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# COGNITIVE AND PHYSIOLOGICAL INITIAL RESPONSES DURING COOL WATER IMMERSION

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*ABSTRACT*

*The initial responses during water immersion are the first mechanisms reacting to a strong stimulation of superficial nervous cold receptors. Cold shock induces tachycardia, hypertension, tachypnea, hyperventilation, and reduced end-tidal carbon dioxide fraction. These initial responses are observed immediately after the immersion, they last for about 3 min and have been also reported in water temperatures up to 25 °C. the aim of the present study was to observe cognitive and physiological functions during immersion in water at cool temperature. Oxygen consumption, ventilation, respiratory frequency, heart rate and expired fraction of oxygen were measured during the experiment. A code substitution test was used to evaluate executive functions and, specifically, working memory. This cognitive test was repeated consecutively 6 times, for a total duration of 5 minutes. Healthy volunteers (n = 9) performed the test twice in a random order, once in a dry thermoneutral environment and once while immersed head-out in 18 °C water. The results indicated that all the physiological parameters were increased during cool water immersion when compared with the dry thermoneutral condition ($p < 0.05$). Cognitive performance was reduced during the cool water immersion when compared to the control condition only during the first 2 min ($p < 0.05$). Our results suggest that planning the best rescue strategy could be partially impaired not only because of panic, but also because of the cold shock.*

**Keywords:** *cool water immersion, hyperventilation, cold shock, cognitive responses, sea survival*

# ZAČETNI KOGNITIVNI IN FIZIOLOŠKI ODZIVI MED POTOPITVIJO V HLADNO VODO

*POVZETEK*

*Med potopitvijo v vodo se začetni odzivi najprej pokažejo kot reakcija na močno stimulacijo površinskih živčnih receptorjev na mraz. Ta stres zaradi mraza sproži tahikardijo, hipertenzijo, tahipnejo, hiperventilacijo in zmanjšan delež ogljikovega dioksida v izdihanem zraku. Takšne začetne odzive zaznamo nemudoma po potopitvi, trajajo približno 3 minute, zaznani pa so bili tudi pri temperaturi vode vse do 25 °C. Cilj pričujoče študije je bil opazovati kognitivne in fiziološke funkcije med potapljanjem v hladni vodi. Med poskusom so bili izmerjeni poraba kisika, dihanje, respiratorna frekvenca, frekvenca srčnega utripa in delež kisika v izdihanem zraku. Za oceno eksekutivne funkcije in predvsem delovnega spomina je bil uporabljen test kodiranja (angl. code substitution test). Ta kognitivni poskus je bil 6-krat zaporedoma ponovljen, v skupnem trajanju 5 minut. Zdravi prostovoljci (n = 9) so bili testirani dvakrat, v naključnem zaporedju, enkrat v suhem, termonevtralnem okolju in enkrat potopljeni v vodi s temperaturo 18 °C z glavami nad vodno površino. Rezultati so pokazali, da so bili v primeru potopitve v hladno vodo povečani vsi fiziološki parametri v primerjavi s stanjem v suhih termonevtralnih pogojih (p < 0,05). V primerjavi s kontrolnim testiranjem se je kognitivna zmogljivost pri potopitvi v hladno vodo zmanjšala le v prvih 2 minutah (p < 0,05). Rezultati kažejo, da bi bilo načrtovanje najboljše reševalne strategije lahko delno poslabšano zaradi panike in tudi stresa zaradi mraza.*

***Ključne besede:*** *potapljanje v hladno vodo, hiperventilacija, stres zaradi mraza, kognitivni odzivi, preživetje v morju*

