UNIVERZA NA PRIMORSKEM

FAKULTETA ZA MATEMATIKO, NARAVOSLOVJE IN INFORMACIJSKE TEHNOLOGIJE

Alex Buoite Stella

Cognitive and physiological effects of the initial responses during cool water immersion

Magistrsko delo

Koper, september 2012

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APLIKATIVNA KINEZIOLOGIJA

Cognitive and physiological effects of the initial responses during cool water immersion

Magistrsko delo

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IZJAVA O AVTORSTVU MAGISTRSKEGA DELA

Podpisani Alex Buoite Stella študent magistrskega študijskega programa 2. stopnje Aplikativna kineziologija,

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Naslov magistrskega dela:
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Povzetek:
Prvi odziv na potopitev v hladno vodo, kot sta ga 1981 definirala Golden in Hervey, je posledica nenadne močne stimulacije kožnih termoreceptorjev na hladno. Močna stimulacija termoreceptorjev na hladno med drugimi povzroči tahikardijo, hipertenzijo, tahipnejo, zvišano ventilacijo in znižano koncentracijo izdihanega ogljikovega dioksida (Golden & Tipton, 2002). S tem, da navedeni fiziološki odgovori zmanjšajo čas zadrževanega vdiha, je kritično prizadeta kapaciteta vdiha. Kot posledica se zaradi predčasnega vdiha in s tem tudi inspiracije vode pojavi povečana nevarnost za utopitev. Prvi odzivi se pojavijo takoj po potopitvi v hladno vodo in trajajo približno 3 minute, z vrhuncem okoli 30 sekund po potopitvi. Zgoraj opisani fiziološki mehanizmi pa niso sproženi le ob potopitvi v hladno vodo, ampak se lahko sprožijo tudi pri temperaturah vode do 25 °C. V primeru potopitve je prvotnega pomena načrtovanje in organizacija strategije reševanja (Cheung, 2010). Študija je začetno ocenila kognitivne funkcije med prvimi odzivi v vodi pri temperaturi 18 ° C. Jakost in trajanje nekaterih fizioloških parametrov (poraba kisika, ventilacija, dihalne frekvence, srčnega utripa in pretečeni delež kisika) sta bila izmerjena z namenom opazovati začetne odzive v hladni vodi. Ustna različica SDMT je bila uporabljena, da bi ocenili izvršilno funkcijo in še zlasti delovni spomin. Rezultati so pokazali, da so se, v primerjavi s suhim termonevtralno stanjem ($p < 0,05$), vsi fiziološki parametri povečali pri potopitvi v hladno vodo. Pri primerjavi obsega odgovorov sta bila srčni utrip in frekvenca dihanja nekoliko nižja v primerjavi s študijami pri 10 in 15 ° C (Tipton, Stubbs in Elliot, 1991; Tipton, Mekjavic in Eglin 2000). Kognitivna zmožnost se je zmanjšala ob potopitvi v hladno vodo, če jo primerjamo s stanjem nadzora, vendar samo v prvih 2 minutah po potopitvi. Vse to dokazuje, da lahko strategijo reševanja neposredno ogroža ne le panika, temveč tudi šok ob kontaktu s hladno vodo.

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Abstract:
The initial responses during water immersion, as defined by Golden and Hervey in 1981, are the first mechanism reacting to a strong stimulation of superficial nervous cold receptors. Cold shock induces tachycardia, hypertension, tachypnea, hyperventilation, and reduced end-tidal carbon dioxide fraction (Datta & Tipton, 2006; Tipton, 1989). The initial responses are observable suddenly after the immersion and lasts for about 3 min (Golden & Tipton, 2002). The initial responses, as defined above, have been observed in not acclimatized people also in water temperatures up to 25 °C (Golden & Tipton, 2002). Different authors proposed to plan the self-rescue strategy during the first minutes after water immersion in a sea survival scenario, for example evaluating distances (Cheung, 2010, Ducharme & Lounsbury, 2008). In the present study, the evaluation of the cognitive functions during the initial responses was performed in water temperature of 18 °C. The magnitude and the duration of oxygen consumption, ventilation, respiratory frequency, heart rate and expired fraction of oxygen were measured to observe the initial responses in cool water. A code substitution test was used to evaluate executive functions and, in specific, working memory. Results indicated that all the physiological parameters were increased during cool water immersion when compared with a dry thermoneutral condition ($p < 0.05$). As observed in previous studies (Golden & Tipton, 2002, Tipton, 1989) physiological parameters progressively returned to normal values. Cognitive performance was reduced during cool water immersion if compared with control condition, but only during the first 2 min ($p < 0.05$). According to the literature (Cheung, 2010), physiological responses do not suggest to perform intensive and complex physical activities. Planning the best rescue strategy could be partially impaired not only because of panic, but also because of the cold shock.

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1 INTRODUCTION

«In the struggle for survival, the fittest win at the expense of their rivals because they succeed in adapting themselves best to their environment»
(C. Darwin)

During the past centuries mankind explored the world over almost its whole surface and beyond, from the hot African deserts up to the cold lands of Antarctica, from the high Tibetan mountains even up to the pale moon. However, one of the first human conquests was the sea: already in the 3,500 BC in Mesopotamia a small ship was built and in the following centuries Phoenicians, Greeks and Egyptians began the history of shipping. These populations sailed through all the Mediterranean and touched also some African Atlantic coasts. In the northern Europe, Vikings ran through the cold water and got to North America. Nowadays, a lot of people cross the seas everyday around the world for leisure, work or trade. In the United Kingdom, 25% of the people who sail for recreational purpose face a possible life threatening situation on the sea (Royal National Lifeboat Institution statistics, 1999). In the United States, from 1985 to 1995 there have been 204 boat collisions, 769 groundings, 438 strikings (e.g, impacting on a solid object), 211 fires, 131 sinkings, 38 capsizes and 18 explosions (USA Today, 11 January 1999). Between 1978 and 1998 more than 5,300 passengers were killed in ferry accidents around the world, and this made ferry travel 10 times more dangerous than air travel (Faith, 1998). Road traffic injuries report from the world health organization (WHO) counts 1.2 million deaths per year around the world. The sea represents a possible threating environment and it is important to know how to face a possible survival condition as it is important to know how to behave on the road. Temperature is a fundamental factor when analyzing sea survival. The sea surface temperature 4 m depth (SST) of the Mediterranean is warmer than in the ocean and in the water surrounding Northern Europe. For the Western Mediterranean, in 2006 the SST annual mean was about 19 °C, while for the Eastern Mediterranean it was about 21 °C, with oscillations in winter and summer of ± 4 °C (Nykjaer, 2009). Whereas, SST of the North Sea reaches 6 °C in winter and 21 °C in summer. With an estimated mean of about 15 °C this meant that falling into the water is likely to lead to death due to swim failure or hypothermia (Golden & Tipton, 2002). Timing is a relevant factor influencing the physiological responses and the rescue experts have always to consider it.

In the first part of this text findings from the literature referring to cold water immersion will be presented, because most studies have been performed in such temperatures (usually 15 °C or lower). However, scientists agree that also with warmer temperatures (up to 25 °C) physiological responses (e.g., tachycardia, hyperventilation, etc.) are observed, increasing risk for drowning (Golden & Tipton, 2002). In the present study we will observe physiological responses (e.g., heart rate, minute ventilation, etc.), measured in cool water temperature (about 18 °C), to simulate temperatures similar to the ones observed in the Mediterranean. In addition, this study will observe cognitive effects of the initial responses to evaluate executive functions performance.

1.1 Sea survival

Worldwide every year 450,000 people lose their life because of drowning (Peden, McGee & Sharma, 2002) and many of these deaths occur in open water. For instance, 5,300 passengers were killed in ferry accidents around the world between 1978 and 1998 (Faith, 1998). Thus, the sea can be a potentially dangerous environment if some precautions and skills are not taken in account. In Annexes a report with some of the major disasters is reported. Physiologists, medical doctors and engineers often cooperate to propose efficient solutions to improve survival chances and organize the best rescue strategies. One of the most discussed subjects is drowning due to hypothermia by cold water immersion. Dating back to 450 BC, Herodotus considered hypothermia to be the primary cause of death. Namely, as the victims were rescued only after many hours of water immersion, their body temperature drastically decreased which presumably lead to death. In Middle Ages, the connection between water temperature and sea survival has been confirmed in experimental settings (Currie, 1798). However, people died also when they were exposed to water only for a short time, thus effort was made to improve life jackets and floating devices. But in 1912 the sinking of *Titanic* showed that despite wearing good personal floating devices, death will eventually occur when one is immersed for a prolonged time in cold water because of hypothermia. The opinion changed through time because the time needed for rescue decreased and it was possible to observe human reactions to cold in different conditions, suddenly or after prolonged period in the water, for example 2 hours after sinking, as for MV Estonia (Golden & Tipton, 2002). Nowadays, with statistical analysis and the improvement of Search and Rescue activities, the main risk is identified as drowning, especially if the sea is not calm (Golden & Tipton, 2002). Thus, early stages of immersion could lead to death because of drowning or inability to swim, while prolonged time into cold water induces organs failure by hypothermia (Golden & Tipton, 2002).

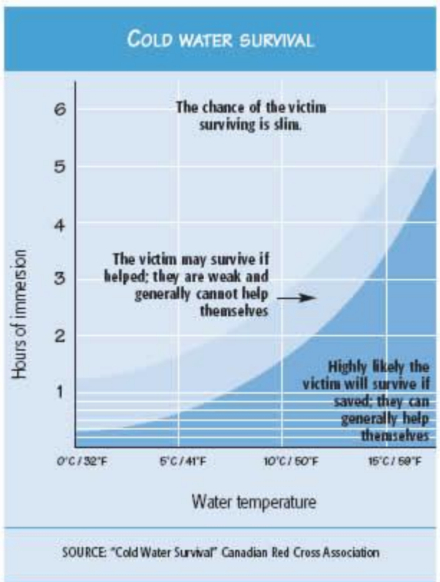
Drowning:

Drowning has been defined as death through suffocation by submersion because of the inability to maintain the airway clear, ingesting also small volumes of fluids, commonly water (Golden & Tipton, 2002). Total submersion is not necessary for drowning since the generally accepted lethal dose of seawater for humans is about 22 milliliters per kilogram of body mass (Modell, 1971). Such volume can be ingested also during intermittent submersions (e.g., waves), and for a man of about 70 kg also half a liter of water could potentially lead to death. Near drowning describes conditions in which people survived, at least temporarily, after aspirating fluids into the lungs (Golden & Tipton, 2002). This situation can provoke several damages to the organism and need to be carefully treated by the rescue personnel. Death by drowning is not caused mainly because of hypoxia, but the mechanisms underlying this condition are different. For example, some water can cross the alveolar membrane entering the blood stream, while a remaining part is trapped in the deeper recesses of the lungs, making them heavier and less elastic. In water-saturated lungs the resistance to blood flow increases significantly, rising the pulmonary artery pressure and increasing pressure in the right side of the heart. Venous congestion affects the right side output decreasing at the same time the left side pressure and blood flow, leading to cardiac arrest also in 2 minutes (Golden & Tipton, 2002).

