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**ASSESSING HYPOTHERMIA RISK AT DIFFERENT
IMMERSION DEPTHS**

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United States Army
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USARIEM TECHNICAL REPORT T24-005

ASSESSING HYPOTHERMIA RISK AT DIFFERENT IMMERSION DEPTHS

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EXECUTIVE SUMMARY

Introduction: The Warfighter must operate in austere cold environments and navigate through challenging terrain while in such conditions. Cold water immersion introduces one of the most challenging environmental conditions due to the risk of hypothermia. This study aimed to expand upon current immersion table guidance by increasing the number of depths and adding an additional metabolic intensity. **Methods:** Two healthy males (17 and 19 years) aimed to complete three experimental trials of cold water (10 °C) immersion at randomized depths of either below groin-level, waist-level, or chest-level. Volunteers stood motionless for one hour before donning a 35 kg rucksack and walking at 1 MPH (0.45 m/s) for the second hour followed by a third hour of loaded walking at 2 MPH (0.89 m/s). Volunteers were unable to complete the chest-level trial due to either equipment malfunctions or personally withdrawing from the study. **Results:** Only partial datasets are available as neither volunteer completed all three trials. Trends can be seen but no sufficient conclusions can be made. Rectal temperature was well defended during the static hour of immersion before dropping rapidly with the start of exercise. Skin temperatures for sites immersed in water fell close to water temperature throughout each trial. **Discussion:** The ambulation in water appears to be a key factor in heat loss, leading to a rapid decrease in rectal temperature once exercise started. Skin temperatures falling to water temperature was unsurprising and appeared to be impacted by the increased movement associated with exercise. Low enrollment can be attributed to many challenges the protocol faced throughout its lifecycle including COVID-19, body fat restrictions, and potentially the long exposure to cold water. **Conclusion:** No sufficient conclusions can be made from the limited data collected. However, the low enrollment and retention of volunteers offers insight into how future protocols can offset recruitment issues.

Introduction

The Warfighter must operate in austere cold environments and navigate through challenging terrain while in such conditions. While exposure to cold air alone poses little risk for hypothermia (O'Brien et al., 1998; Young et al., 1998), decreases in core temperature tend to be greater when immersed in cold water (Castellani et al., 2007; O'Brien et al., 2011). Humans cool two to five times faster while immersed compared to air of the same absolute temperature (Hong, 1984) due to greater conductive and convective heat loss (Castellani and Young, 2016). Therefore, complete or even partial water immersion can result in hypothermia (core body temperature $<35^{\circ}\text{C}$) if exposure is sustained, even in mild cold water ($\sim 20^{\circ}\text{C}$). The amount of heat loss when immersed in water is influenced by water temperature, depth of immersion, and duration of exposure and is balanced by the heat production associated with the activity of the individual. Operational functionality can be severely compromised with sustained cold-water immersion as it becomes necessary to actively rewarm or in severe instances evacuate individuals exhibiting symptoms of dangerously low core temperatures.

Current guidance presented in Technical Bulletin Medical 508 (TB MED 508) (Department of the Army, 2005) can be seen in Table 1. Immersion limits are listed for two depths (knee and waist) and reflect the time needed for core temperature to fall to 35.5°C (Department of the Army, 2005). This guidance assumes individuals are walking with a 35 kg load over uneven terrain (Tikuisis, 1995). Time limits for knee and ankle depth immersion are five and seven hours respectively at the lowest water temperature ($10\text{-}12^{\circ}\text{C}$) indicating the small risk for hypothermia when a small portion of the body is immersed in cold water. Time limits for waist-deep immersions are 1.5 hours at the lowest water temperature ($10\text{-}12^{\circ}\text{C}$), and time limits for neck immersions are five minutes, mostly to avoid the possibility of drowning (Department of the Army, 2005). No data exists currently to inform exposure limits involving depths of only the legs (without groin exposure, henceforth “below groin”), any section of the torso, or when individuals are static. River crossings typical of the swamp phase of U.S. Army Ranger School provide a unique scenario where cadre serving in a lifeguard role may remain static for upwards of an hour at waist depth in 12.8°C water (O'Brien et al., 2020; Figure 1) as an entire platoon completes a rope bridge crossing. To improve avoidance of dangerous core temperatures,