## INTRODUCTION

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). Water temperature is a fundamental factor when analyzing sea survival. The sea surface temperature measured at a 4-metre 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). In contrast, SST of the North Sea reaches 6 °C in winter and 21 °C in summer. With an estimated mean of about 15 °C this means that falling into water likely leads to death due to swimming failure or hypothermia (Golden & Tipton, 2002). Timing is a relevant factor influencing the physiological responses and the rescue experts have always to consider it. Nowadays, with statistical analysis and the improvement of Search and Rescue activities, the main identified risk is drowning, especially if the sea is not calm (Golden & Tipton, 2002). Thus, even early stages of immersion could lead to death because of inability to swim and drowning, while the immersion in cold water for a prolonged time induces organs failure caused by hypothermia (Golden & Tipton, 2002). In 1981, Golden and Harvey identified four stages of immersion being associated with specific risks, resulting in specific protocols for each stage to help Search and Rescue activities: (i) initial responses, (ii) short-term responses, (iii) long-term responses and (iv) post-immersion responses. In this work a greater attention was put on the initial responses. After the immersion in cool water, cold receptors in the skin are strongly stimulated and provoke several physiological responses which include tachycardia, hyperventilation, tachypnea and hypertension (Datta & Tipton, 2006). Each response can adversely affect survival chances and can reduce physical and psychological performances (Cheung, 2010). Physiological responses start immediately after the immersion; 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 30 seconds after the immersion and physiological parameters return to normal values in about 3 minutes (Datta & Tipton, 2006). Since these responses are not observed in warm water, this indicates that there is a neurogenic origin driven by cold receptors located below the skin surface (Datta & Tipton, 2006). Indeed, the initial responses are stimulated through superficial subepidermal cold receptors (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. Clothing plays a key role in determining the magnitude of the initial responses. Significant differences in the physiological responses between participants wearing only swim trunks or other kind of clothing have been reported (Tipton, Stubbs & Elliot, 1990). One of the most threatening situations occurs if the subjects, when initial responses are present, submerge their faces into the water (Tipton, 1989). Breath-holding 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 which primarily affect cardiorespiratory functions, are likely to be responsible for the majority of near-drowning incidents and drowning deaths following accidental immersion in open water below 15 °C. The main physiological consequences of cool water immersion observed in the literature are summarized in figure 1.

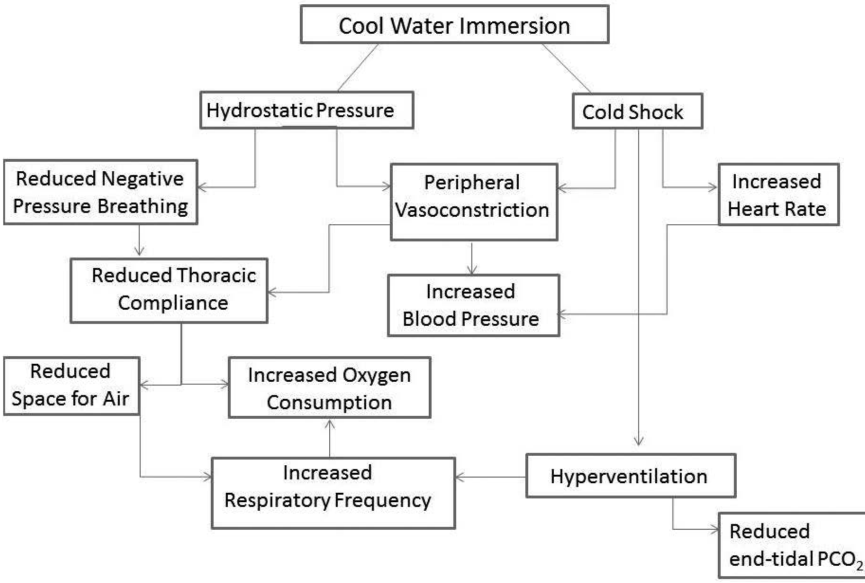


*Figure 1: Physiological effects of cool water immersion.*

Several studies (Lounsbury, 2004; Ducharme & Lounsbury 2007; Cheung, 2010) observed the timeline for self-rescue, evaluating the factors like 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 biggest 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 discussed above, during the initial responses physiological functions are altered and physical reactions are potentially detrimental for the possibilities of rescue. These results suggest that immediately after the immersion, mental performance and visual functions could be reduced. Thus, working memory could be negatively affected during a sea survival scenario. Acute cold exposure in the air (10 °C) declined working memory, choice reaction time and generally the executive function, compared to baseline performance (Muller et al., 2012). Conversely, another study assessed that low demanding cognitive performances are unaffected by cold, whereas high demanding tasks were reduced only with decreasing core temperature and not during the initial phase (Giesbrecht et al., 1993). Using the conditional discrimination task, however, response accuracy was impaired even with moderate cold exposure without core hypothermia (Thomas et al., 1989). 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). 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).