Hypothermia:

Hypothermia not only can lead to death because of the loss of organs' physiological functions, but also because it can reduce muscle functionality, expressed as increasing fatigue and lowering power output. This mechanism is mainly driven by peripheral cooling, slowing enzymatic processes and nerve conduction (Drinkwater, 2008; Kimura et al., 2003). Thus, hypothermia can indirectly lead to death because cold impairs muscle functions and people cannot swim for long periods. There are also conditions in which survivors can utilize a floating device and it increases their chances to survive. However, hours into cold water (time depends on water temperature, clothing and fat mass), even with a good floating device, can lower core temperature below 35 °C. This temperature is known as critical body temperature and defined as "hypothermia", impairing metabolism (Golden & Tipton, 2002). Into the water the exchange of thermal energy between the organism and the fluid is faster and thus more dangerous than into the air. Water thermal conductivity is 24 times that of air and its volume-specific heat capacity is approximately 3,500 times that of the air (Golden & Tipton, 2002). These two physical characteristics explain the greater capacity of water to extract heat. Commonly it is accepted that a person immersed in water with a temperature of 15 °C could survive about six to eight hours, wearing normal clothing and a life jacket (Golden & Tipton, 2002). Prediction equations for survival time of persons wearing normal clothing have been proposed and experimental setting showed a similar trend (Hayward, Eckerson & Collis, 1975; Choi et al., 1996). Clothing, even if saturated by water, always provides some insulation and could increase the survival time also by hours especially in moderately cold water temperatures (Hayes & Cohen, 1987). Figure 1 represents a typical survival timeline for a person immersed into the water, wearing a life jacket and normal clothing.

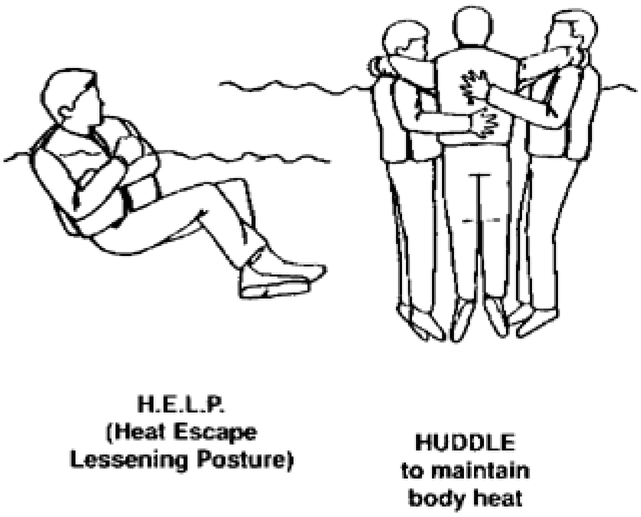
Fig.1: Estimated survival time immersed into the water expressed in time (hours) and related to different water temperature (°C / °F).



Source: Cold Water Survival, Canadian Red Cross Association.

Symptoms of hypothermia are primarily the direct consequence of an impaired metabolism, mainly in the brain, resulting in a speech that tends to be slurred, uncharacteristic behavior and slowed physical and mental activity (Golden & Tipton, 2002). With continued cooling victims become progressively more withdrawn, other body functions deteriorate and at the end they become unconscious and die. To reduce heat loss it is necessary to be well insulated (e.g., clothing) and reduce the body surface in direct contact with the water. If some survivors are together, it is suggested to stay near to benefit of the heat loss from the others and to be more visible for the search and rescue activities. Two positions are suggested by the experts in sea survival, the heat escape lessening position (H.E.L.P.) and the huddle position. Figure 2 illustrates these two techniques.

Fig.2: HELP and HUDDLE positions are suitable for sea survival.



Source: http://sportales.com/swimming/fabster-explains/.

These positions are helpful when facing prolonged period into the water, reducing the risk of hypothermia. However, because of the different responses showed by the organism depending on water temperature and time, every stage of immersion has to be specifically described. In 1981 Golden and Harvey identified four stages of immersion being associated with specific risks, defining specific protocols for each stage and helping Search and Rescue activities:

- *Initial responses (0-3 min):* are physiological mechanisms appearing after cold water immersion and are lasting for the first three min. This stage will be detailed later in the text;
- *Short-term responses (3-30 min):* cold can impair the conduction of nerve impulses, chemical reactions and muscle mechanics, leading to potential swim failure and subsequent drowning. Loss of manual dexterity is one of the possible and main consequences of the short-term cold water immersion, making devices and materials more difficult to operate (e.g., floating devices, ropes, GPS devices, etc.);
- *Long-term responses (more than 30 min):* after prolonged immersion cold can affect tissues and vital organs (e.g., heart, lungs, liver, etc.), reducing their activity and slowly leading to death because of swim failure or directly because of impaired organs' metabolism. Hypothermia usually is observed in this stage;
- *Post-immersion responses (during and after rescue):* even if rescued, survival is not guaranteed since many people that stayed a long period in cold water and later have been successfully rescued died because of the post rescue collapse, depending on the rewarming, or because of the after-drop phenomenon. After-drop occurs because during hypothermia peripheral vasoconstriction reduces blood flow to the core. However, when rewarming people, cold blood from the extremities travels back to the core provoking a drop in core temperature.

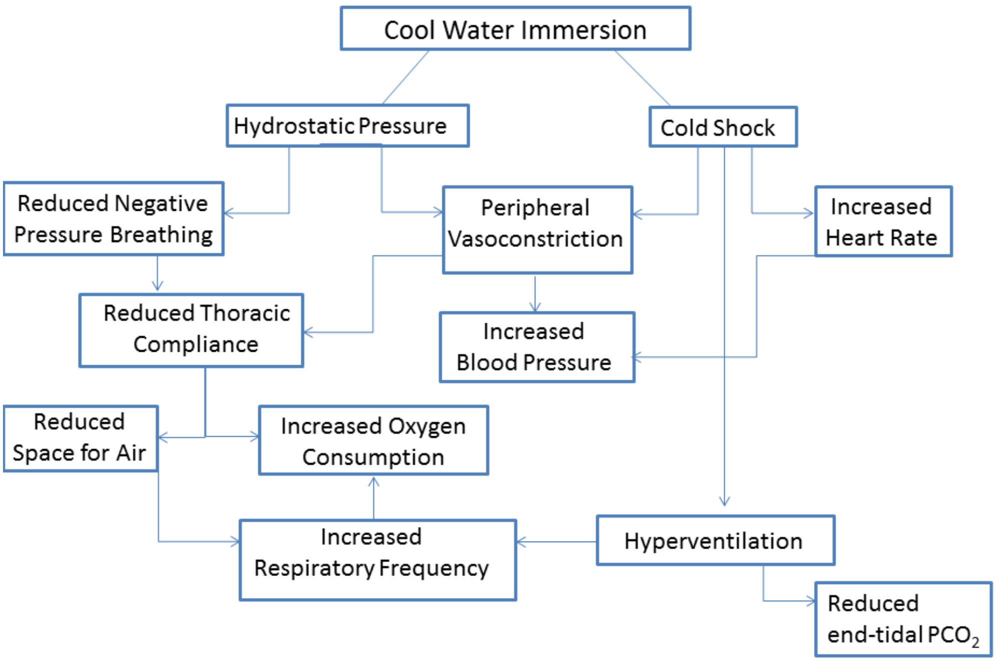
1.3 Initial responses: cold shock

After the immersion in cool water, cold receptors in the skin are strongly stimulated and provoke several physiological responses. These responses are tachycardia, hyperventilation, tachypnea and hypertension (Datta & Tipton, 2006). Each can adversely affect survival chances and can reduce physical and psychological performances (Cheung, 2010). Physiological responses commence immediately after the immersion and their intensity is inversely proportional to water temperature and directly proportional to the body area surrounded by water (Golden & Tipton, 2002). The peak is reached after 30 seconds and physiological parameters return to normal values after about 3 minutes. Since these responses are not observed in warm water, this indicates that there is a neurogenic origin driven by cold receptors located under the skin surface (Datta & Tipton, 2006).

Afferent pathways responsible for the respiratory responses (hyperventilation, increased respiratory frequency, etc.) are likely to be directly mediated by the midbrain (Keatinge & Nadel, 1965). Fat mass helps increasing survival time reducing core cooling rate but does not have preventive effects on the initial responses because of the small layer of fat between cold receptors and skin surface (Datta & Tipton, 2006). Clothing plays a key role in determining the magnitude of the initial responses. A significant difference in the physiological responses between participants wearing only swim trunks or other kind of clothing have been reported (Tipton, Stubbs & Elliot, 1990). Thus, clothing represents a protection factor not only to hypothermia but also against both the cold shock. However, there is no significant difference between conventional and foul-weather clothing in protecting from the cold shock (Tipton, Stubbs & Elliot, 1990). Comparing protection to the limbs with protection to torso, similar respiratory responses have been reported. Heart rate was reduced only if limbs were protected. Finally, both conditions showed a significant reduction of the initial responses if compared with naked subjects (Tipton and Golden, 1987). Thus, limbs are important to be protected, potentially because of the volume-surface ratio and thermal sensitivity (Allen, 1877). Indeed, other external factors influencing the initial responses are the thermal sensitivity of the individual and the acclimation to cold water immersions. The first depends on both genetic factors and acclimation (Kim et al., 2006).

Comparing different protocols of acclimation, best results are obtained if participants rested during the immersion (Tipton et al., 1998). An exercise protocol could partially impair the metabolic acclimation (Golden & Tipton, 1988). Thus, a good standard for acclimation protocols have to be proposed to compare different studies and achieve the best results. Acclimation to cold water is divided in three different patterns: metabolic, insulation and hypothermic (Hammel, 1963). Metabolic adaptation means that the metabolic response to cold temperature is stronger, increasing metabolic heat production. Insulative adaptation allows a greater fall in skin temperature without affecting core temperature. Thus, metabolic rate remain closer to pre-exposure level. Hypothermic adaptation shows a larger fall in core temperature with reduced metabolic response (Golden & Tipton, 1987). Acclimation effects attenuating cardiorespiratory responses are observable also after several months (Tipton, Mekjavic & Eglin, 2000). The authors used a control group and an acclimation group observing changes between the first immersion and 4 days later immersion in 10 °C water. The acclimation group undertook six 3-min head-out immersions in 15 °C water during the 4 days between measurements. Ventilation, respiratory frequency, tidal volume and heart rate were measured, and immersions were repeated also after 2, 4 and 7 months, with no acclimation protocol. Results showed that in all the parameters, excluding tidal volume, there was an acclimation effect mainly in first 30 s, immediately after the acclimation protocol. These effects were still observable after some months, even if their magnitude was gradually lost. In the control group there were no differences. Thus, it would be suggested to periodic cold exposure should occur every 2 months to maintain good acclimation effects and thus to reduce the initial responses (Tipton, Mekjavic & Eglin, 2000). One of the most threatening situations appears if the subject, when initial responses are present, submerges the face into the water (Tipton, 1989). Breath hold maximum time is reduced because of hyperventilation and the conflict between the vagal and the sympathetic systems caused by the immersion reflex can provoke arrhythmias (Datta & Tipton, 2006). Thus, the initial responses, that primarily affect cardiorespiratory functions, are probably responsible for the majority of near-drowning incidents and drowning deaths following accidental immersion in open water below 15 °C. In figure 3 the main physiological consequences of cool water immersion are summarized.

Fig.3: Physiological effects of cool water immersion.