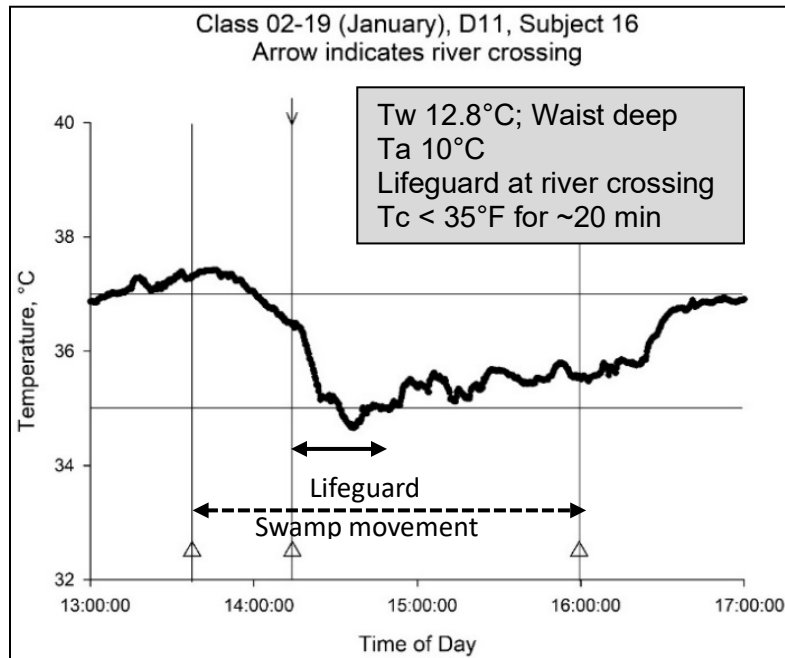
investigating below groin and chest immersion depths is warranted to prevent the need to extrapolate limits between depths.

Simulating the cold-water temperatures that may occur during winter months of swamp phase while measuring body temperatures during a 10 °C water immersion containing both a static and exercise portion was pursued to provide data to expand on current guidance for a greater range of depths to include static immersion. Updated guidance can be leveraged by Army leaders to conduct a proper risk assessment optimizing safety and the performance of mission critical tasks or trainings. Therefore, the aim of this effort was to expand upon the current immersion table in increasing the guidance to a four-depth model and adding an additional metabolic intensity in the form of static.

Table 1. Exposure time limits at various water temperatures and immersion depth

Water Temperature (°F)	Ankle-Deep	Knee-Deep	Waist-Deep	Neck
50-54° (10-12°C)	7 hours If raining, 3.5 h	5 hours If raining, 2.5 h	1.5 hours If raining, 1 h	5 min
55-59° (13-15°C)	8 hours If raining, 4 h	7 hours If raining, 3.5 h	2 hours If raining, 1.5 h	5 min
60-64° (16-18°C)	9 hours If raining, 4.5 h	8 hours If raining, 4 h	3.5 hours If raining, 2.5 h	10 min
65-69° (19-21°C)	12 hours If raining, 6 h	12 hours If raining, 6 h	6 hours If raining, 5 h	10 min
>70° (>21°C)	NO LIMIT	NO LIMIT	NO LIMIT	30 min

Figure 1. Core temperature of a lifeguard during swamp movement and river crossing exercise (indicated by down arrow) at waist depth in 12.8 °C water.