The aim of the present study was to evaluate the initial physiological and cognitive responses during the first minutes after cool water immersion, proposing some "new knowledge" for the psychological effects. In particular, we want to observe the main physiological parameters such as heart rate and ventilation, and executive functions estimated through the symbol digit modalities test, immediately after the immersion and its behavior during the adaptation time. Our hypothesis was that during cool water immersion (18 °C) initial responses are observed and cognitive functions are partially impaired.

## METHODS

### Participants

Nine healthy young males (26.7 ± 4.4 years) participated in the study. All the participants participated voluntarily and were randomly recruited among university students or researchers, age between 18 and 35. None of them were smokers. Prior to participation, they were all instructed about the protocol and the aim of the study. Prior to participation, they were also informed about the possible risks of the study and they signed an informed consent. A physician assessed their health status. If they had an electrocardiography of their previous year, they were asked to send it to the physician for further analysis. Exclusion criteria were cardiovascular, respiratory or neurological diseases, hypertension, Raynaud syndrome, BMI higher than 30 kg/m$^2$. The protocol was approved by the University ethical committee.

### The protocol

A week before the first experimental session, the 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 experimental protocol and before the measurements were carried out, they confirmed they became confident with the cognitive test. Control condition (CON) was performed in a dry thermoneutral environment (25.6 ± 0.9 °C), while an experimental condition (EXP) was performed while they were immersed head-out in 18 °C water. Both conditions were performed at rest and at least two hours after they woke up to avoid sleep inertia. In order to avoid learning effects, a cross-over designed study was carried out with all 9 participants undergoing both conditions in a randomized sequence. No alcohol, coffee, tobacco or carbohydrates were consumed at least 1 hour before the measurements. For EXP, the participants were asked to come to the pool 60 minutes before the start of the measurements in order to acclimatise to the environment (26.5 ± 1.1 °C). During the acclimatisaton and the experimental protocol they wore only short swimming trunks. Body mass, height, and body fat were measured. Just before the immersion, physiological parameters were recorded at rest for 5 min (rest phase, R) and immediately afterwards the participants completed the warm-up of the SDMT. The participants then entered in the pool filled with cool water (18.5 ± 0.4 °C), head-out with water reaching the collarbone. They remained in the water for 5 min, during which six steps of 45 s (step I, II, III, IV, V, VI) were used to average their physiological responses, each step with 5 s of pause. Each period corresponded also to a different sheet of the SDMT. Overall, for every period we obtained a cognitive performance score and a correspondent physiological response for all the parameters measured. Figure 2 describes the measurements protocol.

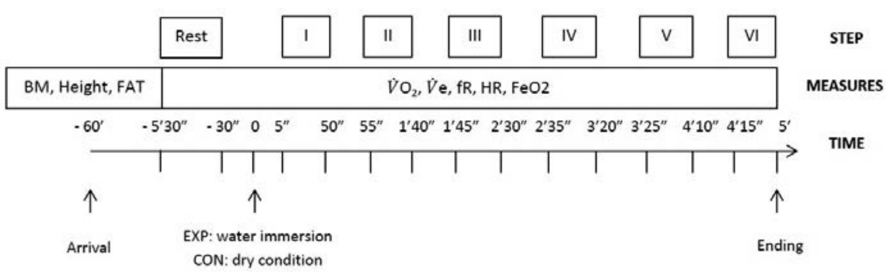


*Figure 2: Protocol timeline for both conditions (CON; EXP), indicating different times, measures and steps. For each step a SDMT sheet was used and analyzed.*

## The measurements

*Water and air temperature*

A water specific analogic thermometer with a mercury column was used to assess water temperature during all the measurements. The thermometer was completely immersed into the water during the measurements and temperature was recorded at the beginning and at the end of participants' 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*

A metabolic cart (Fitmate Plus, Cosmed Srl, Italy) was used to measure physiological functions a device which automatically calibrates itself before every use, sampling air from the environment. Heart rate (HR, bpm) was continuously recorded through a Polar belt (Polar, Sweden) connected with a wireless receiver on the metabolic cart. Ventilation ($\dot{V}\dot{V}$e, L/min), oxygen consumption ($\dot{V}\dot{V}O_2$, $mlO_2$/kg*min), respiratory frequency (fR, 1/min) and the expired fraction of oxygen ($FeO_2$, %) were analyzed and measured by the metabolic cart continuously. Body mass (kg), height (m) and body fat (FAT, %) were measured before the immersion. FAT was measured by using a bio-impedance 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 memory (Nocentini et al., 2006). This test consists of a sheet of paper with a matrix of nine symbols and nine corresponding numbers at the top. An example of the SDMT matrix used in this study is illustrated in figure 3.

