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EVALUATION OF IMMERSION TIME LIMITS FOR RISK OF HYPOTHERMIA DURING WATEBORNE MOVEMENTS AT U.S. ARMY RANGER SCHOOL

United States Army
Medical Research & Development Command

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14. ABSTRACT

Cold water immersion presents one of the most challenging environmental conditions, due to the risk of hypothermia. The environmental stress becomes greater with colder water temperature, greater immersion depth, and longer duration of exposure. Understanding these influences improves mission planning and risk mitigation. The Army Technical Bulletin Medical 508 (TB MED 508), Prevention and Management of Cold-Weather Injuries, provides guidelines for risk management. These guidelines are used by the Army Ranger School during the 6th Army Ranger Training Battalion (6RTB) Florida (or “swamp”) Phase, where waterborne movements are a key component of the environment under which leadership skills are evaluated. In winter months when air and water temperatures fall, the waterborne movements are modified to reduce risk while achieving mission objectives.

The table in TB MED 508 that recommends immersion duration limits based on water temperature and depth was developed using a mathematical model. The model was developed from principles of human thermoregulation and biophysics, and validated against

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ABBREVIATIONS

BH	Back Half: swamp movement that occurs after a river crossing Back Half may also refer to the second swamp movement on Day 11
CP	Check Point or the start of a boat movement
FH	Front Half: swamp movement that occurs before a river crossing
GPS	Global positioning system
HG	High Ground, or the end of a swamp movement
RP	Rally Point or the start of swamp movement when approached by boat
RX	River crossing
SP	Start Point or the start of a swamp movement when approached on foot
SD	Standard deviation
6RTB	Sixth Ranger Training Battalion
6-CYL	Six cylinder thermal model
3-CYL	Three cylinder thermal model
TB MED	Technical Bulletin Medical
Ta	Air temperature
Tc	Core temperature, measured in the gastrointestinal tract for this study
Tw	Water temperature
USARIEM	United States Army Research Institute of Environmental Medicine

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We are grateful to the 82 Ranger School students who volunteered for this study while being evaluated on their leadership skills during a rigorous field training exercise. They were conscientious and enthusiastic, and sincerely interested in contributing to science that could help Warfighters in the future.

This study would not have been possible without the support of the 6th Army Ranger Training Battalion, including LTC John Gibson, CSM Eric Buonopane, Mr. Erik Wilson, and CPT Brown. From facilitating data collection to discussions about applications of guidance, they provided the opportunity to learn how to balance the importance of training and operational objectives against risk assessment and mitigation methods.

The opportunity to evaluate field conditions of partial immersion revealed aspects of exposure that are not fully addressed by current guidance. The influence of wet clothing on body heat loss increases as air temperature falls. Future research to determine the rate of cooling will improve guidance to reduce risk of hypothermia.

"Infantry units would benefit from a working guideline to assist commanders with mitigating risk to force with respect to cold weather immersion limits for training and combat operations. A general guideline for immersion in cold temperatures, communicated throughout the maneuver force, would provide Commanders with the ability to make more informed decisions about assessing and mitigating environmental risks." - LTC Gibson, 6th Army Ranger Training Battalion Commander, 2017-2019.

EXECUTIVE SUMMARY

Cold water immersion presents one of the most challenging environmental conditions, due to the risk of hypothermia. The environmental stress becomes greater with colder water temperature, greater immersion depth, and longer duration of exposure. Understanding these influences improves mission planning and risk mitigation. The Army Technical Bulletin Medical 508 (TB MED 508), Prevention and Management of Cold-Weather Injuries, provides guidelines for risk management. These guidelines are used by the Army Ranger School during the 6th Army Ranger Training Battalion (6RTB) Florida (or “swamp”) Phase, where waterborne movements are a key component of the environment under which leadership skills are evaluated. In winter months when air and water temperatures fall, the waterborne movements are modified to reduce risk while achieving mission objectives.