1.3.1 Respiratory responses

Respiratory responses can be caused by two separate factors, the hydrostatic pressure and the temperature. The first is observable also in warm water. Water density is higher than air and therefore has a differential hydrostatic pressure over the immersed body, establishing negative pressure breathing. Thus, there is a redistribution of blood engorging pulmonary capillaries and competing with air for space in the lung, reducing lung compliance and increasing gas flow resistance (Datta & Tipton, 2006). These shifts increase oxygen consumption in the first minutes, also due to the increased work of respiratory muscles. However, results show that the peripheral cold-induced vasoconstriction does not increase the blood volume shifts caused by the hydrostatic pressure (Choukroun, Guenard & Varene, 1983). Vital capacity is reduced with 6%, maximum voluntary ventilation by 15%, expiratory reserve volume by 66%, resulting in a reduction in functional residual capacity. Some authors reported a fall in the arterial partial pressure of oxygen (Datta & Tipton, 2006). The cold shock provokes an initial gasp, immediately after immersion, usually between 2-3 liters in volume (Datta & Tipton, 2006). A corresponding inspiratory shift in end-expiratory lung volume results in hyperventilation within 1 liter of total lung capacity (Datta & Tipton, 2006). The amount of over-breathing may cause dizziness and confusion during the first minutes of immersion (Tipton, 1989). The sensation of dyspnea may be caused by the breathing close to total lung capacity combined with the afferent drive to breath. A substantial difference is observed depending on the way in which the subject enters the water, observing both temporal and spatial summation. A non-staged immersion in cold water can increase respiratory frequency by 115% and minute ventilation by 644% (Hayward & French, 1989). During the first minutes of immersion, maximum breath-hold time is reduced of 25-30% of the time measured before immersion (Tipton, 1989). The neural drive to breath plays a key role since a lowered carbon dioxide tension before immersion, obtained with a voluntarily hyperventilation, does not affect the respiratory responses (Tipton, Stubbs & Elliott, 1991). Psychological training can attenuate the respiratory responses decreasing anxiety (Barwood et al., 2005). The initial responses can also habituate with an acclimation protocol, reducing respiratory values also by 50% (Tipton et al., 1998).

1.3.2 Cardiovascular responses

During immersion the immediate vasoconstriction of the skin vessels increases peripheral resistance to blood flow and increases flow returning to the heart through the veins. As a consequence, blood pressure rises dramatically because of the simultaneous increase in heart rate and stroke volume, and the increased vasomotor resistance in the periphery (Tipton, 1989). Coronary arteries are evenly affected by these responses and the rise in blood pressure can represent a threat for people suffering of hypertension (e.g., rupture of blood vessels or strokes). Thus, blood pressure represents a potential risk for people facing cold shock (Golden & Tipton, 2002). Furthermore, sudden and unexpected stress induces the production of catecholamine that may also produce undesirable abnormal cardiac rhythms (Tipton, 1989). As discussed earlier, one of the most relevant cardiac threats occurs if the face is immersed in the water and the diving reflex elicited even if cerebral blood flow is maintained when the face is immersed (Kjeld, Pott & Secher, 2009). This vagal stimulation after the face is immersed into the water decreases heart rate, respiratory frequency and ventilation (Golden & Tipton, 2002). The competition between the sympathetic response of the cold shock, trying to increase heart rate, and the vagal stimulus of the diving reflex that slows heart rate, can provokes arrhythmias, cardiac arrest (i.e., vagal inhibition) and sudden death, or hydrocution, in susceptible individuals (Tipton, Kelleher & Golden, 1994).

1.4 Cognitive aspects of sea survival

Several studies (Lounsbury, 2004; Ducharme & Lounsbury 2007; Cheung, 2010) observed the time line for self-rescue, evaluating factors as the time needed to reach a critical low core temperature while immersed into the water or the maximal distance that a survivor can swim while wearing normal clothing in cold or cool water. All these studies concluded that one of the largest challenges in the initial phases of survival scenarios is taking the best decision, like "stay or swim" (Lounsbury, 2004; Ducharme & Lounsbury, 2007; Cheung, 2010). As shown previously, during the initial responses physiological functions are altered and physical reactions are potentially detrimental for the possibilities of rescue. For example, hyperventilation while swimming could provoke the ingestion of water and increase muscular exhaustion. A study of Lounsbury (2004) showed that waves and the location of the head at sea level impaired the capacity of estimating the distance from shore. In the same study they observed that 3 minutes after the immersion the prediction was quite accurate, while in the first minutes results were overestimated. These results suggest that immediately after the immersion, mental performance and visual functions could be reduced. Executive functions is a term that groups different cognitive processes such as planning, working memory, attention, problem solving, verbal reasoning, inhibition, mental flexibility, multi-tasking, initiation and monitoring of actions (Chan et al., 2008). The problem solving model proposes that there are specific sub-functions working in different phases. Their functions work to represent a problem, plan for a solution, maintain the strategies in short-term memory in order to perform them by certain rules, and the evaluate the results detecting and correcting errors (Zelazo et al., 1997). Working memory is a component of short-term memory and is part of a system that processes information for brief periods of time and high demanding tasks. Selective attention is the ability to avoid distractions. Thus, working memory could be negatively affected during a sea survival scenario. Anatomically, the main cortical region organizing executive function is set in the prefrontal cortex (Zelazo et al., 1997). Neuropsychologists defined several conditions in which executive function plays a relevant role, in dangerous or technically difficult situations. The effects of stress and environment on cognitive processes will be summarized below. Acute cold exposure in the air (10 °C) declined working memory, choice reaction time and generally executive function, compared to baseline performance (Muller et al., 2012). These results are probably caused by a dry cold shock, since mild hypothermia seems to not impair cognitive performance (O'Brien et al., 2007). Conversely, a different study assessed that low demanding cognitive performance are unaffected by cold, but high demanding tasks were reduced only with core temperature decreasing and not during the initial phase (Giesbrecht et al., 1993). However, with the conditional discrimination task, response accuracy was impaired even with moderate cold exposure without core hypothermia (Thomas et al., 1989). Head position while immersed, influences cooling rate and mental performance with higher cooling rates and lower cognitive performance if the dorsum of the head was immersed (Lockhart et al., 2005). The hypothesis of a reduced cognition caused by the initial responses is suggested also by the reduced total and oxygenated hemoglobin in the frontal area during hyperventilation, measured by multi-channel near-infrared spectroscopy (Watanabe et al., 2003). In the same study researchers observed that in the frontal area, without hyperventilation, total hemoglobin and oxygenated hemoglobin were increased during executive functions.

Hyperventilation provokes hypocapnia and, consequently, can provoke either hypoxia as direct consequence in the cerebral cortex or as indirect consequence of hypocapnia. In a Stroop-like task, performance was reduced after overbreathing hypocapnic air, probably because of hypoxia-induced apneas (Van Diest et al., 2000). Blood pressure is evenly raised during the initial responses and this can influence executive functions. Indeed, cognitive performance is inversely correlated to resting blood pressure also in young healthy adults (Suhr, Stewart and France, 2004). In conclusion, disputed results have been presented to assess the interaction between cold exposure, acute or chronic, and cognitive functions. Responses could depend on the psychological test used, the experimental setting and protocol. However there are possibilities that the initial responses adversely affect cognitive performance even without panic and fear.

1.5 Aim of the study

The aim of the present study is to evaluate the initial physiological and cognitive responses during the first minutes after cool water immersion, proposing a “state of the art” for the psychological effects. In particular, we want to observe the main physiological parameters such as heart rate and ventilation, and executive functions estimated with the symbol digit modalities test, immediately after the immersion and its evolution during the adaptation time.

Hypothesis of the present study was that in the first minutes after cool water immersion it is possible to observe physiological reactions and that psychological performance is affected by it.

Goal of this study is to share our findings and provide not only researchers but also common people and Search and Rescue (SAR) personnel with information about the human responses after falling into 18 °C water. We sincerely hope that this work will help to the people who everyday works, lives or simply travels on the water and increase their safety and chances to survive.

2 METHODS

2.1 Participants

Nine healthy young males (26.7 ± 4.4 years) participated in the study. Their body mass was 76.3 ± 6.6 kg and their body mass index (BMI) was 23.9 ± 1.5 kg/m^2. Body fat was 16.8 ± 3 %. Body surface area (BSA) was 1.92 ± 0.11 m^2. All the participants voluntarily participated and were recruited among university students or researchers, age between 18 and 35 yrs. They were all instructed about the protocol and aim of the study. Prior to participation they signed an informed consent and they were informed about the possible risks of the study. A medical doctor assessed their health status. If they had an electrocardiography of their previous year, they were asked to send it to the medical doctor for further analysis. During the execution of the experimental protocol a medical doctor was present. Exclusion factors were cardiovascular, respiratory or neurological diseases, hypertension, Raynaud syndrome, BMI higher than 30 kg/m^2.

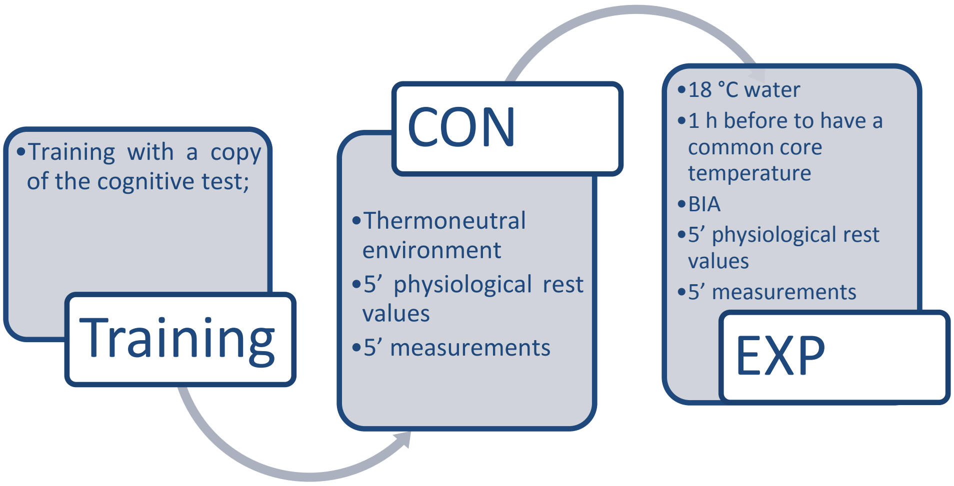
1.1 Protocol

No alcohol, coffee, Tabaco or carbohydrates were consumed at least 1 hour before measurements. One week before the first measurement session, participants received a training copy of the symbol digit modalities test (SDMT) in order to become confident with the cognitive test. Participants were instructed about the training protocol and before measurements they confirmed they became confident with the cognitive test. 9 people participated in the study.

4 participants performed the control condition (CON) in the morning at a fixed time, at least two hours after they woke up to avoid sleep inertia, one week before cool water immersion. CON was performed in a thermoneutral environment (25.6 ± 0.9

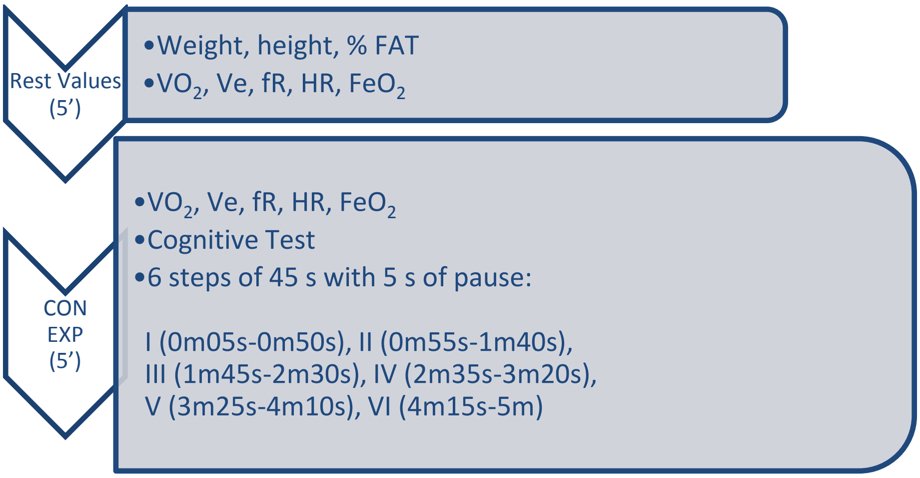
°C) at rest and the same physiological parameters as for the experimental protocol (EXP) were measured. The first trial of the SDMT has been performed and results have been recorded. After one week, at the same time of day at which CON started, participants performed the experimental condition. The remaining 5 participants performed EXP before and one week after CON, with the same rules of the first group. Figure 4 summarizes timeline for the first group.