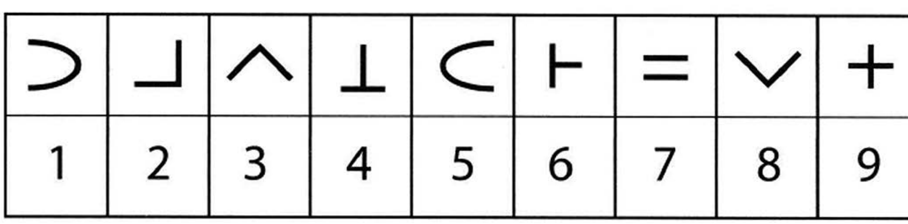


*Figure 3: An example of a SDMT matrix from Nocentini et al., 2006.*

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 of matching a maximum of 110 symbols in 90 seconds. The test can be proposed in both written and oral versions, 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 also in experimental studies observing the environmental effects on mental performance (Suhr, Stewart, & France, 2004; Hodgdon et al., 1991; Wright, Huli, & Czesler, 2002, Pepper et al., 1985). In the present study the time was halved (45 s per every sheet instead of 90 s) in order to increase the temporal resolution. To perform the SDMT, a sheet of paper having on the top a matrix with 9 different symbols and their corresponding numbers, from 1 to 9, were printed on a sheet of paper. Below the matrix, there was a sequence of 55 symbols for which participants had to match the corresponding number; a blank square at the side of each symbol allowed researchers to record the corresponding number indicated by the participant. The 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 pressure, the test started. Participants had 45 s to match as many symbols as they could with a maximum of 55 symbols for each sheet. After 45 s a different sheet showing a different matrix and a different 55 symbols sequence was provided to the participants. The measurements started 5 s after the participants were immersed and changed every 45 s with 5 s of pause after each step for 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. None of the participants completed the entire symbol sequence. The SDMT score (i.e., the number of correct combinations symbol-number) and the number of errors they committed during the test were recorded.

## 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 (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 metabolic cart. A gas mixing chamber inside the metabolic cart collected expired gases and the software averaged the results every 15 s. Heart rate increment was calculated as a percentage of the maximal heart rate, estimated with Tanaka's equation (2001), $HR_{MAX}$ (bpm) = 208–0.7*age (yrs). During the 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 were considered positive if EXP values were greater than CON. Repeated measures ANOVA were used to depict difference among conditions and between the steps within 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 were carried out with SPSS 19.0. We observed if there was any possible effect of the cognitive test on the physiological parameters or vice versa.

# RESULTS

## Characteristics of the participants

The participants' 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 % of body mass. Body surface area (BSA) was 1.92 ± 0.11 m$^2$.

## Physiological Parameters

Physiological values at rest did not differ statistically between conditions (CON and EXP), with a small difference only in the $FeO_2$, which was significantly higher in EXP (+ 0.51, $p < 0.05$).

During CON, the main physiological parameters, $\dot{V}\dot{V}O_2$, $\dot{V}\dot{V}e$ and $FeO_2$ were not significantly different among the different steps and rest. Conversely, fR increased significantly from rest to step 2 (+ 14.3 1/min, $p < 0.05$) and HR was significantly different from rest to step 1, step 4, step 5 and step 6 (respectively + 9.4, + 9.1, + 7.9, + 9.6, L/min $p < 0.05$ for all). During EXP, a statistical difference was observed for all the parameters, except for $FeO_2$. $\dot{V}\dot{V}O_2$ was significantly greater than rest only in step 1 (+ 7.2 $mlO_2$/kg*min, $p < 0.05$), and a similar behavior was observed for $\dot{V}\dot{V}e$ (+ 24.5 L/min, $p < 0.05$). fR was significantly greater than rest in step 1 (+ 23 1/min, $p < 0.01$), in step 2 (+ 18.6 1/min, $p < 0.01$) and in step 5 (+ 16 1/min, $p < 0.05$). HR was significantly increased only from rest in step 1 (+ 29.7 bpm, $p < 0.05$). Figures from 4 to 8 show the results of the different physiological parameters, comparing CON and EXP, throughout the experiment.

