Impact of a 10,000-m Cold-Water Swim on Norwegian Naval Special Forces Recruits

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ABSTRACT

Background: Special Operation Forces (SOF) operate regularly in extreme environmental conditions that may affect tactical and physical performance. The main aims of the present study were to elucidate the impact of a long cold-water swim on SOF recruits' dexterity, performance, and reaction time. **Material and Methods**: Eleven recruits from Norwegian Naval Special Operation Command (NORNAVSOC) that were participating in a 10,000-m open water swim with a dry suit in 5°C cold water volunteered to participate in this study. The exercise was part of their training. Grip strength, lower body power, and dexterity were measured before, immediately after, and 24 hours after the swim. In addition, core and skin temperatures were measured continuously during the swim and until 45 minutes after the swim. **Results**: After the swim, moderate to large reductions in core temperature, lower body power, and reaction time were observed. Moreover, very large to extremely large reductions in skin temperature, grip strength, and dexterity were also observed. **Conclusion**: These results demonstrate that exposure to a 10,000-m swim in 5°C water using standard equipment led to a significant drop in the recruits' temperature and performance. These findings could have a meaningful impact on the planning of training, operations, and gear used for SOF.

KEYWORDS: *stress hormones; body temperature; skin temperature; military medicine; swimming; physical fitness; combat swimmer; combat diver*

Introduction

Special Operation Forces (SOF) have an exceedingly physically and psychologically demanding occupation, which often include training and operations under stressful and challenging environmental conditions.[1] Due to climatic conditions, the Norwegian Naval Special Operation Command (NORNAVSOC) operators are regularly exposed to cold environments in many of their operations and training, especially during operations on, under, and from the sea. Water temperature during winter in the Nordic countries is regularly below 5°C (41°F). Therefore, one of the possible stressors applied to SOF operators, both in training and operations, is local cooling and hypothermia. Following that, it is vital to investigate the effects of cold weather and particularly cold water operations among SOF personnel.

In an interesting study from Jimenez et al., a decrease in core temperature, as well as cardiovascular and immunological changes, were reported in SOF operators.[2] However, the knowledge of how exposure to swimming in cold water affects the performance of SOF operators is limited. As the SOF operators must prepare to do missions after exiting from cold water, it is crucial to understand how cold water influences their performance. A typical mission for a SOF operator could be a long swim into a target, in which the mission transforms to involve tasks such as climbing a ladder, using a weapon, clipping into a harness, and similar.

The main aim of the present study was therefore to elucidate the burden and impact of a long cold-water swim on the dexterity, performance, and reaction time of SOF operators. The impact on skin and core temperature, as well as biomarkers for stress and muscle damage, were also measured.

Methods

Design and Recruits

Eleven male recruits (age 23.9 ± 2.1 years, 83.3 ± 6.8 kg) from NORNAVSOC that completed a 10,000-m swim in the open sea during wintertime in Norway, as a part of their qualification training program to become a SOF operator, volunteered to participate in the study (Table 1).

Ethical Considerations

The study was approved by the Regional Committee for Medical Health Research Ethics, Oslo, Norway (REK) reference number REK southeast C-35176, and by the data protection officer at Oslo University hospital (19/28581). Before providing written informed consent, recruits received information about potential risks of participation and were particularly informed that a withdrawal from the research project would not influence the selection process to become a SOF operator.

Timeline and Test Descriptions

The recruits were familiarized with the tests 24 hours prior to the swim. Pre-tests were performed early in the morning (5 a.m.–6 a.m.) before entering the water. Immediately after the swim, the first set of tests were performed (0 hours). The last set of tests were performed 24 hours after finishing the swim. The recruits completed the swim with a Kevlar dry suit (Ursuit, www.ursuit.com/en/ursuit-heavy-light1) with latex

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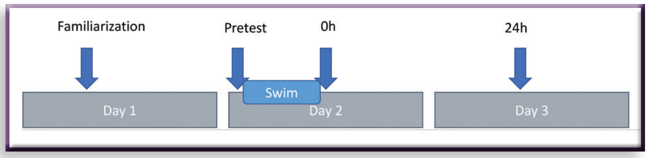
sealing on the neck and wrists, completed with a neoprene long neck 7-mm hood, 5-mm Neoprene five-finger gloves, fins, and a diving mask (Figure 1).