Fig.4: Protocol utilized by the first group (n = 4) of participants. The second group (n = 5) inverted CON and EXP.



Participants were asked to reach the pool 60 min before the start of the measurements to acclimatize to the environment (26.5 ± 1.1 °C). During acclimation and experimental protocol they wore only short swim trunks. Body mass, height and body fat was measured. 5 min 30 s before immersion, baseline values were recorded for 5 min. Thirty seconds before the immersion the participants completed the warm up line of the SDMT. Then participants entered in the pool filled with cool water (18.5 ± 0.4 °C), head-out and water reaching the collarbone. Six steps of 45 s, corresponding to a different sheet of the SDMT, were used to average physiological responses. Every step had 5 s of pause between each and participants remained into the water for 5 min. For every step we obtained a cognitive performance score and a correspondent physiological response for all the parameters measured. Figure 5 describes measurements protocol.

Fig.5: Measurements protocol in both CON and EXP.



2.3 Measurements

Water and air temperature:

A water specific analogic thermometer with mercury column was used to assess water temperature during all the measurements. The thermometer was completely immersed into the water during measurements and temperature was recorded at the beginning and at the end of paticipants' immersion. The two results were averaged and presented. Air temperature was measured with a digital thermometer for outdoor activities (Rocktrail IAN 58787, Bedfordshire, UK).

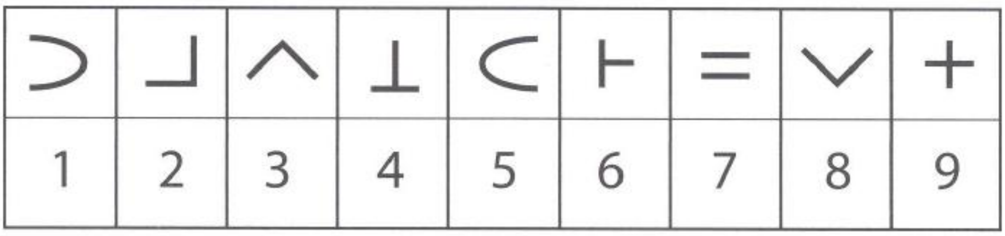
Physiological Parameters:

Metabolimeter (Fitmate Plus, Cosmed Srl, Italy) was used to measure physiological functions and it was automatically calibrated before every use. Heart rate (HR, bpm) was continuously recorded through a Polar belt (Polar, Sweden) connected with a wireless receiver on the metabolimeter. Equally ventilation ($\dot{V}e$, L/min), oxygen consumption ($\dot{V}O_2$, $mlO_2/kg*min$), respiratory frequency (fR, 1/min) and the expired fraction of oxygen (FeO_2, %) were analyzed and measured by the metabolimeter. Body mass (kg), height (m) and body fat (FAT, %) were measured before immersion. FAT was measured using a bioimpedence device according to device's guidelines (Handy3000, DS Medica Srl, Italy).

Cognitive Performance:

The Symbol Digit Modalities Test (SDMT), a code substitution test, is a reliable and repeatable method used in neuropsychology to assess information processing speed, selective attention and working memoryThis test consists in a sheet of paper with a matrix of nine symbols and nine corresponding numbers at the top. In figure 6 there is an example of the SDMT matrix used in this study.

Fig.6: example of a SDMT matrix.



In the same sheet, below the matrix, there is a sequence of symbols with a blank square where participants have to write the corresponding number using the matrix at the top, as fast as possible. The common protocol consists in matching a maximum of 110 symbols in 90 seconds. This test can be proposed in both written and oral version, the written protocol can be influenced by manual dexterity and coordination (Nocentini et al., 2006). This kind of test is widely used in clinical settings to assess cognitive functions in patients with dementia or other neurological diseases. However, it has been used and suggested also in experimental studies observing the environmental effects on mental performance (Suhr, Stewart and France, 2004; Hodgdon et al., 1991; Wright, Huli and Czesler, 2002, Pepper et al., 1985). In the present study time was changed (45 s every sheet instead of 90 s) in order to increase the temporal resolution. It consisted in a sheet of paper having on the top a matrix with 9 different symbols and its corresponding numbers, from 1 to 9. Below the matrix there was a sequence of 55 symbols with a blank square where researchers could write the number matched by the participants. Participants could look at the matrix during the whole execution of the measurement session. After an initial warm up in which they filled out a line with 10 symbols without any time limit, they started the test. Participants had 45 s to match as many symbols they could with a maximum of 55 symbols for each sheet. After 45 s a different sheet with a different matrix and different 55 symbols sequence was provided to the participant. Measurements started 5 s after the participants being immersed and changed every 45 s with 5 s of pause for each step until 5 min. One experimenter showed the sheet of the SDMT to the participant, while another experimenter recorded the results on a different copy of the same sheet. Results have been recorded for every different step in order to obtain a temporal evaluation of the cognitive performance. If the maximum of 55 symbols was completed before the step finished, time would be recorded. However, none of the participants completed the entire symbol sequence. We recorded the SDMT score (i.e., the number of correct combinations symbol-number) and the number of errors they committed during the test.

2.4 Calculations and data analysis

Body surface area (BSA, m^2) was calculated through body mass and height with the Du Bois and Du Bois equation (Du Bois & Du Bois, 1916). Heart rate (HR), ventilation ($\dot{V}$e), respiratory frequency (fR), oxygen consumption ($\dot{V}O_2$) and oxygen expired fraction (FeO_2) were recorded and displayed by the metabolimeter. A gas mixing chamber in the metabolimeter collected expired gases and matabolimeter software averaged the results every 15 s. Heart rate increment was calculated as percentage of the maximal heart rate, estimated with Tanaka's equation (Tanaka, Monahan & Seals, 2001), HR_{MAX} (bpm) = 208–0.7*age (yrs). During analysis, physiological responses have been averaged in order to obtain steps of 45 s.

Physiological and psychological responses are expressed as mean ± standard deviation. Differences between conditions are presented with positive numbers if EXP was greater than CON. Repeated measures ANOVA was used to observe difference among conditions and between steps in the same condition. P-values lower than 0.05 are considered significantly different. A t-test with a Bonferroni corrected p-value was used for post-hoc comparison. Correlation analysis (Pearson's coefficient) was performed between cognitive performance and physiological responses. All statistics was carried out with SPSS 19.0.

3 RESULTS

Characteristics of participants:

In table 1 characteristics of participants are summarized, indicating values for each participant and sample means ± standard deviation.

Tab.1: Anthropometrical characteristics of the participants (means ± standard deviations).

	1	2	3	4	5	6	7	8	9	Means ± SD
Age (yrs)	32	29	22	24	20	24	32	30	27	26 ± 4
Height (m)	1.78	1.92	1.79	1.80	1.75	1.83	1.80	1.73	1.70	1.77 ± 0.05
Body mass (kg)	73	85	77	83	77	75	83	64	71	75.5 ± 7.3
BMI (kg/m^2)	23.0	23.1	24.0	25.61	25.1	22.4	25.6	21.4	24.6	24.1 ± 1.8
FAT (%)	18	15.5	16	14.5	22	12	18	15	20	16.9 ± 3.7
BSA (m^2)	1.90	2.13	1.96	2.03	1.92	1.97	2.03	1.76	1.82	1.92 ± 0.11
HR_{MAX} (bpm)	185	188	193	192	194	191	186	187	189	189 ± 3

Physiological Parameters:

Before the psychological test, physiological values at rest (CON and EXP) were statistically indistinguishable in both conditions (CON and EXP), with a small difference only in the FeO_2. FeO2 was significantly higher in EXP (+ 0.51, $p = 0.02$). In table 2 results are presented.

*Tab.2: Physiological parameters at rest during CON and EXP. Results are shown as mean ± SD. Oxygen consumption ($\dot{V}O_2$, mLO_2/kg*min), ventilation ($\dot{V}e$, L/min), respiratory frequency (fR, 1/min), heart rate (HR, bpm) and expired fraction of oxygen (FeO_2, %). Significant differences are shown (NS = no significant).*

	CON	EXP	Sig.
$\dot{V}O_2$, mLO_2/kg*min	5.28 ± 1.10	4.88 ± 0.93	NS
$\dot{V}e$, L/min	11.5 ± 2.6	12.8 ± 4.7	NS
fR, 1/min	16 ± 4	15 ± 4	NS
HR, bpm	76 ± 8	81 ± 12	NS
FeO_2, %	16.75 ± 0.34	17.26 ± 0.68	0.02

Observing time in the same condition, during CON $\dot{V}O_2$, $\dot{V}e$ and FeO_2 were not significantly different among the different steps and rest. Conversely, fR significantly differed from rest to step 2 (+ 14.3, p = 0.042) and HR was significantly different from rest to step 1, step 4, step 5 and step 6 (respectively + 9.4 p = 0.027, + 9.1 p = 0.046, + 7.9 p = 0.005, + 9.6 p=0.05). During EXP it was possible to observe a statistical difference in all the parameters, except for FeO_2. $\dot{V}O_2$ was different only from rest to step 1 (+ 7.2, p = 0.03), and similar behavior was observed in $\dot{V}e$ from rest to step 1 (+ 24.5, p = 0.028). fR was significantly different from rest to step 1 (+ 23, p = 0.001), from rest to step 2 (+ 18.6, p = 0.007) and from rest to step 5 (+ 16, p = 0.048). HR significantly differed only from rest to step 1 (+ 29.7, p = 0.048). Figure 7 presents results for $\dot{V}O_2$ before and during cognitive test, comparing CON and EXP.

*Fig.7: Oxygen consumption ($\dot{V}O_2$, $mLO_2/kg*min$) trend during time, comparing CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate a different step. Results are shown as mean ± SD. Significant difference between conditions are marked. * $p < 0.05$, ** $p < 0.01$.*

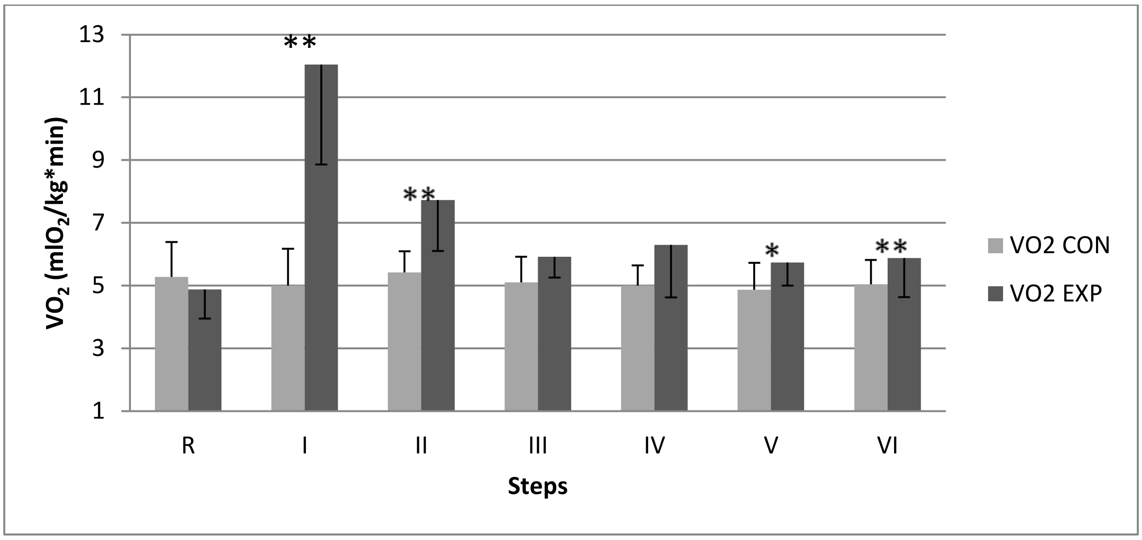


Figure 8 presents results for $\dot{V}e$ before and during cognitive test, comparing CON and EXP.