The table in TB MED 508 that recommends immersion duration limits based on water temperature and depth was developed using a mathematical model. The model was developed from principles of human thermoregulation and biophysics, and validated against laboratory data. During Ranger School, chronic exertional fatigue, sleep loss, and negative energy balance result in blunted thermoregulatory responses to cold, including delayed vasoconstriction and shivering, and greater heat loss due to reduced subcutaneous body fat and decreased tissue insulation. This increases the risk of hypothermia relative to a typical research study population. To develop the immersion table for Ranger School students, a lower body fat composition was used in describing the individual (12%, compared to 15%), and a higher target core temperature (Tc) of 35.5°C was used, compared to a typical limit of 35.0°C. The model was validated against Ranger School students undergoing a cold air exposure; however, it was never validated against students during cold-water immersion.

The purpose of the present study was to obtain core temperature measurements of Ranger School students during waterborne movements conducted during winter classes. These data would then be used to evaluate the current immersion table. Data were collected on 57 students in January, February, and March classes of 2019 during two waterborne movements conducted on Day 11 and Day 13 of Florida Phase, as well as on Day 4 when water techniques were taught. Physical characteristics (height, weight, body fat %), clothing, load carried, walking speed, environmental conditions (air temperature, relative humidity, wind speed, solar radiation, water temperature), and immersion depth and duration were measured. By testing during at least 3 separate course dates, a range of environmental and immersion conditions were encountered.

The data from this study support the time limits in the immersion table when students were partially immersed, with the lower body in the water and upper body dry. All cases when core temperature fell below 35°C (95°F) occurred after a river crossing, when the whole body was immersed to the neck and clothing remained wet afterwards. Further guidance is needed when clothing is wet, particularly as air temperature falls below 15°C (60°F). Recommendations also include expansion of the immersion table by including additional depths.

INTRODUCTION

US Army Ranger School was formally established in 1952. The 6th Army Ranger Training Battalion (6RTB) is the site of the final “swamp phase” at Camp Rudder, Eglin Air Force Base in Florida. This phase is known for its field training exercise that incorporates waterborne movements through swamps and across streams. During winter months, there is a risk of hypothermia as colder water temperatures contribute to a higher rate of heat loss, compared to air. There have been two occasions where students died due to hypothermia resulting from prolonged water immersion. These occurred in January, 1977 and February, 1995. In both instances, students were in deeper water for longer times than expected, and the air temperature was falling. Each of these factors increases body heat loss.

Guidance for immersion limits was modified following these accidents. Physiologists at the US Army Research Institute of Environmental Medicine (USARIEM) used a mathematical thermal model to simulate thermal responses to partial cold water immersion. In 1995, the recommended changes to the immersion guidelines reduced time limits for waist-deep immersions at moderate temperatures (50 to 69°F), but relaxed time limits under colder conditions (40 to 49°F).

The 61 day Ranger School course creates conditions of exertional fatigue, sleep loss, and negative energy balance, resulting in loss of body fat and muscle mass. The consequence for thermoregulatory response to cold is a higher risk of hypothermia than for otherwise rested, fed individuals (Young, Castellani et al. 1998). This was taken into account when applying a three cylinder (3-CYL) thermal model (Tikuisis, Gonzalez et al. 1988), by adjusting body fat and using a target core temperature (Tc) of 35.5°C as the limit for immersion duration. The current immersion limits are presented in Technical Bulletin Medical 508 (TB MED 508), Prevention and Management of Cold-Weather Injuries (Department of the Army 2005).

Validation of thermal models specifically for the conditions of Ranger School is challenging. The only way to obtain data on individuals who are in the physical condition of Ranger School students is to include that specific population in research studies. Furthermore, simulating the conditions of the waterborne movements, which includes walking through swamps where footsteps sink into mud and in which water depth may vary, is not possible in a laboratory environment. One study measured thermoregulatory responses during 3 hours of walking (0.44 and 0.88 m/s) while immersed (waist- and chest-deep) in cold water (10 and 15°C) (Castellani, O'Brien et al. 2007). The data from this study would have suggested the current immersion guidance is conservative; however volunteers were rested, fed individuals of typical body fat for their age group, walked on an underwater treadmill, did not carry a rucksack, and had not undergone any of the stressors of Ranger School. The study data were used to validate thermal models, both the 3-CYL model used to update the immersion table after 1995, and a newer six cylinder (6-CYL) model.