FIGURE 1 *Timeline for familiarization and testing.*



Recruits rated their subjective recovery status before all test points using the Perceived Recovery Status (PRS) scale, on a scale ranging from 0 (not recovered at all) to 10 (completely recovered).[3] About 30 minutes after the swim, the recruits also rated their perceived exertion (RPE) on a scale ranging from 0 (nothing at all) to 10 (very, very hard).[4] A sheet showing visually cued responses was used before verbal answers were obtained.

Core temperature was measured continuously with an e-Celsius Performance capsule temperature sensor (BodyCap, www.bodycap.us/e-celsius-performance/) that was swallowed approximately 2 hours before the swim. The capsule size is 17.7 × 8.9 mm and was programmed to sample data every minute. Skin temperature (T_{skin}) was measured using iButton DS1922L (Maxim Integrated, www.maximintegrated.com). The sensor was placed on the skin of the left underarm with an adhesive Tegaderm dressing (3M, www.3m.com) 5 cm above the wrist cuff on the dry suit, and it measured the skin temperature on the subjects in 1-minute intervals.

Body mass, fat mass, and muscle mass were measured with the Inbody 720 (Biospace, www.inbody.com/eng/product/inbody720.aspx), four-electrode bioelectrical impedance scale. Two tests of physical performance among SOF operators were conducted based on previous.[5,6] First, maximal grip-strength on both hands was measured with the Jamar Deluxe Hand Dynamometer model 0030J4 (JWL industries, www.jlwforce.com/).The subjects held the dynamometer in their hand with a 90° angle in the elbow. Second, the test subjects squeezed the dynamometer as hard as they possibly could for 3 seconds. Two separate tests on both right and left arm. The highest value was used in the analysis. Third, lower body power was measured with a countermovement jump (CMJ) on the Force Platform FP8 (Hur Labs, www.hurlabs.com/force-platform-fp8) using procedures described elsewhere.[5]

Blood samples were taken using serum vacutainers containing gel separators and clot activator (BD, www.bd.com). The samples were clotted in room temperature for 30 minutes before being centrifuged at 2000*g* force for 10 minutes and refrigerated on site. All tubes were transported to a certified clinical laboratory (Fürst Medisinsk Laboratorium, Oslo, Norway) and analyzed for creatinine kinase (CK), C-reactive protein (CRP), cortisol, and testosterone levels.

Dexterity was measured using a test in which the recruits assembled two separate and different sized pairs of bolts, washers, and nuts. Their assembly time was recorded. Reaction time was measured with a series of STROOP tests on an iPad (HindSoft Technology Pvt Ltd, EncephalApp software, www.encephalapp.com). The Stroop test is a validated test for measuring reaction time.[7]

Analyses (Statistics)

All data, except PRS and RPE, were log-transformed and analysed in Excel (Microsoft, www.microsoft.com/en-us/microsoft-365/excel). Changes were calculated with *t*-tests in a spreadsheet, which allowed for two predictors. This made it possible to sort out the effect of other variables on the recruits' change in performance (such as the effect of change in core temperature on performance).[8] Primary analyses investigated changes occurring during the swim, with the following recovery 24 hours later. Secondary analyses investigated the possible mediating effects of changes in core and skin temperature on the performance variables.

The magnitude of changes was evaluated with the following scale: < 0.2, trivial; 0.2–0.6, small; 0.6–1.2, moderate; > 1.2, large; 1.2–2.0, very large. All inferences were made with Magnitude Based Decisions (MBD), which is suggested for small samples.[9,10] Changes were evaluated with a 95% confidence interval (CI) in relation to the smallest meaningful change (0.2 standard deviation [SD], the baseline SD). They should at least have a 25% chance of benefit and less than 0.5% chance of harm to be clear. Effect of mediators (change in core and skin temperature) were evaluated mechanistically; if the substantial positive and negative values overlapped (0.2 and 0.2), the effect was deemed unclear and was otherwise evaluated probabilistically as described above. Plots were produced using programming language Python 3.7.6. and statistical data visualization packages MatPlotLib 3.1.1. and Seaborn V0.10.1.[11–13]

Results

One subject dropped out before the swim started, and one was taken out during the swim for unknown reason by the officers responsible for the swim. Therefore, in total, 9 of the 11 test subjects finished the 10,000-m swim and were included in the final analysis.

TABLE 1 *Baseline Characteristics of the Test Subjects (N = 9)*

Variable	Mean ± SD
Age (year)	23.9 ± 2.1
Weight (kg)	83.3 ± 6.8
Skeletal muscle mass (kg)	43.7 ± 3.2
Body fat (%)	8.6 ± 2.5
Swim time (min)	258.4 ± 17.1
Start T_{core} (°C)	37.4 ± 0.3
Start T_{skin} (°C)	32.2 ± 0.5

T_{core} = core temperature, T_{skin} = skin temperature on the left arm.