Methods

Volunteers

As study data was meant to inform decisions specifically made during the swamp phase of U.S. Army Ranger School, the population targeted was selected to emulate the low levels of body fat typical of a Ranger candidate (O'Brien et al., 2020). Existent literature suggests that lower subcutaneous fat levels provide less insulation to thwart heat loss and therefore support larger reductions in core temperature (Toner and McArdle, 1996). Volunteer recruitment was restricted to DEXA-measured total body fat values <18% for males and <24% for females. Volunteers were excluded from participation if they reported a history of cold injuries or a diagnosis of Raynaud's syndrome. The characteristics of successfully tested volunteers can be seen in Table 2.

Table 2. Anthropometric measurements of volunteers (n=2)

Volunteer	VOL03	VOL13
Sex	Male	Male
Age (years)	17	19
Height (cm)	184.91	190.75
Body Mass (kg)	79.09	79.18
Body Fat %	11.7	16.7
Body Surface Area (m ²)	1.97	1.99

Testing Procedures

Volunteers visited the laboratory on four occasions, one familiarization session and three experimental trials detailed in Table 3.

Table 3. Outline of study visits

Visit	Day	Purpose	Length of Visit
1	1	Familiarization	3 hours
2	3	Trial 1	Up to 4 hours
3	10	Trial 2	Up to 4 hours
4	17	Trial 3	Up to 4 hours

During the familiarization session, volunteer height and weight were collected, a dual energy X-ray absorptiometry (DEXA; Prodigy Advance (General Electric Healthcare, Madison WI)) scan was performed to determine body fat percentage, and volunteers completed a 3D body surface scan via SizeStream (SS20 Scanner, SizeStream, Cary, NC). Volunteers were fit with an appropriately sized Army Combat Uniform (ACU) and boot before entering the warm immersion pool (33-35 °C) to verify appropriate water depths (below groin, waist, and chest) standing on the underwater treadmill (AquaGaiter HS, Hudson Aquatic Systems, Angola, IN).

Upon arrival to the laboratory for experimental trials, volunteers ate a standardized breakfast before inserting a probe thermistor (YSI 401, Yellow Springs Instruments, Yellow

Springs, OH) or a temperature capsule (e-Celsius® Performance Capsule, BodyCap, Saint-Clair, France) as a rectal suppository. Thermistors were affixed (EUS-UU Skin Probe Thermistor, Grant Instruments, Beaver Falls, PA) to 11 skin surfaces (abdomen, pectoralis, subscapular, ventral aspect of forearm, triceps, calf, anterior thigh, dorsal foot, dorsal hand, dorsal middle finger, forehead). Mean skin temperature (\bar{T}_{sk}) was calculated using the following sex-specific equation (Castellani et al., 2023; Castellani et al., 2021): $\bar{T}_{sk} (male) = (0.074 \cdot T_{head}) + (0.087 \cdot T_{chest}) + (0.174 \cdot T_{subscap}) + (0.096 \cdot T_{abdomen}) + (0.083 \cdot T_{triceps}) + (0.059 \cdot T_{arm}) + (0.026 \cdot T_{hand}) + (0.023 \cdot T_{finger}) + (0.189 \cdot T_{thigh}) + (0.117 \cdot T_{calf}) + (0.072 \cdot T_{foot})$. Volunteers sat quietly for 30-minutes to collect baseline thermoneutral core and skin temperatures. The volunteer entered the immersion pool (10 °C) at one of three randomized depths (below groin-level, waist-level, and chest-level) and stood motionless for one hour. The second hour immersed had volunteers don a 35 kg rucksack and walk at 1 MPH (0.45 m/s) followed by a third hour of loaded walking at 2 MPH (0.89 m/s). Trials ended when at least one of the following criteria were met: the volunteer's core temperature dropped below 35.0 °C, the volunteer requested to end testing, the volunteer completed the 3-hour immersion, or the principal investigator choose to end the trial for technical or medical reasons.

Results

Only a partial dataset is available as the study was not able to sufficiently recruit and retain volunteers during its funded period of performance. The partial datasets collected involved rectal temperature data (n = 2; Figure 2) and 11-site skin temperature data (n=1; Figures 3 and 4). Some trends can be observed but no sufficient conclusions or guidance can be determined. Both volunteers withdrew from the study prior to their final experimental trial which, dictated by randomization, was the chest depth in both instances. One volunteer's skin temperature data was deemed non-viable due to equipment malfunction.