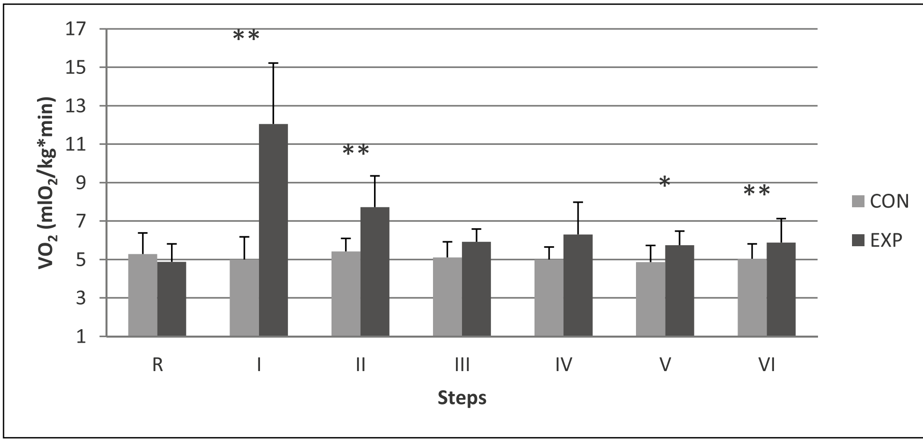


*Figure 4: Oxygen consumption ($\dot{V}\dot{V}O_2$, $mLO_2$/kg*min) measured during CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate different steps. Results are shown as mean ± SD. Significant difference between conditions are marked. * $p < 0.05$, ** $p < 0.01$.*

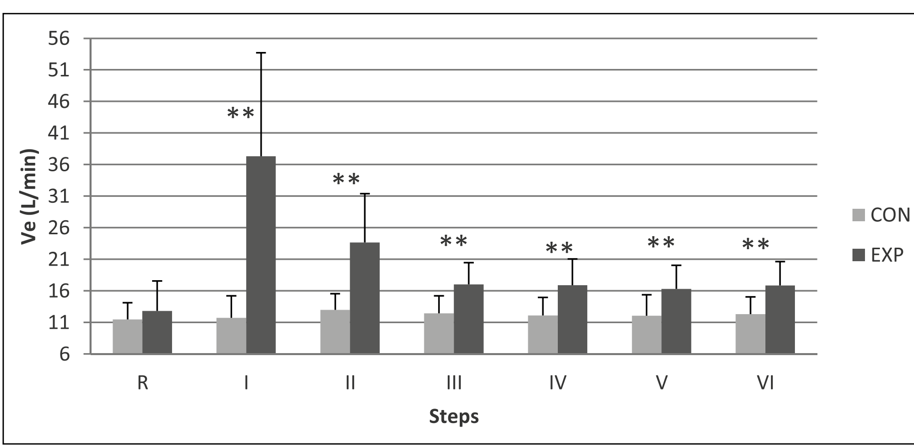


*Figure 5: Ventilation ($\dot{V}\dot{V}e$, L/min) measured during CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate different steps. Results are shown as mean ± SD. Significant differences between the conditions are marked. * $p < 0.05$, ** $p < 0.01$.*

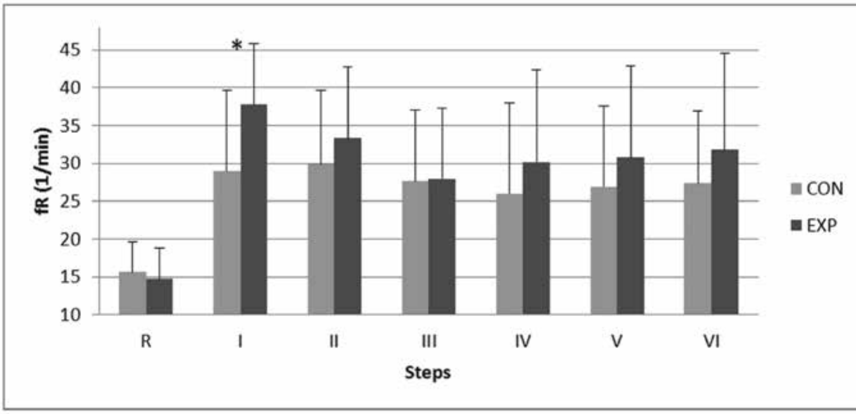


*Figure 6: Respiratory frequency (fR, 1/min) measured during CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate different steps. Results are shown as mean ± SD. Significant differences between the conditions are marked. * p < 0.05, ** p < 0.01.*