Baseline Characteristics

Performance

Moderate to very large negative effects were observed for most variables on performance after the swim (0 hours), except for PRS, which were trivial. Twenty-four hours after the swim, some changes were still small and negative (Table 2).

Blood samples

Moderate to very large clear elevated values were observed for CK and cortisol, while testosterone was decreased after the swim (Post 0). For CRP, the change was trivial. Twenty-four hours after the swim, cortisol and testosterone returned to near pre-test values, while CK and CRP were elevated from 0 hours to 24 hours (Table 3).

TABLE 2 *Baseline Values and Percent Changes at 0 Hours and 24 Hours Compared to Baseline in Performance Variables During the Study*

Variable	Pre-Test (Mean ± SD)	Post 0 Hours (%) (Δ Mean ± SD; CI)	Inference	Post 24 Hours (%) (Δ Mean ± SD; CI)	Inference
STROOP, s	107 ± 9	7.1 ± 14.0; 11.1	M†† ↓	–2.6 ± 12.5; 9.1	S^uncl ↑
Dexterity, s	27.3 ± 6.3	249 ± 83; 173	EL†††† ↓	–4.5 ± 20.3; 14.0	S^uncl ↑
PRS	4.2 ± 1.2	0.0 ± 0.0; 0.0 (CI)	T	14.4 ± 8.8; 6.9	S** ↑
Grip right, kg	58 ± 8	–34.1 ± 15.9; 7.7	VL†††† ↓	–6.1 ± 3.2; 2.3	S†† ↓
Grip left, kg	55 ± 6	–40.6 ± 47.1; 18.3	VL†† ↓	–4.4 ± 8.6; 6.2	S† ↓
CMJ height, cm	33.2 ± 5.4	–14.4 ± 11.0; 7.1	M††† ↓	0.0 ± 6.7; 5.1	T‡‡
CMJ power, W	3,743 ± 392	–10.9 ± 6.1; 4.1	M†††	–5.7 ± 4.3; 3.1	S††† ↓

PRS = perceived recovery status, CMJ = counter movement jump.
Trivial (T): < 0.2, small (S): 0.2–0.6; moderate (M): 0.6–1.2; large (L): 1.2–2.0; very large (VL): 2.0–4.0; extremely large (EL): < 4.0.
*Possibly beneficial, **likely beneficial, ***very likely beneficial.
†Possibly harmful, ††likely harmful, †††very likely harmful, ††††most likely harmful.
‡Possibly trivial, ‡‡likely trivial, ‡‡‡very likely trivial, ‡‡‡‡most likely trivial.
^uncl Unclear (need more data).
↑ = Better; ↓ = Worse.

TABLE 3 *Pre-test, 0 Hours, and 24 Hours Absolute Values in Blood Biomarkers During the Study*

Variable	Pre-Test (Median ± IQR)	Post 0 Hours (Median ± IQR)	Inference	Post 24 Hours (Median ± IQR)	Inference
CK, U/L	284 ± 132	322 ± 210	M††† ↑	314 ± 307	M††† ↑
Cortisol, nmol/L	659 ± 117	846 ± 120	L†††† ↑	675 ± 140	T^uncl ↓
CRP, mg/L	5 ± 5	4 ± 5	T‡‡‡‡	17 ± 11	M††† ↑
Testosterone, nmol/L	18 ± 6	7 ± 4	VL†††† ↓	16 ± 4	T† ↓

CK = creatine kinase, CRP = C-reactive protein.
Trivial (T): < 0.2, small (S): 0.2–0.6; moderate (M): 0.6–1.2; large (L): 1.2–2.0; very large (VL): 2.0–4.0; extremely large (EL): < 4.0.
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↑ = Better; ↓ = Worse.

Core and Skin Temperature

The mean core temperature decreased from 37.4 ± 0.3°C to 37.0 ± 0.9°C during the swim. When including the after-drop, core temperature dropped 1.5 ± 0.8°C. An after-drop was observed in all test subjects after the swim (green dotted line in Figure 2), with an average drop at –1.1 ± 0.3°C measured from the point when the subjects exited the water until the core temperature was at the lowest after the swim.

Figure 2 shows the change in core temperature. During the exercise, one of the recruits reached a core temperature of 34.4°C, which is below the threshold of hypothermia (35°C). Five of the recruits had a core temperature below 36°C during the exercise. All lowest core temperature readings were measured after the recruits had exited the water.