Rectal temperature appears to be relatively well defended during the static hour of immersion, regardless of depth for both volunteers. Both volunteers demonstrated a rapid decrease in their respective rectal temperatures with the onset of exercise for both depths tested. Volunteer 03 requested to stop after 20 minutes of exercising at the below groin depth. The same volunteer hit the safety threshold of 35.0 °C during the waist exposure and was subsequently pulled from the water and rewarmed. Volunteer 13 noted a burning sensation in his feet during

the below groin trial with a pain rating of 9 on a 10-point scale and was subsequently withdrawn just prior to an elapsed 2-hours immersed. Volunteer 13 completed the full 3-hour duration when immersed to the waist.

Upon entering the water, Volunteer 13 showed an unsurprising drop in skin temperature for the thigh, foot, and calf in both trials. Each immersed site quickly settled close to the water temperature (10 °C) apart from the foot temperature which did not reach water temperature until the onset of exercise in both trials. Mean skin temperature was greater with the below-groin depth compared to the waist depth resulting from greater abdomen temperatures.

Figure 2. Rectal temperatures for both volunteers during waist and below groin-level immersions trials. Dotted horizontal line demonstrates the hypothermia threshold.

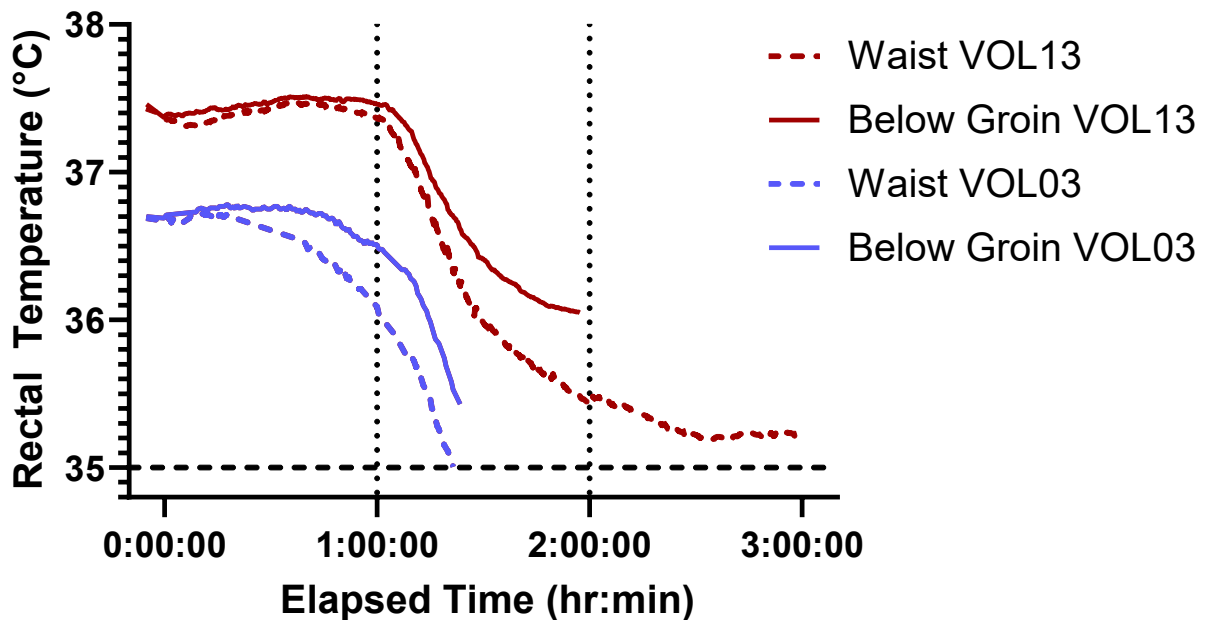


Figure 3. Mean skin temperature for Volunteer 13 during both waist and below groin-level immersions

