperature is quite likely, especially in combination with direct radiation of the sun. This increase in temperature can result in tachycardia (10). Three minutes after surfacing from the dive the HR was back to the pre dive baseline but not to initial HR, potentially due to the excitement from the dive.

The only arrhythmias observed in our study were single supraventricular and single uniform ventricular extrasystoles. Supra ventricular extrasystoles are frequent in older children and adolescents (23) and not considered to be of pathological significance (25). Ventricular extrasystoles are also common in healthy children (7) and associated with a very low mortality risk only (2). These premature beats are considered benign if they disappear during physical exercise (7, 17) which was proven in one child. Consequently grave arrhythmias did not occur in any subject. However, it is surprising that more than fifty percents of the subjects (5 in 9) presented extrasystoles. Nevertheless these findings are not necessarily abnormal. A stress test such as an exercise test or tilt test with ECG-monitoring and a Holter-ECG might have provided additional information. However, these tests were not part of the study design. In future studies, more extensive evaluation of cardiac rhythm should be included.

In conclusion, this study revealed a decrease in HR in children during a SCUBA dive to eight meters of depth. Apart from the diving response itself, cold stress most likely accounted for the HR deceleration observed. No higher grade arrhythmias could be monitored during the SCUBA dives. Further studies on cardiac effects of SCUBA diving in children are required as sample-size and gender distribution are limited in the current study. These studies might help to evaluate the effect of water and body temperature on heart rate more clearly.

**Ethical Standards and Conflict of Interest**

The experiments comply with the current laws and have been approved by the committee on human ethics (Institutional Review Board) of the Medical Faculty of the University of Wuerzburg. The authors declare that there is no conflict of interest.

**References**