The skin temperature increased the first 20 minutes of the swim before it gradually dropped during the last part of the swim. The drop in T_{skin} was on average –9.8 ± 3.3°C during the exercise (Figure 3).

Discussion

The main findings in the present study were the reductions in lower body power, reaction time, grip strength, and dexterity immediately after the swim. After 24 hours, most effects of the swim were small or returned close to the baseline. After the swim, CK and cortisol were elevated compared to baseline, while CRP was not changed compared to baseline.

During the first 15 minutes of the swim, core temperature increased in all recruits, indicating elevated heat production compared to heat loss. After the initial 15 minutes, the core temperature was remarkably stable until 150 minutes, when some recruits started to decline (Figure 2). This finding indicated well-functioning and properly insulated dry suits, as long as the recruits were able to maintain normal swimming. The drop in core temperature was probably caused by reduced heat production due to exhaustion. Furthermore, after the swim, an after-drop was observed in all recruits, although they doffed in heated shelters (Figure 2, green, dotted lines). This physiological response is important to be aware of among operations in cold water. Reductions in skin temperatures of a similar magnitude have been associated with decreased internal muscle temperature, which in turn leads to decreased muscle force.[14] In our study, lower body power was reduced after the swim but normalized at 24 hours. The swim was rated moderate (RPE) by the recruits and may indicate that the energy cost was not considerable during the swim.

Maximum voluntary contraction grip strength has been shown to decrease after cold water immersion.[15] One interesting question is how much time it takes before grip strength returns to normal. Our study revealed that grip strength was back to near pre-test levels after 24 hours. Therefore, with these novel findings, one can speculate that a decrease in skin temperature may affect performance and could be an essential variable to consider in addition to core temperature.

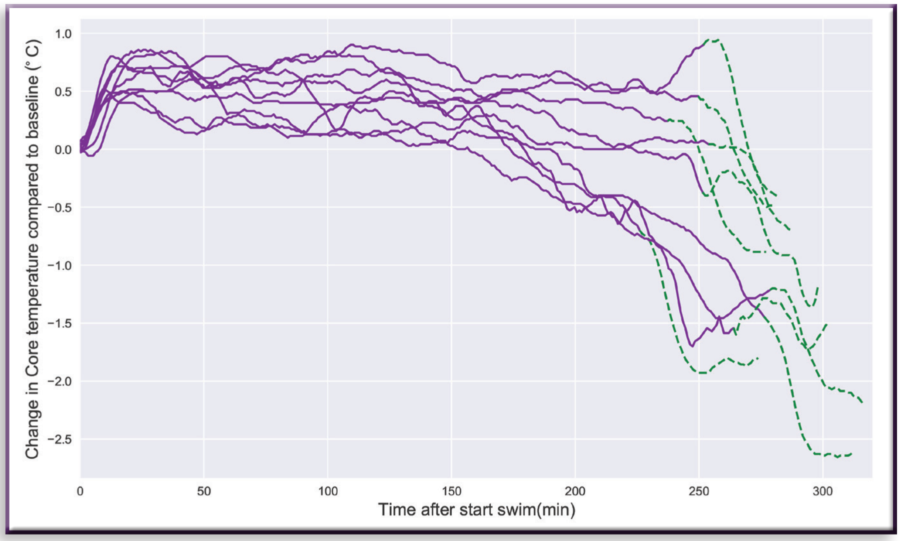

FIGURE 2 *Change in core temperature compared to baseline during the swim (full purple line) and the first 45 minutes after the swim (dotted green line).*