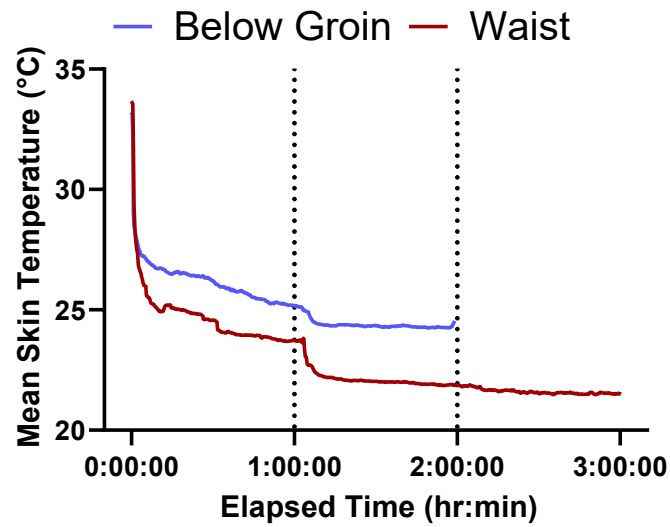
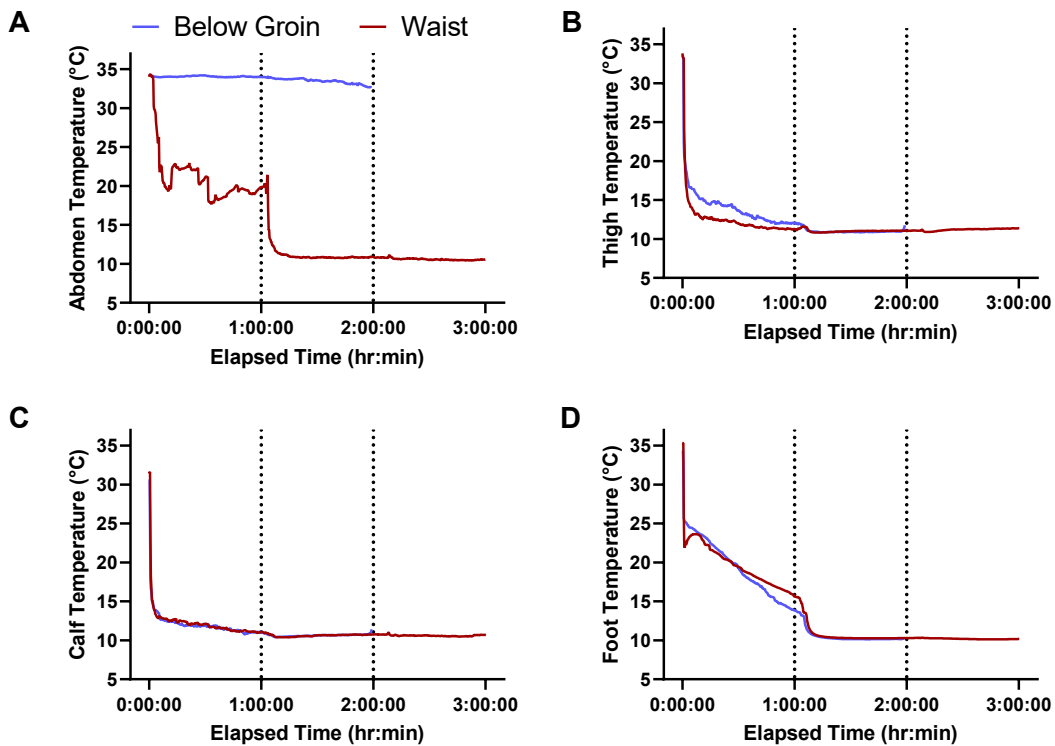


Figure 4. Abdomen, thigh, calf, and foot skin temperatures for Volunteer 13 during both waist and below groin-level immersion trials



Discussion

Regarding rectal temperature, the sharp increase in the rate of rectal temperature decline with the initiation of exercise is noteworthy. Ambulation in water appears to be a critical factor increasing heat loss and reducing rectal temperature. Likely explanations include an increase in convective heat transfer between the stirred water and the skin facilitated by movement as well as more rapid circulation of cooled blood from the periphery to the core resulting from muscle pump action.