*Fig.8: Ventilation ($\dot{V}e$, L/min) trend during time, comparing CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate a different step. Results are shown as mean ± SD. Significant difference between conditions are marked. * $p < 0.05$, ** $p < 0.01$.*

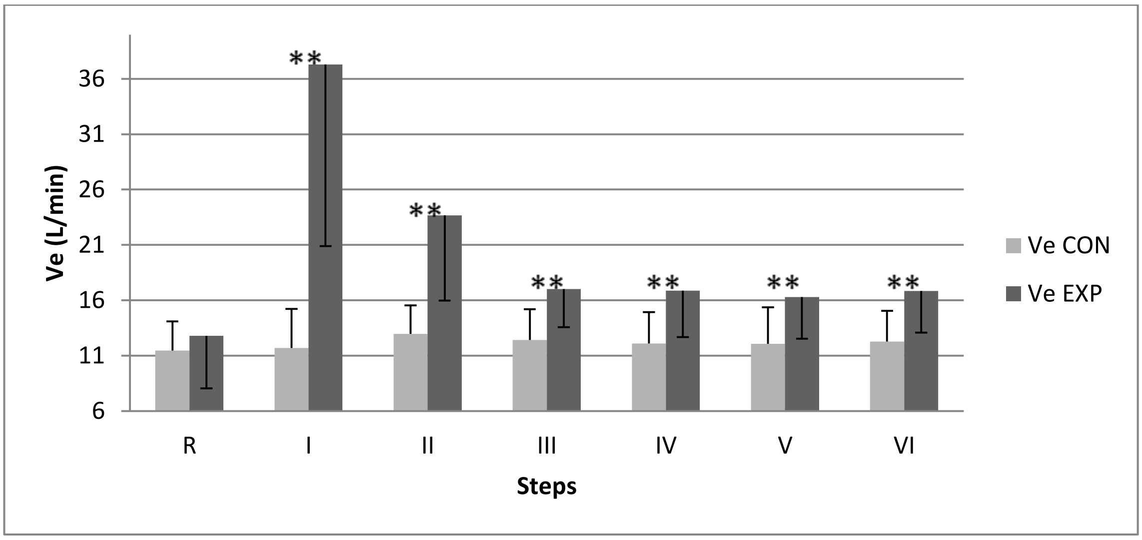


Figure 9 presents results for fR before and during cognitive test, comparing CON and EXP.

*Fig.9: Respiratory frequency (fR, 1/min) trend during time, comparing CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate a different step. Results are shown as mean ± SD. Significant difference between conditions are marked. * p < 0.05, ** p <0.01.*

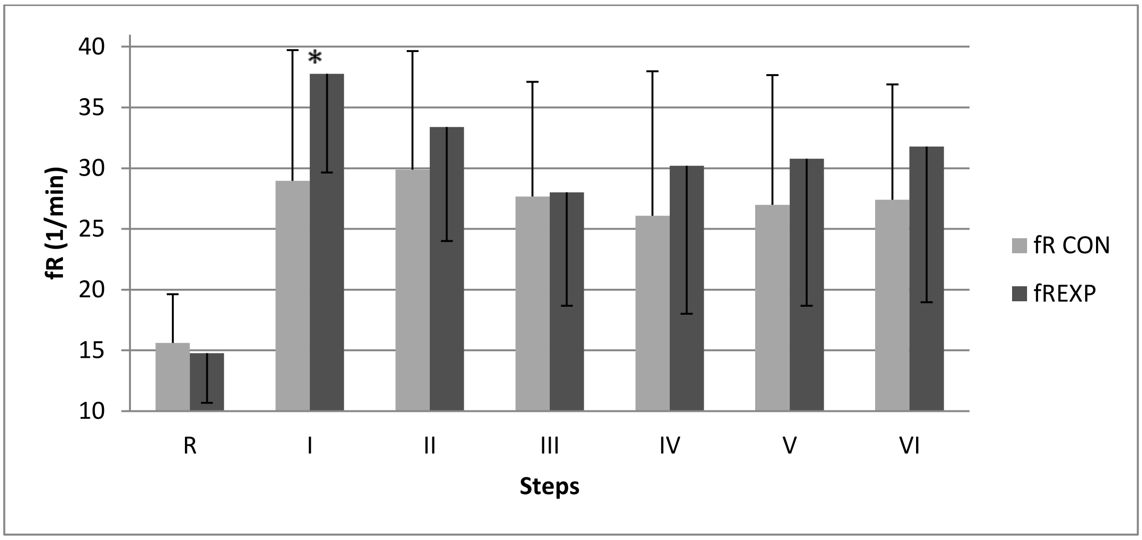


Figure 10 presents results for HR before and during cognitive test, comparing CON and EXP.

*Fig.10: Heart rate (HR, bpm) trend during time, comparing CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate a different step. Results are shown as mean ± SD. Significant difference between conditions are marked. * p < 0.05, ** p <0.01.*

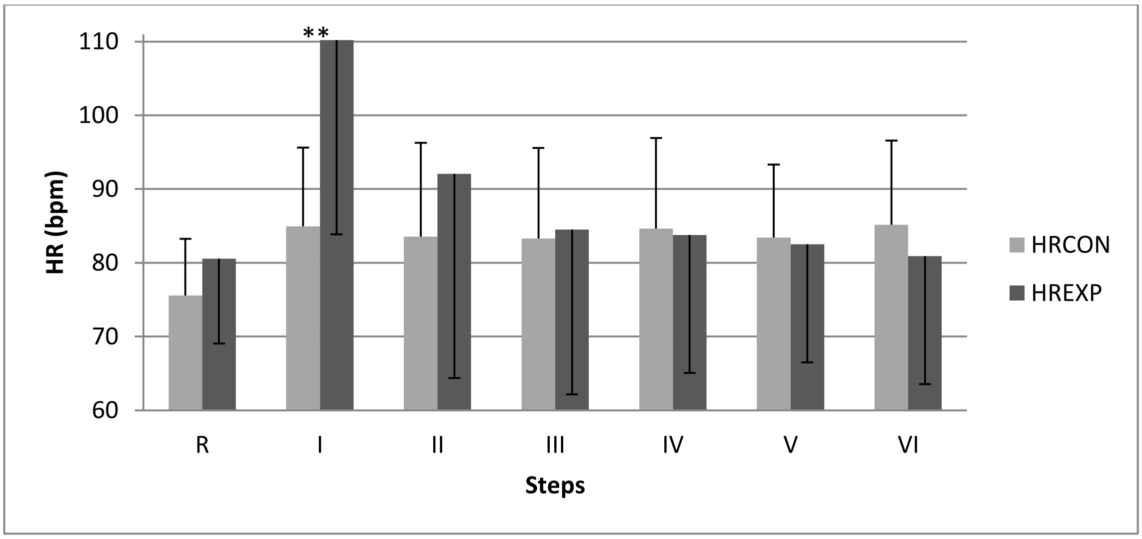
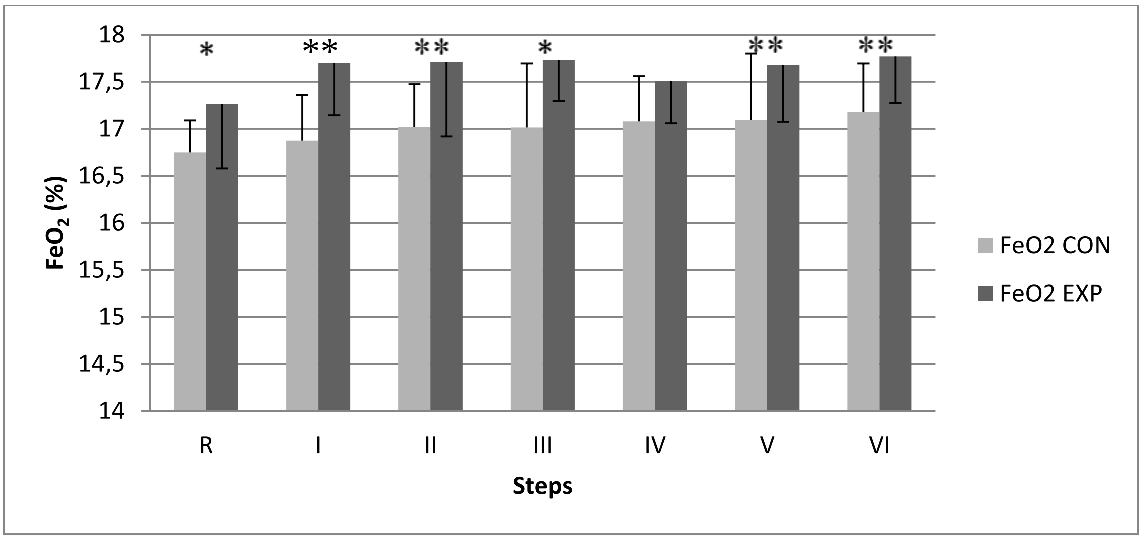


Figure 11 presents results for FeO_2 before and during cognitive test, comparing CON and EXP.

*Fig.11: Expired fraction of oxygen (FeO_2, %). trend during time, comparing CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate the different steps. Results are shown as mean ± SD. Significant difference between conditions are marked. * p < 0.05, ** p <0.01.*



Considering the difference between both conditions, step 1 was significantly different in all the physiological parameters. During EXP, $\dot{V}O_2$, $\dot{V}e$, fR, HR and FeO_2 showed an increase in their values, respectively + 7.05 ($p = 0.00$), + 25.6 ($p = 0.001$), + 8.8 ($p = 0.016$), + 25.2 ($p = 0.003$) and + 0.8 ($p = 0.00$). In step 2, there was a significant difference between CON and EXP in $\dot{V}O_2$ (+ 2.3, $p = 0.003$), $\dot{V}e$ (+ 10.7, $p = 0.001$) and FeO_2 (+ 0.69, $p = 0.006$). Conversely, fR and HR were not statistically different between both conditions. During step 3, between CON and EXP, only $\dot{V}e$ (+ 4.6, $p = 0.007$) and FeO_2 (+ 0.72, $p = 0.023$) were significantly different. In step 4, only $\dot{V}e$ was different between CON (12.1 ± 2.8) and EXP (16.9 ± 4.2), increased during immersion (+ 4.8, $p = 0.007$). Step 5 showed a significant difference between both conditions in $\dot{V}O_2$ (+ 0.9, $p = 0.027$), $\dot{V}e$ (+ 4.2, $p = 0.002$) and FeO_2 (+ 0.58, $p = 0.007$). In step 6, the final step, $\dot{V}O_2$ (+ 0.8, $p = 0.003$), $\dot{V}e$ (+ 4.6, $p = 0.00$) and FeO_2 (+ 0.59, $p = 0.003$) remained significantly different between EXP and CON. Results for all the parameters during CON and EXP are presented in table 3.