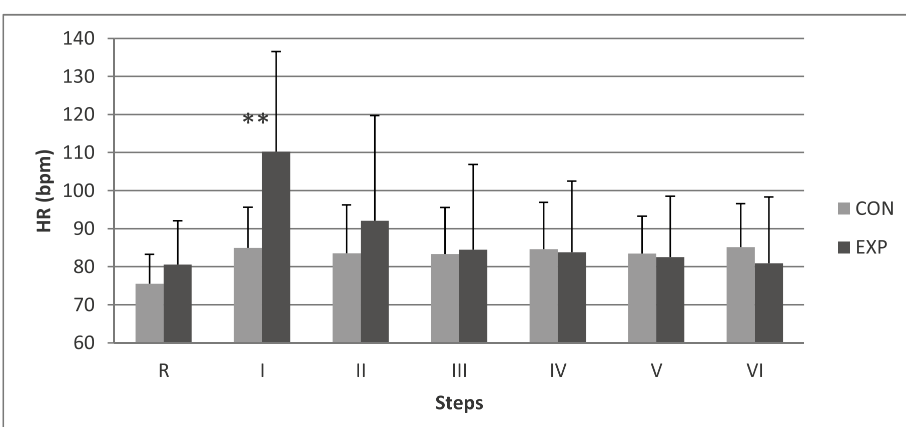


*Figure 7: Heart rate (HR, bpm) measured during CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate different steps. Results are shown as mean ± SD. Significant differences between the conditions are marked. * p < 0.05, ** p < 0.01.*

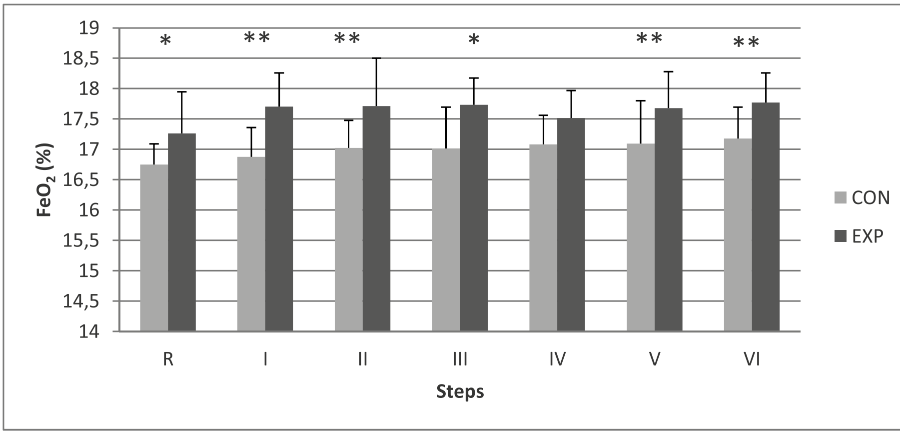


*Figure 8: Expired fraction of oxygen ($FeO_2$, %) measured during CON (light grey) and EXP (dark grey). R (rest), roman numbers indicate different steps. Results are shown as mean ± SD. Significant differences between the conditions are marked. * $p < 0.05$, ** $p < 0.01$.*

