The heart rate of breath-hold divers during static apnea: effects of competitive stress.

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Lindholm P, Nordh J, Gennser M. The heart rate of breath-hold divers during static apnea: effects of competitive stress. Undersea Hyperb Med 2006; 33(2):119-124. Breath-hold divers compete with regard to depth, time and/or distance. The present observations were carried out on athletes performing static apnea where they perform one breath-hold for as long a duration as possible with the body and face immersed in water. Heart rate was measured on eight competitors participating in the Swedish Championship in static apnea 2001, both during the competition and during a separate training session using the Polar® NV system. The duration of apneas during the competition ranged from 3 minutes 27 seconds to 5 minutes 33 seconds. The divers exhibited significantly faster heart rates prior to and during the first 90 seconds of apnea in connection with competition, than during training. One subject experienced a loss of motor control during the competition. We suggest that mental stress in humans, caused here by a competitive situation, leads to an increase in the heart rate during apnea.

INTRODUCTION

During the past decade a new type of water sport called apnea has developed. Originating from (breath hold) spear fishing, in which competitions have been held for decades, a growing number of athletes have begun to compete in breath-hold diving with regards to depth, time and/or distance. In the case of static apnea the athlete immerses the body and face in a swimming pool and then holds a single breath for as long as possible. The athletes are usually dressed in a wetsuit and float motionless face-down on the surface for the duration of the apnea.

During breath-holding, the oxygen stores in the lungs and blood are depleted until the partial pressure of oxygen in the brain becomes so low that the diver risks a loss of consciousness (LOC). Usually, the overwhelming urge to breathe will force the diver to break the breath hold before he becomes unconscious. In order to avoid disqualification, the athlete must perform the breath-hold and surface without assistance and without observable signs of brain hypoxia, such as loss of motor control (LMC) and/or LOC. The duration of an apnea is determined by the size of the oxygen stores (e. g, the lung volume), as well as by the rate of oxygen consumption. Therefore, the athletes try to relax as completely as possible in order to reduce their oxygen consumption.

Another factor that might influence the rate of oxygen consumption is the diving response. This response, as demonstrated in diving mammals, helps to prolong the duration of their dives (1, 2) by decreasing oxygen consumption during apnea via bradycardia and peripheral vasoconstriction. In human beings a slowing of the heart rate has been found to be associated with oxygen conservation during apnea under both resting (3, 4) and exercising conditions (5-7). The diving response during apnea is elicited primarily by the respiratory arrest per se and is thus active even in a diver wearing wetsuit and face-mask (8, 9). It is our experience that in the case of the sport of static apnea, many athletes achieve better times during...
training than in connection with competitions and it is generally assumed (among divers) that the extra stress associated with actual competition reduces the ability of the athlete to hold his/her breath. In many sports, anticipation and emotional stress prepare the athlete for the coming exertion as shown by an increased heart rate (10) whereas during apnea the athlete attempts to remain as relaxed as possible, both before and during the event in order to reduce oxygen consumption.

Divers with a stronger bradycardic response to breath-holding can endure apnea for longer durations (11) possibly due to a slower rate of oxygen desaturation (3). Wolf et al (4) found that in human subjects who performed mental arithmetic during breath-holding this “mental stress” reduced the extent of bradycardia, and caused a more rapid reduction of the arterial oxygen saturation (4).

There have been no previous reports on changes in heart rate during apnea in connection with competitions and the present investigation was designed to explore this question. In order to select a national team from Sweden to participate in the third World Championships held in the Mediterranean Sea in 2001, a national championship in apnea was held. Some of the Swedish competitors at this event volunteered to have their heart rate measured during the competition in static apnea and, for comparison, during a training session. Our hypothesis was that their heart rates would be higher during the competition than during training.

METHODS

Subjects

Eight healthy male volunteers who participated in the national championships in apnea (including static apnea) were studied. Subjects were age 25±5 years (Mean±SD), weight 76±9 kg, and height 181±4 cm. BMI was 23±3 kg/m². The Ethics Committee at Karolinska Institute approved the experimental protocol and all subjects gave their informed written consent prior to participation.