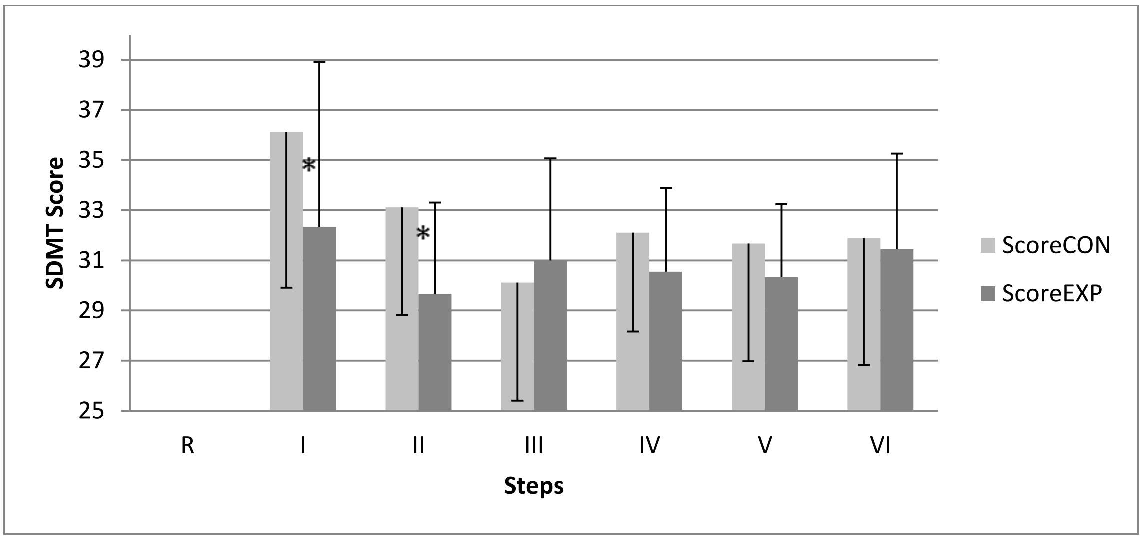
*Tab.3: Physiological responses during different steps for CON and EXP. Results are shown as mean ± SD. Significance is marked for differences between CON and EXP. * p < 0.05, ** p < 0.01.*

		$\dot{V}O_2$ (mLO_2/kg*min)	$\dot{V}e$ (L/min)	fR (1/min)	HR (bpm)	FeO_2 (%)
R	CON	5.3 ± 1.1	11.4 ± 2.6	16 ± 4	76 ± 8	16.75 ± 0.34 *
	EXP	4.9 ± 0.9	12.8 ± 4.7	15 ± 4	81 ± 12	17.26 ± 0.68 *
I	CON	5 ± 1.2 **	11.7 ± 3.5 **	29 ± 11 *	85 ± 11 **	16.87 ± 0.48 **
	EXP	12 ± 3.2 **	37.3 ± 16.4 **	38 ± 8 *	110 ± 26 **	17.70 ± 0.55 **
II	CON	5.4 ± 0.7 **	12 ± 2.6 **	30 ± 10	84 ± 13	17.02 ± 0.45 **
	EXP	7.7 ± 1.6 **	23.7 ± 7.7 **	33 ± 9	92 ± 28	17.71 ± 0.79 **
III	CON	5.1 ± 0.8	12.4 ± 2.8 **	28 ± 9	83 ± 12	17.02 ± 0.68 *
	EXP	5.9 ± 0.7	17 ± 3.5 **	28 ± 9	84 ± 22	17.73 ± 0.44 *
IV	CON	5 ± 0.6	12.1 ± 2.8 **	26 ± 12	85 ± 12	17.08 ± 0.48
	EXP	6.3 ± 1.7	16.9 ± 4.2 **	30 ± 12	84 ± 19	17.51 ± 0.45
V	CON	4.9 ± 0.9 *	12.1 ± 3.3 **	27 ± 11	83 ± 10	17.09 ± 0.71 **
	EXP	5.7 ± 0.7 *	16.3 ± 3.8 **	31 ± 12	82 ± 16	17.68 ± 0.60 **
VI	CON	5 ± 0.8 **	12.3 ± 2.8 **	27 ± 9	85 ± 11	17.18 ± 0.52 **
	EXP	5.9 ± 1.2 **	16.9 ± 3.8 **	32 ± 13	81 ± 17	17.77 ± 0.49 **

Cognitive Performance:

In both CON and EXP it was not possible to observe any statistical difference among the different steps in both the SDMT score and number of errors. In comparison to conditions, score was different when comparing step 1 (– 4 points, p = 0.05) and step 2 (- 3 points, p =0.038). In step 1 CON was 36 ± 6, and EXP 32 ± 7. In step 2 CON was 33 ± 4, and EXP 30 ± 6. The number of errors was not statistically different between conditions. Figure 12 presents results for the SDMT score during cognitive test, comparing CON and EXP.

*Fig.12: SDMT score (number of correct answers) trend during time, comparing CON (light grey) and EXP (dark grey). R (rest) is absent, roman numbers indicate a different step. Results are shown as mean ± SD. Significant difference between conditions are marked. * p < 0.05, ** p <0.01.*



Correlation analysis showed no significant correlation between physiological parameters and cognitive performance (SDMT score). However, FeO_2 showed the strongest correlation with cognitive performance (r = 0.563, p = 0.057). Significant correlations were observed among physiological parameters between $\dot{V}e$ and fR (r = 0.919, p < 0.001), $\dot{V}e$ and FeO_2 (r = 0.644, p = 0.024) and fR and FeO2 (r = 0.629, p = 0.028).

4 DISCUSSION

Rest values and SDMT effect:

Results show that before participants performed the cognitive test, in both CON and EXP, their physiological parameters were similar to the ones expected while resting in orthostatic stance. To understand the effect of the SDMT on the physiological parameters and the possible adaptation during the immersion, we observed the physiological responses in the different steps. Physiological responses were $\dot{V}O_2$, $\dot{V}e$, fR, HR and FeO_2. Comparing the different steps in CON, it is possible to observe that HR is slightly increased during the cognitive test, but not in all steps. However, the largest difference was found between the rest values and the first step (9.4 ± 1.9 bpm). fR was found increased only in step 2. Conversely to HR, there was not interaction between the cognitive test and fR. The initial thought was that an oral cognitive test would have influenced physiological parameters recorded at the mouth because of speaking. However, these results suggest that the execution of the SDMT did not alter the physiological responses.

Adaptation of physiological responses:

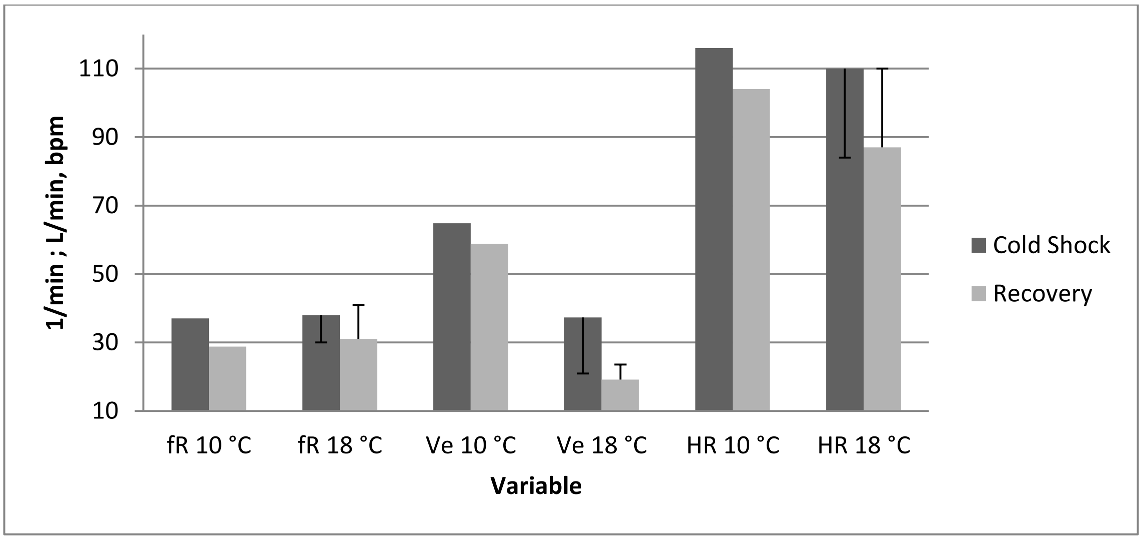
In literature (Datta & Tipton, 2006; Tipton, 1989) the initial responses after cold shock have been reported to last for about 3 min, with the peak reaching after 30 s and with progressive attenuation afterwards (Datta & Tipton, 2006; Golden & Tipton, 2002). The present study confirms these previous results, showing similar values in HR (- 6 bpm) and fR (+ 1 1/min) if the first step is compared with the first 30 s in 10 °C water. In the same comparison, $\dot{V}e$ was higher (+ 28 L/min) in 10 °C water (Tipton et al., 2000). Also in 15 °C water $\dot{V}e$ was higher (+ 17 L/min), while both HR and fR were similar to 18 °C water (respectively, + 4 bpm and -5 1/min) (Tipton et al., 1998). $\dot{V}O_2$, $\dot{V}e$ and HR adapted fast, that is in the second step (i.e., after 45 s after immersion), since there was no significant difference between the rest values and steps following the first one. FeO_2 was found not different before or during immersion, while fR significantly increased in both step 1 and step 2. Thus, after about 2 minutes it was possible to observe an adaptation process also in the fR. In 18 °C water adaptation was slightly faster than the one observed in colder water, for example in 10 °C, exception made for fR. This trend was also observed while comparing 5 °C, 10 °C or 15 °C water temperatures (Tipton, Stubbs & Elliott, 1991; Tipton, Mekjavic & Eglin, 2000). If data are analyzed observing adaptation rate, as percentage of the difference between cold shock (first 30 s) and recovery (30-180 s), fR adaptation rate was faster in 10 °C water than in 18 °C. $\dot{V}$e and HR adaptation rate was greater in warmer water (18 °C). In table 4 adaptation rates are summarized.

Tab.4: Adaptation rate, defined as percentage of difference between cold shock (first 30 s) and recovery (30-180 s) and normalized per minute. Respiratory frequency (fR), ventilation ($\dot{V}$e) and heart rate (HR) are compared in 10 °C and 18 °C water.

Temperature (°C)	fR (%/min)	$\dot{V}$e (%/min)	HR (%/min)
10	15	5	14
18	12	30	32

Better speculations would have been permitted though continuous data collection in this study and a direct comparison between different water temperatures with similar devices and protocols. Figure 13 presents comparisons for physiological parameters between immersion in water at the temperature of 10 °C (Tipton, Mekjavic & Eglin, 2000) and 18 °C (present study).

Fig.13: Comparison between fR (1/min), $\dot{V}$e (L/min) and HR (bpm) in the first 30 s (Cold Shock, dark grey) (I step) and the recovery during following 150 s (Recovery, light grey) (II, III, IV steps), between 10 °C (means, Tipton, Mekjavic & Eglin, 2000) and 18 °C water (means ± SD, present study).