Considering the difference between the two 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 $mlO_2$/kg*min ($p < 0.01$), + 25.6 L/min ($p < 0.01$), + 8.8 1/min ($p < 0.05$), + 25.2 bpm ($p < 0.01$) and + 0.8 % ($p < 0.01$). In step 2, there was a significant difference between CON and EXP in $\dot{V}O_2$ (+ 2.3 $mlO_2$/kg*min, $p < 0.01$), $\dot{V}e$ (+ 10.7 L/min, $p < 0.01$) and $FeO_2$ (+ 0.69 %, $p < 0.01$). Conversely, fR and HR were not statistically different between the two conditions. During step 3, only $\dot{V}e$ (+ 4.6 L/min, $p < 0.01$) and $FeO_2$ (+ 0.72 %, $p < 0.05$) were significantly different between the two conditions. In step 4, only $\dot{V}e$ was different between CON and EXP, being increased during immersion (+ 4.8 L/min, $p < 0.01$). Step 5 showed a significant difference between the two conditions in $\dot{V}O_2$ (+ 0.9 $mlO_2$/kg*min, $p < 0.05$), $\dot{V}e$ (+ 4.2 L/min, $p < 0.01$) and $FeO_2$ (+ 0.58 %, $p < 0.01$). In the last step (step 6), $\dot{V}O_2$ (+ 0.8 $mlO_2$/kg*min, $p < 0.01$), $\dot{V}e$ (+ 4.6 L/min, $p < 0.01$) and $FeO_2$ (+ 0.59 %, $p < 0.01$) remained significantly greater in EXP as compared to CON.

## Cognitive Performance

In both CON and EXP no statistically significant difference was observed among the different steps in both the SDMT score and the number of errors. Comparing conditions, the score was lower in EXP in step 1 (36 ± 6 vs. 32 ± 7, - 4 points, $p < 0.05$) and step 2 (33 ± 4 vs. 30 ± 6, - 3 points, $p < 0.05$). The number of errors was not statistically different between conditions. Figure 9 illustrates the results for the SDMT score, comparing CON and EXP.

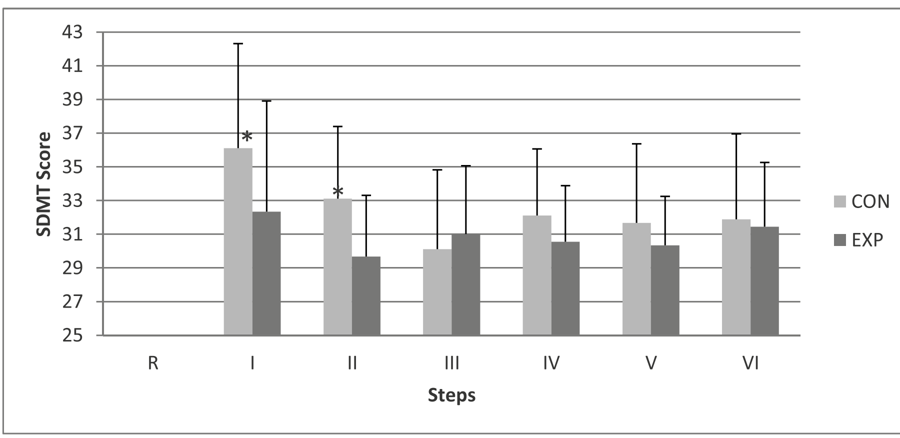


*Figure 9: SDMT score (number of correct answers) measured during CON (light grey) and EXP (dark grey). R (rest) is absent, roman numbers indicate different steps. Results are shown as mean ± SD. Significant differences between the conditions are marked. * p < 0.05, ** p < 0.01.*

No significant correlation could be detected between physiological parameters and cognitive performance (SDMT score), $FeO_2$ showing the strongest correlation with cognitive performance ($r = 0.563$, $p = 0.057$). Significant correlations were observed among physiological parameters, in particular between $\dot{V}$e and fR ($r = 0.919$, $p < 0.001$), $\dot{V}$e and $FeO_2$ ($r = 0.644$, $p < 0.05$) and fR and FeO2 ($r = 0.629$, $p < 0.05$).

# DISCUSSION

## Main findings

According to our work hypothesis, the results of the present investigation suggest the presence of physiological responses during the first minutes after cool water immersion at 18 °C. However, the amplitude and the duration of these responses are reduced if compared with colder water temperatures. Additionally, also cognitive functions seem to be negatively affected by cool water immersion, probably because of the detrimental influence of altered physiological parameters.