Measurements

Heart rate was measured with the Polar® NV system (Polar Electro Oy, Kempele, Finland) which consists of an electrode band fastened across the chest and a heart rate recorder with data storage capacity worn on the wrist. The heart rates were stored as R-R intervals and the data analyzed employing the Polar Precision Performance 2.0 interface and software and Microsoft Excel software.

Protocol

All of the subjects had some experience wearing the Polar system prior to the competition. Control measurements during static apnea were performed within a one-month period before or after the competition. In both the control and competitive situation, the subjects performed a series of preparatory apneas prior to the apnea during which heart rate was monitored. The subjects used their own personal breathing patterns (hyperventilation) before the apneas, which were performed in 27°C ±1°C water wearing a whole-body neoprene wetsuit and a face-mask. In the control situation, subjects were asked to perform a long apnea without pushing themselves to their maximal limit.

The test protocol could not be allowed to interfere with the subjects at any time during the warm-up or actual performance of the static apnea during the competitions and thus, it was not possible to collect an end-tidal sample of gas, either before or directly after the apnea.

Analysis

The average heart rates during 10-sec intervals, starting 30 sec prior to and continuing until the end of apnea, were calculated. The values obtained under different conditions were compared statistically using two-way ANOVA for dependent variables with significance accepted at p<0.05. (Statistica, Statsoft, Tulsa, OK).
RESULTS

Of the 21 competitors involved in the national championship trials, 8 participated in the present study. Seven of these subjects finished in 2nd, 3rd, 5th, 9th, 11th, 15th and 18th place in the competition. One subject was disqualified. Breath-hold duration (Mean±SD) was 257±49 seconds during control and 309±78 seconds during the competition.

All of the subjects held their breath for at least three minutes and the mean heart rate for consecutive 10-second intervals during this period of apnea was calculated. In comparison to training, the heart rate during competition was significantly higher prior to (p<0.01) and during apnea (p=0.01). During the apnea, the heart rate declined with apnea duration (p<0.001). The ANOVA also showed a significant interaction term between condition and duration. From Figure 1 it can be seen that the difference between the two conditions is diminished as the duration of the apnea progresses, and to evaluate this difference we analyzed the differences using confidence intervals (12). At 100 seconds of duration the confidence interval of the difference between competition and training included zero, thus we interpret the data such that the significant difference between conditions was important for the first 90 seconds. Following termination of the apneas, the subjects were often breathing heavily, which caused the measurements to be unreliable and thus prevented analysis of heart rates during this period.

Two of the 21 competitors were disqualified because they exhibited signs of hypoxia. One of these was one of our subjects, who demonstrated loss of motor control upon surfacing after the apnea. This subject was exhaling and attempting to get out of the water when he received assistance from the safety attendant. He was able to speak clearly and appeared to remember the incident, but had no postural control for a period of approximately 10 seconds immediately after he was pulled from the water.

DISCUSSION

The major finding of the present study is that the average heart rate of athletes performing

![Fig 1](http://archive.rubicon-foundation.org)

Fig 1. Mean (SD; n=8) heart rates 30 seconds prior to and during the first 2.5 minutes of apnea. The vertical line represents the start of apnea o = competition; = training. The values for these two conditions were significantly different during breathing prior to apnea (p<0.01), and during apnea (p=0.01).
static apnea was higher during competition than in connection with training, when the duration of the apnea was subjectively less important for the subject. This is similar to observation and comparison between training and competitions in other sports events (13). Although, apnea can be considered a physically demanding sport, the challenge for the athlete is in many ways more similar to precision sports. In order to perform well and to achieve apnea of as long duration as possible, the athlete strives to be as relaxed as possible both prior to and during the apnea. Mental stress has been shown to increase both heart rate and oxygen uptake (14, 15), although HR under mental stress appears to overestimate the oxygen uptake compared to the same HR during exercise (14).

There are no quantitative data on oxygen consumption and heart rate during resting apneas, however it has been shown that the reduction in HR during apnea is related to a reduced desaturation rate in arterial oxygen saturation (3).