Further speculations have been proposed to analyze temperature dependent trend determining the amplitude of physiological responses. Results confirm previous findings, observing slightly greater magnitude in colder water (Tipton, Stubbs & Elliott, 1991). Comparisons between 10 °C (Tipton, Mekjavic & Eglin, 2000), 15 °C (Franks et al., 1997; Golden & Tipton, 1988) and 18 °C (present study) observed similar responses between 10 °C and 15 °C. fR was similar in all three temperatures, while HR was similar only between 10 °C and 15 °C water. In 18 °C magnitude was slightly reduced. $\dot{V}$e showed the greater decrease in 18 °C, but in 15 °C magnitude was greater than in 10 °C, confirming previous findings. (Tipton, Stubbs & Elliott, 1991). Since our findings suggest a non-linear trend, mathematical models are possible to be proposed if more than three temperatures would be observed (e.g., 3 °C difference, from 8 °C to 20 °C).

Cool Water Immersion:

As reported in previous studies (Golden & Tipton, 2002), cool water immersion provokes different physiological responses in the organism. As shown in the present study, these responses are observed also in water at 18 °C. Comparing results for each step from CON to EXP, it is possible to notice that all parameters significantly increased during the first minute after immersion. In step 1, $\dot{V}O_2$ was 153 % higher than its resting value, while $\dot{V}$e was 200 % in most of the cases if compared to data prior to the immersion. fR showed the largest variation between participants, probably because this parameter is related to anxiety and thus, maybe it depended on participants' emotional status. HR during the first minute of immersion reached the 58 ± 14 % of the HR_{MAX}, estimated with Tanaka's equation (Tanaka, Monahan & Seals, 2001). Usually, this range of cardiac strain does not represent a risk also for elderly or people with no severe heart diseases. However, in colder water the cardiac response because of swimming and panic could increase HR (Friedman & Thayer, 1998). As a consequence, combined with the effect of the hydrostatic pressure, systolic and diastolic blood pressure could rise even further and become a potential risk factor (Golden & Tipton, 2002). Acute hypertension could cause heart attack, stroke, acute pulmonary edema and, if aneurysms are present, blood vessels rupture with consequent hemorrhage (Tipton, 1989). As observed in the results, there was an adaptation process in all the physiological parameters during immersion. However, some of them remained significantly increased if the same step was compared with CON. Hyperventilation decreased continuously step after step but was always significantly higher compared to $\dot{V}$e in CON. Similar trends have been observed also in the $\dot{V}O_2$ and FeO_2. $\dot{V}O_2$ variation reflects the increased amount of energy required by the heart and respiratory muscles during the initial responses (Tipton, 1989). FeO_2 changes are related to changes in tidal volume as a consequence of the ratio between minute ventilation and respiratory frequency. As reported by the experts, the increased $\dot{V}e$ is one of the main hazards during a sea survival situation, decreasing maximal breath-hold time and increasing the chances to ingest also a small but lethal quantity of water (Cheung, 2010; Datta & Tipton, 2006; Golden & Tipton, 2002). Increased HR and $\dot{V}e$ are consequences of the hydrostatic pressure and are worsen by cold temperature (Datta & Tipton, 2006). Thus, also with water temperature common in large parts of the seas, as we observed in our study, initial responses could reduce survival chances.

Cognitive response:

The score obtained by the SDMT differed substantially from participant to participant, indicating different information processing speeds. Thus, we reported a relevant variability in the cognitive response and this probably affected statistics. Cognitive performance did not significantly change during the execution of the SDMT both in CON and EXP. Additionally, it can be a good method to evaluate temporal changes in the cognitive performance. Comparing SDMT score between conditions, we observed a significant difference only in the first two steps. Cognitive performance was reduced during the first two minutes of cool water immersion if compared with the same steps in the thermoneutral dry environment. Two participants out of nine performed better during the first step after immersion, compared to CON, while in step 2 only one participant showed a better result into the water. As noticed before, the large variation among participants reduced the mean difference between conditions. However, during the first step two participants showed a score 10 points lower, one participant 8 points lower and one participant 6 points lower if immersed. Results are summarized in table 5.

Tab.5: SDMT score for each participant in control (CON) and experimental (EXP) condition during the first step (0m05s – 0m50s).

	1	2	3	4	5	6	7	8	9
CON	31	30	36	28	44	43	34	44	35
EXP	21	28	40	30	42	33	28	37	32

This difference observed in four participants is relevant for assuming a reduced information processing speed if immersed in cool water. The number of errors was not relevant in this study, if participants matched the wrong number they immediately corrected by themselves. There was no difference in both time sequence and condition, with maximum one error in one sheet. Even if there was not a significant correlation between SDMT score and physiological responses, it is possible to assume that cognitive performance is slightly impaired during the first minutes after cool water immersion. As shown in a different study, hyperventilation reduces the volume of oxygenated hemoglobin in the prefrontal cortex, while a cognitive performance requires a higher perfusion in the same area (Watanabe et al., 2003). Thus, hyperventilation could impair executive functions because of cerebral hypoxia (Tipton, 1989). In this study it was not possible to determine if the effects of hyperventilation were at the basis of the observed impairment. Another hypothesis is that the new environment and the immediate cold shock could slow information processing because the subject feels confused and distracted by the cold sensation on the skin. In a potential hazardous situation as during a shipwreck, this physiological effect combined with fear and confusion could be detrimental for the cognitive processes necessary for self-rescue. Our results obtained with this study confirm the suggestions proposed by the experts on sea survival (Cheung, 2010, Ducharme & Lounsbury, 2008). Magnitude and duration of the initial responses are dependent on different factors and should be taken into account when planning self-rescue. After the peak is reached in the first 30 s, attenuation of the physiological responses is related to water temperature. Indeed, studies reported that warmer temperatures reduced the duration of the initial responses rather than the magnitude (Tipton, Stubbs & Elliott, 1991). Clothing is relevant not only reducing the temperature fall rate, but also attenuating the initial responses. However, no differences have been reported between different clothes (i.e., water proof and conventional clothes) (Tipton, Stubbs & Elliott, 1990). Additionally, speed of immersion strongly influences the initial responses, working as temporal summation (Golden & Tipton, 2002). During the first minutes after cool water immersion it is not recommended to swim or perform complex physical activities (e.g., climbing a rope, inflating the floating device or swimming underwater). The increased physiological responses reduce the efficiency of swimming and muscular fatigue appears earlier (Ducharme & Lounsbury, 2008). Also in 18 °C water the physiological responses represent a potential risk factor for people who suddenly fall into the water. Heart attacks and strokes could represent a relevant risk also in not extremely cold water temperatures, mainly in the elderly or in people with medical history of cardiovascular diseases and hypertension. Similarly, hyperventilation provokes several direct and indirect consequences. As we have seen, increased $\dot{V}e$ could facilitate the ingestion of water and reduce maximal breath-hold time. The latter makes it increasingly difficult to escape from a submerged boat or to resist if waves are frequent and strong (Golden & Tipton, 2002). One of the main consequences is hypocapnia (i.e., a reduced concentration of carbon dioxide), a stimulus that provokes vasoconstriction and increases the risk of ischemia, ventricular fibrillation and disorientation (Tipton, 1989). Without considering potential pathological issues as consequence of cool water immersion, survival is possible if people choose the right solutions and the best rescue strategy. Our results show that cognitive performance, in terms of information processing speed, is slightly reduced and behave similarly to the initial responses. Thus, decisions could be negatively affected by this factor and could potentially misevaluate the situation. Additionally, evaluation of distances and swimming capacity is often impaired because of the position of the head and panic (Lounsbury, 2004). Thus, it is a good advice to use the first minutes to calm and decide what to do, being careful and closely evaluating distances and possibilities.

As reported in the present study, cool water immersion induces in the organism several physiological responses, such as increased ventilation and heart rate. Additionally, working memory performance is slightly reduced during the first minutes of cool water immersion, potentially impairing cognitive functions.

5 FUTURE PERSPECTIVES

This study demonstrated that also with water temperatures that usually are not considered as hazardous for the organism (18 °C), physiologically responses represent a potential threat for survivors and cognitive performance is partially reduced. In the last decades different articles have been published reporting the effects of different variables on the initial responses, such as clothing or training. Some solutions were reported not to affect the physiological initial responses, such as alcohol ingestion (Franks et al., 1997), while others were beneficial. Alcohol impairs cognitive performance and is detrimental for survival, while other strategies (e.g., clothing) could have positive effects. Clothing reduced the initial responses and a positive effect was reported also after acclimation or psychological training. Additionally, to understand the effect of the hydrostatic pressure it would be suggested to observe the physiological and cognitive initial responses also in thermoneutral water. The present work aims to offer a "start point" for further studies on this topic, taking into consideration also the cognitive factor. One of the main hypotheses is to measure the initial responses and the cognitive performance of people trained to rescue people into the water. Personnel from the SAR departments, navy or divers, who usually train to solve problems with time pressure an adverse environmental conditions, might not be able to fight both physiological and psychological detriments. To understand the direct cause of the decrement in the cognitive performance further analysis could be performed measuring different parameters (e.g., oxygenated hemoglobin). The cooperation between scientists and experts that everyday face the risks of sea survival is necessary to develop the best solutions for all the ones who work, live and travel on the sea.

6 CONCLUSIONS

Cold shock after water immersion provokes several physiological responses in non-acclimatized young healthy men. These initial responses have been observed also in water temperature of ~18 °C, temperature comparable with many water surfaces in the world. The magnitude and duration of these responses are reduced if compared to results from studies performed in colder water (10 °C and 15 °C). The increased cardiovascular and respiratory strain appearing during the first minutes does not suggest performing intensive and complex physical activities. Conversely, planning the rescue strategy can be partially impaired not only by panic but also directly by cold shock. Reducing the effects of cold shock could diminish the risk of cardiorespiratory failure or drowning, and it would increase the chances to preserve cognitive performance.

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ANNEXES

TABLE OF ANNEXES

ANNEX 1: Slovene Abstract

Vsako leto okoli 500.000 ljudi na svetu izgubi življenje zaradi utopitve, kjer se visoko število smrti zgodi na odprtem morju (Peden, McGee & Sharma, 2002). Na primer, med letoma 1978 in 1998 je približno 5.300 ljudi izgubilo življenje zaradi utopitve pri nesreči trajekta (Faith, 1998).