## Rest values and SDMT effect

Results show that before performing the cognitive test, in both CON and EXP, participants' physiological parameters were similar to those expected while resting in orthostatism. To exclude the possible effect of the SDMT on the physiological parameters and the possible adaptation during the immersion, we observed the physiological responses through the different steps. Comparing the different steps in CON, it is possible to observe that HR was slightly increased during the cognitive test, but not in all the steps, the largest difference being found between the rest values and the first step (9.4 ± 1.9 bpm). fR was found increased only in step 2, but no interaction was found with the cognitive test. These results suggest that the execution of the SDMT did not alter the physiological responses.

## Adaptation of physiological responses

In the 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 the 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 reported by others. 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, namely, already in the second step (i.e., after 45 s after immersion), since there was no significant difference between the rest values and the steps following the first one. $FeO_2$ was 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).

## 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 for each step the results of CON and EXP, it is possible to notice that all the parameters significantly increased during the first minute only in EXP. In step 1, $\dot{V}O_2$ was 153 % higher than its resting value, while $\dot{V}e$ was 200 % in most cases if compared to data prior to the immersion. fR showed the largest variation between the participants, probably because this parameter is related to anxiety and thus, maybe it depended also 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 the elderly or people with no severe heart diseases. However, in colder water the cardiac response could also increase HR (Friedman & Thayer, 1998) because of swimming and panic. 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). The results show there was an adaptation process in all the physiological parameters during the 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 in the literature, 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 potentially 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 worsened 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 the statistics. Cognitive performance did not change significantly 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 the immersion, compared to CON, while in step 2 only one participant showed a better result in the water. As noticed before, the large variation among the participants reduced the mean difference between conditions, as illustrated in figure 10.

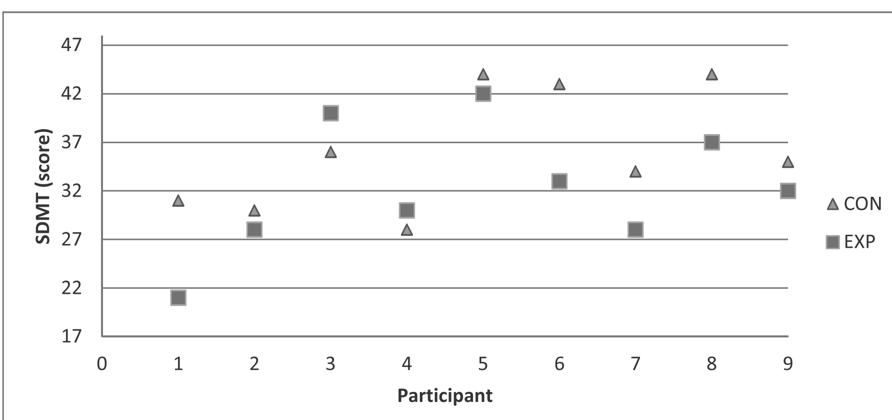


*Figure 10: SDMT score (number of correct answers) measured during CON (light grey triangles) and EXP (dark grey squares) for each participant during the first step. Two participants had a better score in EXP than in CON.*

The difference observed in four participants is relevant for assuming a reduced information processing speed when immersed in cool water. The number of errors was not relevant in this study; indeed, whenever the participants matched the wrong number they immediately corrected it 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, the results of the present study suggest 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 potentially hazardous situation, like a shipwreck, this physiological effect combined with fear and confusion could be detrimental for the cognitive processes necessary for self-rescue. 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. Without considering some potential pathological issues as a 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. It is good advice to use the first minutes to calm and decide what to do, being careful and closely evaluating distances and possibilities.

In this study we observed that the SDMT did not alter the physiological responses that were increased because of the cold shock in the first minute after cool water immersion. However, the magnitude of these responses does not seem to be particularly hazardous for the organism. Also, cognitive functions seem to be negatively affected during the first 2 minutes of immersion, indicating a possible effect of the physiological parameters on the psychological response.

## CONCLUSIONS

Cold shock after water immersion provokes several physiological responses in non-acclimatized young healthy men. These initial responses were 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 could impair intensive and complex physical activities. Conversely, planning the rescue strategy can be partially impaired not only by panic but also directly by cold shock. In this study we reported that cognitive functions could be partially reduced after cool water immersion, possibly because of the physiological responses. Reducing the effects of cold shock through acclimatization, entering slowly into the water or wearing protective clothing, could diminish the risk of cardiorespiratory failure or drowning and it would increase the chances to preserve cognitive performance.

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