Cold water immersion guidance used by the 6RTB was revised in 1977, then revised again in 1995. The current immersion table, included in TB MED 508, is shown in Table 1. The table provides immersion time limits based on water temperature and depth, and assumes individuals are walking while carrying a 35 kg load. The 6RTB guidance for waterborne operations includes one key difference, which is to state that the lower of air or water temperature will be used, providing added safety when air temperature is lower than water temperature. The table in TB MED 508 makes no mention of air temperature. The model simulations used to construct it were likely run using a neutral air temperature, or an air temperature that was no lower than water temperature. Heat loss in water is about 25 times greater than in air; therefore, the effect of a lower air temperature will be less than what would occur with water at that same temperature. However, there is currently no other way to assess the effect of lower air temperature on the rate of cooling during partial immersion.

Table 1. The immersion table as presented in TB MED 508

Water Temperature (° F)	Ankle-Deep	Knee-Deep	Waist-Deep	Neck
50-54°	7 hours If raining, 3.5 hrs	5 hours If raining, 2.5 hrs	1.5 hours If raining, 1 hrs	5 minutes
55-59°	8 hours If raining, 4 hrs	7 hours If raining, 3.5 hrs	2 hours If raining, 1.5 hrs	5 minutes
60-64°	9 hours If raining, 4.5 hrs	8 hours If raining, 4 hrs	3.5 hours If raining, 2.5 hrs	10 minutes
65-69°	12 hours If raining, 6 hrs	12 hours If raining, 6 hrs	6 hours If raining, 5 hrs	10 minutes
>70°	NO LIMIT	NO LIMIT	NO LIMIT	30 minutes

Note: The immersion table in Ranger School guidance indicates a time limit for 50-54°F at Waist depth of 1 h, whereas the table in TB MED 508 indicates 1.5 h.

The purpose of this study was to: a) measure temperature of Ranger School students during waterborne movements conducted in winter classes, and b) evaluate the immersion table limits for mitigation of hypothermia. The hypothesis was that the cold-water immersion table (TB MED 508, Table 3-3) is appropriate for risk mitigation of hypothermia for Ranger School students undergoing waterborne movements.

METHODS

Each class of Florida Phase has three days of planned water immersion, which may include boat travel, river crossings (head-out immersion), and navigating through swamps (partial immersion).

- Day 4 is a waterborne techniques day where boat movement and “covert gap crossing” (rope bridge construction and river crossing) are taught and practiced by students. Students set up a rope bridge and the entire platoon crosses the river (RX1). Then the process is repeated (RX2). Neck-deep immersion lasts ~1 min when crossing. Between crossings students are relatively static with wet clothing for the ~45 min it takes to complete the process.

- Day 11, named The Boiling after the river that is crossed, can be considered two separate swamp movements. The full, planned waterborne movement starts with a boat movement (CP, Check Point) to a landing at the edge of the Yellow

River where the first swamp movement begins (RP, Rally Point). There is no river crossing on this section (FH, "front half"). Upon reaching high ground (HG), a land-based mission takes place. After completing the objectives, the platoons convene at a Start Point (SP) to navigate through a second swamp (BH, Back Half), reaching the Boiling River, where they erect a rope bridge, cross the river (RX), then resume moving through the swamp to high ground. The time spent in the swamps is just over an hour for the first movement, and ~2.5 hrs for the second movement, for a total of ~3.5 hrs. This second swamp movement typically starts in the evening, after 2000 h, which in winter months is after sundown.

  - Note that for JAN Day 11 the Boiling route was shortened to remove the boat movement and complete only the second swamp movement, which was conducted in reverse.
  - For FEB Day 11, the boat movement and first swamp movement were completed, but the second swamp movement (BH) was cancelled due to a low cloud ceiling for medevac support.

- Day 13, named The Weaver after the river that is crossed, starts with a boat movement (CP) to a landing at the edge of the Yellow River where the swamp movement begins (RP). This swamp is typically muddier than Day 11, which can increase the effort of movement. Upon reaching the Weaver River, platoons erect a rope bridge, cross the river (RX), then resume moving through the swamp to high ground (HG). The time for the swamp movement is ~3 hrs.

Day 4, waterborne techniques, is conducted for every class, with risk mitigation measures implemented according to weather and water conditions. The location is near Camp Rudder, with medical personnel on site, including emergency vehicles. In contrast, due to the remote location of waterborne movements on Day 11 and Day 13, these may be modified or cancelled if conditions fall outside guidance limits.

This study was conducted during four winter classes (December through March) to provide a range of weather and water (depth, temperature) conditions.