Unlike the anticipatory tachycardia seen in human athletes, anticipatory low heart rates prior to diving have been observed in seals (2). Kooyman and Campbell (16) showed that initial heart rate in freely diving Weddell seals varied inversely with dive duration up until 25 min long dives. The authors suggested that their results indicated that the diving response was not an on-off response, but could be modulated by the animal’s anticipated dive plan. In contrast, in our subjects anticipation of long dives appeared to counteract the initial heart rate reduction and maintain the heart rate at a higher level compared to the training apneas. Although our subjects probably attempted to achieve a long apnea, even in the training situation, they are likely to have been more focused on producing their longest possible apnea in the competitive situation. Thus, it would seem that in humans, anticipation of a maximal duration dive tends to increase the heart rate. This lack of a stronger bradycardia in humans trying to perform an apnea of long duration is in agreement with the findings of Andersson et al. (17), who asked subjects to perform face-immersion breath-holds of either maximal or short duration and observed no influence of anticipation of a long apnea on the heart rate.

Seals have also been shown to reduce their heart rate more rapidly and to a lower level in connection with forced dives than during free diving in shallow waters (2). Application of the corresponding stressful situation to humans, i.e., unexpected and/or forced submersion, is clearly unacceptable because of the risk of drowning. However, competitive diving might be used as a model for induced stress in subjects, if the outcome of the competition is important enough to them. Another such stressful situation is the use of breath-hold diving in the training and selection of military recruits. If the findings on heart rate described here can be shown to be accompanied by changes in oxygen consumption this would emphasize even more clearly that safety guidelines for breath-holding should not be based solely on laboratory experiments involving relaxed subjects.

During the competition apnea the athlete tries to minimize stimuli other than the physical sensations of the apnea itself. This limits the type of measurements that could be performed here, since the equipment and/or testing protocol could not be allowed to interfere with the subjects at any time during the warm-up or actual performance of the static apnea. Thus, it was not possible to ask our subjects for an end-tidal sample of gas, either before or directly after the apnea. The level of carbon dioxide in such a sample would have been useful in evaluating the level of hyperventilation achieved by the subjects.

It is possible that our subjects hyperventilated to a greater extent prior to the
competitive apnea than in the training situation, and that this could explain the difference in heart rates observed, since a higher frequency of breathing accelerates the heart rate (18). However, hyperpnea cannot explain the higher heart rates exhibited during the competitive apnea itself; nor could hypocapnia induced by hyperventilation have caused tachycardia, since hypercapnia has been demonstrated to increase heart rate during apnea (19). In contrast, hypoxia has been reported to reduce heart rate during apnea (19, 20). Although hypoxia is unlikely to have influenced the heart rate at the beginning of an apnea, this condition might explain the slower heart rate observed during the later period of the competitive apnea in the subject who was disqualified for hypoxic loss of motor control.

As the duration of the apnea progressed, the differences in heart rate between competition and the training situation decreased (Fig. 1). Apnea can be divided into two phases, the easy-going and struggle phases (21). The easy-going phase, a state of relaxation devoid of any physical urge to breathe, ends when diaphragm contraction begins. This contraction starts when the arterial PCO₂ rises to the physiological breakpoint and thereafter the subject must fight against an increasing urge to breathe layered over the sensation of a contracting diaphragm. It could be argued that the stress during the struggle phase was similar under both conditions employed here, which could explain the smaller differences in heart rate during the later period of apnea.

We suggest that mental stress in humans, caused here by a competitive situation, leads to an increase in the heart rate prior to and during apnea, which could possibly reduce the potential of the diving response to conserve oxygen. Thus it is possible that mental stress affects the performance of a breath-hold diver negatively, a possibility that merits consideration, e.g. when testing the performance of navy recruits in underwater swimming tests. The safety limits for breath-hold diving based on routine training might not be adequate when the diver is under stress.

ACKNOWLEDGMENTS

This study was supported financially by FOI, the Swedish Defense Research Agency (project no EF0202).

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