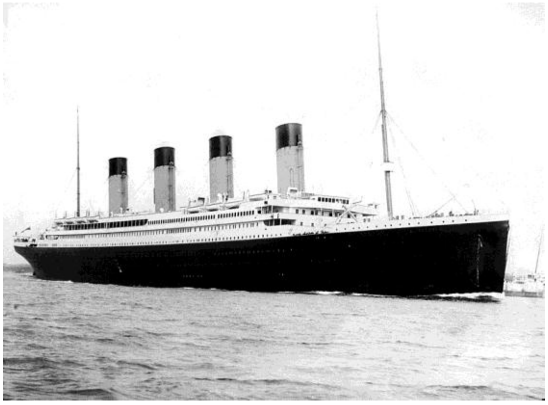
Med potapljanjem delujejo različni mehanizmi: v odvisnosti od temperature vode, oblačil, valov in časa. Hladno najprej povzroči periferno hipotermijo, upočasnjuje prevodnost živcev in povečuje mišično utrujenost. Take težave se zlahka pojavijo po daljšem obdobju v plavanju (Cheung, 2010, Golden & Tipton, 2002). Hladna voda naknadno oslabi metabolizem organov, predvsem srca, ledvic, pljuč in postopoma vodi v smrt zaradi hipotermije jedra (Golden & Tipton, 2002). Utopitev je prvi vzrok smrti med prvimi minutami v vodi, do smrti lahko pride namreč tudi zaradi zaužitja manjših količin morske vode (Modell, 1971). Prvi odziv na potopitev v hladno vodo, kot sta ga 1981 definirala Golden in Hervey, je posledica nenadne močne stimulacije kožnih termoreceptorjev na hladno. Močna stimulacija termoreceptorjev na hladno med drugimi povzroči tahikardijo, hipertenzijo, tahipnejo, zvišano ventilacijo in znižano koncentracijo izdihanega ogljikovega dioksida (Golden & Tipton, 2002). S tem da navedeni fiziološki odgovori zmanjšajo čas zadrževanega vdiha, je kritično prizadeta kapaciteta vdiha. Kot posledica se zaradi predčasnega vdiha in s tem tudi inspiracije vode pojavi povečana nevarnost za utopitev. Prvi odzivi se pojavijo takoj po potopitvi v hladno vodo in trajajo približno 3 min, z vrhuncem okoli 30 sekund po potopitvi. Potopitev v hladno vodo pa lahko zaradi aritmije, ki jo povzroči zadrževanje vdiha in sprožitev potapljaškega refleksa, sproži tudi zastoj srca (Tipton, 1989; Datta & Tipton, 2006). Zgoraj opisani fiziološki mehanizmi pa niso sproženi le ob potopitvi v hladno vodo, ampak so lahko sproženi tudi pri temperaturah vode do 25 °C. Na primer, povprečna temperatura sredozemskega morja je v letu 2006 je znašala okoli 20 °C (Nykjaer, 2009). V tem primeru so v nevarnosti predvsem posamezniki, ki niso pogosto izpostavljeni nizkim temperaturam. V primeru potopitve je prvotnega pomena načrtovanje in organizacija strategije reševanja (Cheung, 2010). Stres in akutni šok vplivata na kognitivne sposobnosti in izvršilne funkcije z posledico napačne presoje okoliščin in načina reševanja (Spitznagel et al., 2009; Schoof, Wolf and Smeets, 2009). Hipoteza zmanjšanega zaznavanja, ki je posledica prvih odzivov, je mogoče sklepati tudi zaradi zmanjšane totalnega hemoglobina in emoglobina s kisikom v čelnih površinah med hiperventilacijo, merjeno z večkanalno infrardečo spektroskopijo (Watanabe et al., 2003). "The Symbol Digit Modalities Test" (SDMT) je test, z uporabo katerega lahko ocenimo sposobnost delovnega spomina in pozornosti. Posledično je SDMT test zanesljiv indikator hitrosti odločanja (Nocentini et al., 2006). Testi, kot je SDMT, so priporočeni za uporabo v okoljskih študijah, uporabo le tega pa priporoča tudi skupina »Performance Evaluation Tests for Environmental Research" (Pepper et al., 1985). Cilj te raziskave je bil ugotoviti začetne fiziološke in kognitivne odzive po prvih minutah za potopitvijo v hladno vodo, ob tem pa pregledati stanje stroke, kar se tiče psiholoških učinkov. Ta študija si prizadeva deliti ugotovitve in hkrati sodelovati z reševalnim osebjem in ljudmi, ki plujejo, z namenom povečati varnost na morju med potovanji. Študija je začetno ocenila kognitivne funkcije med prvimi odzivi v vodi pri temperaturi 18 ° C. Ta temperatura je primerljiva s temperaturo, ki so jo zaznali npr. v Sredozemlju. Pri študiji je sodelovalo devet mladih zdravih moških (starosti 26,7 ± 4,4 let). Nihče od udeležencev ni bil aklimatiziran na vodo ob potopitvi. Jakost in trajanje nekaterih fizioloških parametrov (poraba kisika, ventilacija, dihalne frekvence, srčnega utripa in pretečeni delež kisika) sta bila izmerjena z namenom opazovati začetne odzive v hladni vodi. Ustna različica SDMT je bila uporabljena, da bi ocenili izvršilno funkcijo in še zlasti delovni spomin. Meritve so potekale v povprečju vsakih 45 s, da bi pridobili časovni trend tako fizioloških parametrov in kognitivne sposobnosti. V stanju kontrole (CON) so udeleženci izvedli SDMT pri termonevtralni temperaturi (26 ° C). Med kognitivnim preizkusom so bili fiziološki parametri enakomerno registrirani. Pogoj preizkusa (EXP) je potekal v majhnem bazenu, ki je bil napolnjen s hladno vodo (18 ° C). CON in EXP so se ponovili teden dni po meritvi predhodnega stanja ob isti jutranji uri, da ne bi prišlo do učinkov cirkadianega ritma. Pol skupine je izvedlo CON pred EXP, preostali del pa je opravil prej EXP in nato CON. Udeleženci so za vajo prejeli kopijo kognitivnega testa teden dni pred meritvami. Udeleženci so dobili navodila za obe vrsti protokola in meritev, ob tem pa so se že pomerili s kognitivnim testom. Po 5 min. merjenja vrednosti v stanju počitka, so udeleženci začeli reševati kognitivne teste, ki so potekali dodatnih 5 min., tako v CON kot v EXP. Zaključni rezultat je predstavljalo šest nivojev podatkov v odvisnosti od korespondenčnih fizioloških in kognitivnih vrednosti. Težo, višino in maso maščob smo zabeležili pred meritvami. Rezultati so pokazali, da so se, v primerjavi s suhim termonevrtalnim stanjem ($p < 0,05$), vsi fiziološki parametri povečali pri potopitvi v hladno vodo. Kar se tiče opazovanja fizioloških parametrov med CON, je študija pokazala, da pomenljivih učinkov zaradi kognitivnega testa. Pri primerjavi obsega odgovorov sta bila srčni utrip in frekvenca dihanja nekoliko nižja v primerjavi s študijami pri 10 in 15 ° C (Tipton, Stubbs in Elliot, 1991; Tipton, Mekjavic in Eglin 2000). Nasprotno, je bila vrednost ventilacije na minuto višja v hladni vodi. Kot je bilo ugotovljeno v že izvedenih raziskavah (Golden & Tipton, 2002, Tipton, 1989), so se fiziološki parametri postopoma vrnili na normalno vrednost. Vendar pa se je frekvenca dihanja prilagodila v krajšem času, če so se udeleženci potopili v vodo pri temperaturi 10 ° C namesto pri

temperaturi 18 ° C. Te rezultate smo pridobili s primerjavo rezultatov iz različnih študij in različnih protokolov (Tipton, Mekjavic in Eglin, 2000). V akutni fazi začetnih odgovorov (tj. prva minuta), je bila poraba kisika 153% višja od vrednosti med fazo počitka, medtem ko se je minutna ventilacije dvignila za 200% vrednost v primerjavi s stanjem mirovanja. Bremenitev kardivaskularnega sistema pa je bila ocenjena kot odstotek teoretične najvišje stopnje frekvence srčnega utripa. V prvi minuti je srčni utrip dosegel 58 ± 14% najvišje teoretične stopnje utripa. Povečava srčnega napora, napora ožilja ter dihal, ki se je pojvaila v prvih minutah, ne kažejo na to, da bi lahko potekale intenzivne in kompleksne telesne dejavnosti. Kognitivna zmožnost se je zmanjšala ob potopitvi v hladno vodo, če jo primerjamo s stanjem nadzora, vendar samo v prvih 2 minutah po potopitvi. Med prvo minuto pod vodo je bila vrednost SDMT (npr. število pravilnih odgovorov) za 11% nižja v primerjavi z vrednostjo CON ($p = 0,05$). V drugi minuti po potopitvi je bila SDMT vrednost EXP v primerjavi z vrednostjo CON za 9% nižja ($p < 0,05$). Po drugi minuti ni prišlo do bistvenih razlik med vrednostmni. Vse to dokazuje, da lahko strategijo reševanja neposredno ogroža ne le panika, temveč tudi šok ob kontaktu s hladno vodo. Priporočljive so nadaljnje raziskave, ki bi se poglobile v kognitivne vidike preživetja v morju, še zlasti v prvi fazi po potopitvi. Zmanjšanje posledic termičnega šoka bi zmanjšalo tveganje srčne odpovedi in bi povečalo možnost za ohranitev kognitivnih zmogljivosti. Primerjava med različnimi pogoji, da bi lahko razumeli učinke, ki jo ima na kognitivno dejavnost temperatura oblačil, aklimatizacije ali vode, bi lahko pomagala pri organizaciji in izboljšanju protokolov preživetja v morju.

ANNEX 2: Sea Accidents

In Friuli-Venezia Giulia, a small northeastern Italian region, a total of 826 people have been rescued by the Search and Rescue (SAR) from 2009 to 2011 (Capitaneria di Porto Trieste). In this annex we will describe the most important. Maybe the most known is the sinking of RMS *Titanic*, occurred on 15th April 1912, after a collision with an iceberg in the Atlantic Ocean. On the ship there were 2,223 passengers, included 800 people from the crew.

Fig.14: RMS Titanic, White Star Line, departing Southampton on 10th April 1912.



Because of the cold water (- 2 °C) and the small number of lifeboats (there was not a suitable number of seats for all the passengers), that night only 706 people survived and were rescued. Similarly, the *Empress of Ireland* left Quebec City the 28th May 1914 but only few hours later, the early morning of the 29th May 1914, the ship crashed with a Norwegian cargo and sank in only 14 minutes. 1,012 people died on 1,477 passengers directed to Liverpool. One of the most relevant disasters in history of navigation during peacetime, was the shipwreck of MV *Doña Paz*. This passenger ferry sank after colliding with the MT Vector on December 20 1987, travelling from Leyte Island to Manila. Only 24 survivors were rescued with a possible death toll of 3,132 people.

ANNEX 2: Sea Accidents

Fig.15: MV Doña Paz.

World wars have been the cause of the largest tragedies on the sea, like the RMS *Lancastria* (more than 6,000 deaths, 1940), *Laconia* (5,200 deaths, 1942), *Wilhelm Gustloff* (over 10,000 deaths, 1945). The SS *Rex* has been hit by 123 rockets of the Royal Air Force and, after burning for 4 days, sank in the gulf between Trieste and Koper. In Europe one of the most relevant tragedies was the shipwreck of *Estonia* in 1994, a ferry travelling from Tallinn to Stockholm. During the early morning of the 28th September 1994 the ship sank in 30 minutes and only 137 passengers survived on 989 people on board. More recently, the Italian *Costa Concordia* sank on 13th January 2012 near Giglio Island, in the Mediterranean, and among its 4,229 passengers 32 people died.

Also during leisure-sailing events people lose their lives, like in the 1979 Fastnet race (15 deaths on 136 survivors). Observing the causes of many of these disasters, it is possible to recognize that the human error is the most common. In the last centuries ships quality reached a level that permits sailors to face almost all kind of weathers, but many times the overconfidence leaded to tragedies. The expertise and professionalism of the SAR authorities prevented and still prevents many deaths and rescues a lot of possible victims every day all around the world. Thanks to the lessons learnt through the history, new safety measures have been implemented and maritime regulations have been improved. The International Convention for the Safety of Life at Sea (SOLAS), born after Titanic shipwreck, is one example of this improvement, forcing the shipping companies to provide an adequate number of lifeboats for all the passengers.

ANNEX 3: Symbol Digit Modalities Test example

Fig.16: SDMT sheet example.