TEST PARTICIPANTS

Eighty-two students from the first four winter classes of 2019: December (01-19, DEC), January (02-19, JAN), February (03-19, FEB), and March (04-19, MAR) volunteered to participate in this study, representing ~10% of each class (17 to 24 students per class of ~200). Three individuals were withdrawn for reasons unrelated to the study. Water level was high during DEC; therefore, waterborne movements on Day 11 and Day 13 were cancelled. Data were not collected during Day 4 for the DEC class. Data from immersion days were collected on 57 participants from the remaining three classes.

Anthropometric Data

Anthropometric data were collected on Day 5. Standing vertical height, in stocking feet, was measured using a stadiometer. Body mass was measured both nude and while carrying a full load, using a calibrated electronic scale (Model 876, Seca, Chino, CA) accurate to 0.1 kg. Skinfold thickness was measured (Lange Skinfold Caliper, Cambridge Scientific Industries, Inc., Cambridge, MD) at four sites (bicep, tricep, suprailiac, subscapula), and body fat calculated according to Durnin and Wormersly (Durnin and Wormersly 1974). Students visibly lost weight over the next week, and in hind sight it would be better to make these measurements at the end of the course when the mass and body fat more closely reflect their condition on Days 11 and 13.

Table 2. Anthropometric measurements of participating students (mean ± SD, range)

	Class 01-19	Class 02-19	Class 03-19	Class 04-19
# Volunteered # Withdrawn	24 (2 female) 2 (1 female)	17 (2 female) none	21 none	20 1
Height cm	173.0 ± 5.4 (161.3 – 182.4)	177.0 ± 5.7 (167.2 – 189.5)	176.8 ± 4.3 (163.5 – 182.5)	176.0 ± 8.5 (163.5 – 200.5)
Body Fat %	12.4 ± 2.9 (7.6 – 18.6)	16.0 ± 2.5 (11.7 – 21.1)	11.9 ± 2.6 (5.0 – 15.5)	9.9 ± 2.4 (4.5 – 17.3)
Nude Mass kg	74.6 ± 8.6 (60.3 – 86.7)	83.0 ± 6.8 (70.5 – 96.6)	79.4 ± 6.2 (68.2 – 91.2)	74.6 ± 7.6 (63.1 – 89.4)
Loaded Mass kg	117.4 ± 10.4 (100.8 – 134.7)	131.1 ± 9.4 (112.8 – 146.7)	123.9 ± 7.3 (111.4 – 136.8)	118.0 ± 10.5 (99.0 – 142.3)
Carried* Load kg	42.8 ± 4.9 (32.9 – 51.3)	48.1 ± 5.1 (38.9 – 56.1)	44.4 ± 5.6 (34.3 – 55.3)	43.3 ± 5.6 (35.9 – 54.9)

*Carried load for initial body weight measurements varied among individuals depending on specialized equipment, and remaining food and water.

TEST PROCEDURE

On each of the water immersion days, participants were equipped with temperature sensors and data logging instrumentation. A chest strap with a data logger (Equivital™ Sensor Electronics Module, Hidalgo, Cambridge, UK) for core temperature was worn around the chest next to the skin. On the evening before immersion, participants ingested a telemetric temperature capsule (Vitalsense Jonah™ Ingestible Core Temperature Capsule, Mini Mitter Inc, BEND, OR). This allowed time for the capsule to move past the stomach and into the gastrointestinal tract before temperature measurements were obtained. The capsule was given on Day 3, Day 10 and Day 12. A global positioning system (GPS) (QStarz, Qstarz International Co., Ltd., Taipei, Taiwan) was tied to the rucksack or a belt loop.

Waterborne techniques on Day 4 occurred between 0900-1200 h. Waterborne movements on Day 11 and Day 13 began ~1200 h and continued into the evening.

Environmental Measurements

Meteorological conditions, including ambient temperature, relative humidity, wind speed, and solar radiation were measured by a weather station set up in a central location (WeatherHawk 500 series, WeatherHawk, Logan, UT). Local air and water temperatures and water depth were measured at standard locations by the Ranger School staff during each waterborne movement.

DATA ANALYSIS

Data are presented as mean ± standard deviation (SD). There are considerable differences in individual responses to cold, particularly in Ranger School students where there has been an ongoing negative energy balance and on any particular day there are differences in amount of sleep, recent nutrition, load carried, etc. Individual data and/or range of values are presented to illustrate this variability.