Skin temperature unsurprisingly reached a similar temperature to the water temperature (10 °C) seemingly as a function of time. Increased movement associated with exercise further agitating the water also likely accelerated reductions. The rate at which the foot temperature decreased was slower than the thigh and calf temperatures, likely due to the insulative properties of the worn sock and boot. Mean skin temperature responses appear similar between the immersion depths tested, with any differences largely attributable to differences in the total surface area exposed to cold water.

This protocol faced many challenges throughout its lifecycle to include significant difficulties with volunteer recruitment. Data collection began in the midst of COVID-19 restrictions when the number of Human Research Volunteers brought on-site for recruitment was significantly reduced. Further, the long exposure to cold water unique to this study was likely a negative contributing factor in garnering volunteer consent to participate. The total number of individuals consented, enrolled, and completed for the study are detailed in Table 4 below. Consented volunteers were individuals who signed the informed consent after being briefed on the protocol. Screened volunteers were those who were cleared by medical staff to be deemed physically capable to perform the minimum tasks asked of the protocol. Enrolled volunteers consisted of the number of individuals assigned by the Human Research Volunteer Program Manager. Of the enrolled volunteers, only three volunteers met the inclusion criteria and conducted the experimental trials.

Table 4. Overview of volunteers who consented for the protocol.

Consented Volunteers	Screened Volunteers	Enrolled Volunteers	Volunteers Within Body Fat Threshold	Volunteers Data Acquisition	Volunteer Target
46	42	18	4	3	12

The most challenging aspect for recruiting volunteers was the body fat percentage inclusion criterion, (<18% for males and <24% for females). Notably, only one volunteer met this threshold within the first 18 months the study was in active collection. In an effort to expand the potential volunteer pool, the study protocol was amended to increase the body fat percentage threshold (<24% for males and <34% for females) in accordance with Army Regulation 600-9, the Army Body Fat Composition Program (Department of the Army, 2019).

Other difficulties were incurred with volunteers who met all inclusion criteria and moved onto data collection, resulting in two volunteers being withdrawn from the study before completing any experimental trials. One volunteer voluntarily withdrew himself after being given the rectal probe to insert. Another volunteer could not withstand the perceptual experience that accompanies cold-water immersion and withdrew from the study. Two volunteers who respectively completed two of the experimental trials both withdrew themselves prior to their last trial.

Conclusions and Recommendations

The limited data collected from this study does not allow for clear analysis of trends or firm conclusions to be made but does serve as a learning opportunity to offset future recruitment issues. A few modifications are proposed: (1) evaluation of volunteer body fat percentage and comparison to inclusion thresholds should occur at scale for all consented volunteers as soon after on-post arrival as possible; (2) rather than require the insertion of a core temperature pill or probe to measure deep body temperature and maintain volunteer safety, the viability of successfully collecting core temperature data real-time from an ingested temperature pill should be explored; (3) as Ranger school attendees spend relatively little time static while water immersed, a shorter experimental trial consisting of immediately and continually walking in cold

water may be warranted. Previous research has seen success with volunteers walking for one hour in 10 °C and 15°C water at 1 MPH or 2 MPH (Castellani et al., 2007). Moreover, the shorter trials would allow for less staffing requirements and could allow for multiple volunteers to be tested in the same day instead of the longer testing sessions that took place; (4) investigation of alternative populations for recruitment, aside from the Human Research Volunteer population brought to the institution, may be warranted to provide better access to volunteers with low body fat. Ideally, obtaining further data from Ranger candidates themselves could be explored, although logistics and lack of study controls would limit the number of variables measured.

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