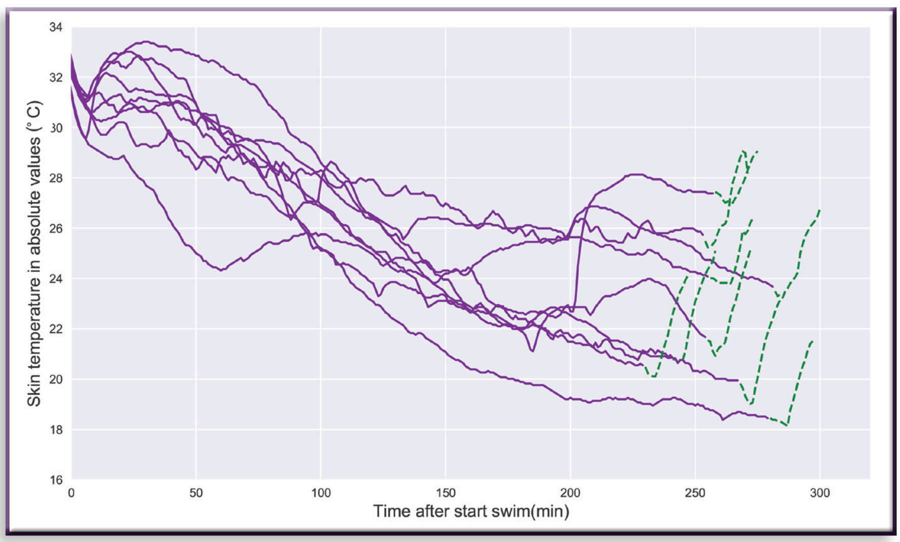

FIGURE 3 *Skin temperature plotted individually for the swim (purple line), and approximately 10 minutes after exiting the water (dotted green line).*

Although the recruits were swimming in a dry suit, and 5-mm five-finger Neoprene gloves, manual dexterity declined by nearly 250% during the swim. Studies have concluded that immersions of the hand in cold water for as short as 5 minutes results in impairment in both gross and fine manual dexterity.[16] It is worth noting that our study subjects were in the water for an average of 258 minutes, and we observed a clear gradual reduction in T_{skin} on the forearm (Figure 2). The blood flow to the hands responds rapidly upon cold, inducing vasoconstriction, which leads to decreased temperature in the fingers and hands. Due to the nature of the exercise, we were not able to measure skin temperature in the fingers of the recruits.

The large decrease observed in manual dexterity may be detrimental for operators as their ability to perform mission tasks, such as using weapon or operating emergency equipment, could be seriously impaired.[17] Following the immediate impairment, ongoing cold exposure and vasoconstriction have several other adverse potential outcomes, such as non-freezing cold injuries from decreased blood flow. These injuries can lead to necrosis, immersion foot or frostbite.[18] Therefore preventing decreased T_{skin} and dexterity are vital.

In the present study, we induced two main stressors to the study subjects, cold water and demanding physical activity, that elicited high cortisol and low testosterone levels in line with previous studies.[5,19] We also observed an increase in CK after strenuous exercise, which is likewise in line with previous studies.[20,21] Surprisingly, and of notable interest, was the clear increase in CK despite the recruits not performing a typical weight-bearing activity, as investigated in previous studies. It is possible that there is increased muscle damage in the legs due to the recruits propelling their motion with the use of fins. To our knowledge, muscle cooling or decreased core temperature does not increase CK levels. Therefore, this finding should be investigated further.

The CRP levels were within normal ranges after the swim but elevated at 24 hours. Similar results are observed after long-distance racing, in which the CRP plasma values were elevated the day after.[21]

The recruits used fins to propel their 10,000-m swim. In general terms, large and stiff fins are more energy demanding but increase the maximal propulsion per kick. Smaller and more flexible fins improve the economy of swimming at more submaximal speeds.[22] Zamparo et al. showed that the use of fins decreases the energy cost by around 50% when compared to flutter kick without fin. They further elucidated that kick frequency should be decreased as much as possible to reduce the energy cost.

Limitations

First, the present study had a small sample size, and some small findings were not clear. However, this is due to the nature of the training of NORNAVSOC recruits. Second, including a control group that was cooled but not swimming would have been beneficial to differentiate between the effects of strain and the effects of temperature. Third, all recruits in the present study underwent heavy strain before starting this study. Therefore, their baseline levels could already be outside normal ranges on some variables. Fourth, including more skin temperature measurements in different areas of the body could have provided some valuable information. Fifth, some variables were still negatively affected by the swim after 24 hours, and optimally another measure after 48 hours would have been interesting.

Conclusion

The results demonstrate that exposure to a 10,000-m swim in 5°C water using standard equipment for the NORNAVSOC led to a significant drop in the SOF recruits' performance. Findings could have a meaningful impact on the planning of training, operations, and gear used for Special Forces.

Practical Applications

We observed apparent declines in several variables in this study. The impact of these will be of importance when planning training and missions for SOF operators. Individuals coming out of cold water might have degraded strength, dexterity, and reaction times. Future studies should focus on how to prevent lowered core and skin temperatures. For the individual, this might include improvement of cold-water specific gear.

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Disclosure

The authors have no conflicts of interest to declare.

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Author Contributions

PAS and JM conceived the study concept. JH and PAS obtained funding. PAS recruited participants. JM and PAS planned the study, collected the data, and analyzed the data. JM wrote the first draft, and all authors read and approved the final manuscript.

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