To evaluate the immersion table, the group mean and individual Tc during waterborne movements that were at or near the immersion table time limits were compared to the 35.5°C target Tc. Ranger School students are known to be more susceptible to cooling due to the stressors inherent in the course. Designing the immersion table for a Tc limit of 35.5°C provides a margin of safety before reaching 35.0°C (95°F), the temperature threshold considered to be the beginning stage of hypothermia and when shivering is near maximal level. As core temperature approaches 32.2°C (90°F), shivering may cease, resulting in more rapid heat loss.

RESULTS

Day 4

Water immersion on Day 4 consisted of two separate river crossings. Each platoon constructed a rope bridge, then the platoon moved across with spacing between each person. The time for each person to cross the rope bridge was less than 1 min, with the time for the entire platoon to cross lasting ~45 min. The rope bridge was then taken down, and the process repeated to return to the original side. While each neck-deep immersion lasted less than one minute for each individual to cross the river, they stood in wet clothing while waiting for the remaining members of the platoon. From the time the first student arrived on the far shore, the platoon completed crossing, the rope bridge was taken down, the second rope bridge was constructed, and the second river crossing began, about an hour elapsed. This may vary among students, as the order they cross may not be the same for both crossings.

The water and air temperatures for Day 4 are presented in Table 3, along with the time students were waiting between river crossings, and the number of students with a Tc below 35°C. Note that the immersion table does not apply to this situation, since immersion time is very brief for most students (~1 min to cross the river).

Table 3. Conditions on Day 4 for each class, with time between river crossings, and number of students with Tc below 35°C.

Class	Tw	Ta	Time between RX1-RX2	# students with Tc < 35°C
JAN	18.5°C (65°F)	20-22°C (~70°F)	39 ± 7 min	None
FEB	16.1°C (61°F)	12-18 (~60°F)	48 ± 12 min	Two after RX2
MAR	13.9°C (56°F)	13-17 (~60°F)	63 ± 11 min	One after RX1 Three after RX2

Figure 1 shows Tc at the time of each river crossing (RX) on Day 4, with the water and air temperatures (Tw, Ta) and duration between crossings also indicated. Overall, there were five cases when a student's Tc fell below 35°C, one of which occurred after the first river crossing. In JAN, all participants maintained Tc within a neutral temperature range (36.5-37.5°C). In FEB, the mean Tc remained within the neutral temperature range, but some individuals fell below that range by the time of the second river crossing (RX2), with the Tc of two individuals briefly reaching 35°C. In MAR, the mean Tc fell below the neutral range by the time of RX2. The Tc of one participant fell briefly below 35°C after both RXs, and the Tc of two additional participants fell below 35°C after RX2. Figure 2 shows two of these individuals, one in a platoon that completed the river crossing first (Panel A, Subject 5), and the other in a platoon that completed the boat movement first and whose Tc was therefore elevated before beginning the river crossing (Panel B, Subject 20). In both FEB and MAR classes, after completing RX2, students changed into dry clothing.

Figure 1. Day 4 mean (SD) and individual Tc at the time of each RX

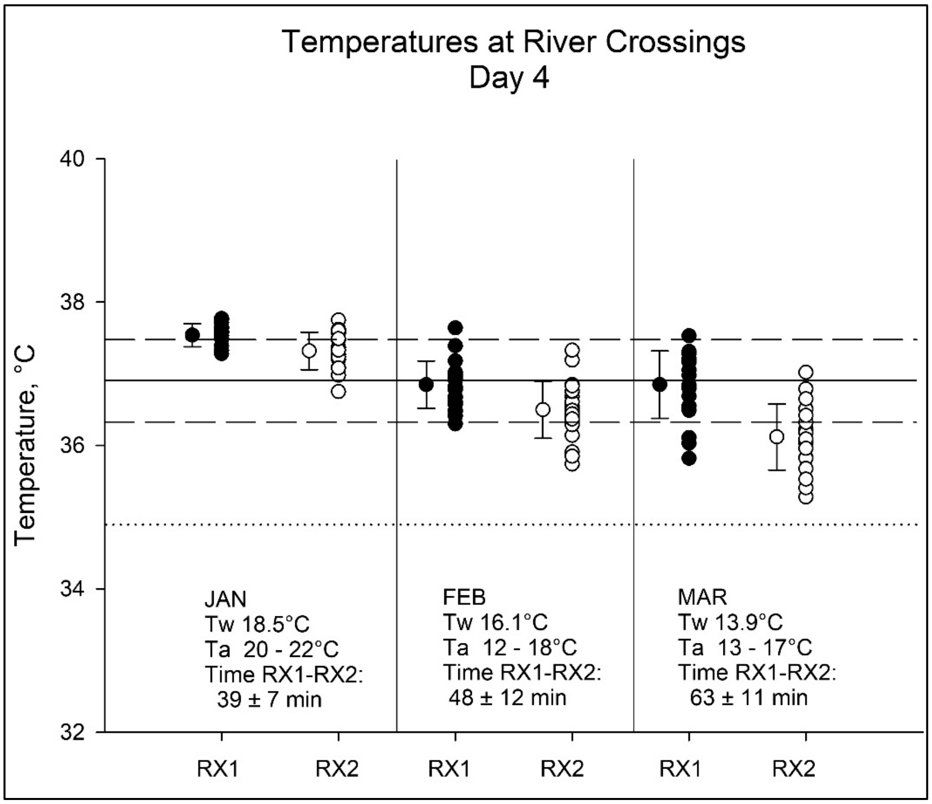
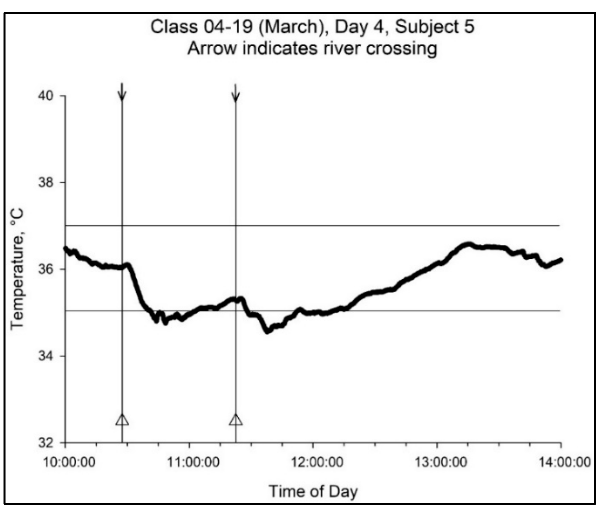
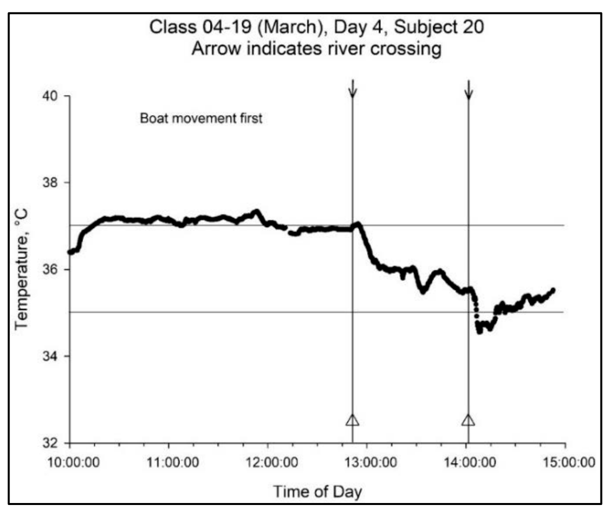


Figure 2. Responses of two of the four students with Tc < 35° on MAR Day 4





The cases of Tc reaching 35°C occurred after the river crossing while students were static with wet clothing. The only information pertaining to wet clothing provided by the immersion table is an adjusted time limit for "if raining." When this condition was modeled, it was assumed that the clothing on the upper body became wet from rain, reducing the insulation value. The model did not account for any added effect of conductive or evaporative heat loss due to wearing wet clothing, and did not consider the effect of Ta lower than Tw. Although Tw is lower in MAR, compared to FEB, it is not possible to determine whether the greater fall in Tc during MAR is due to heat loss during RX1 or whether it is the longer duration while static in wet clothing between RX1 and RX2. The Ta was similar between FEB and MAR.

Day 11 and Day 13

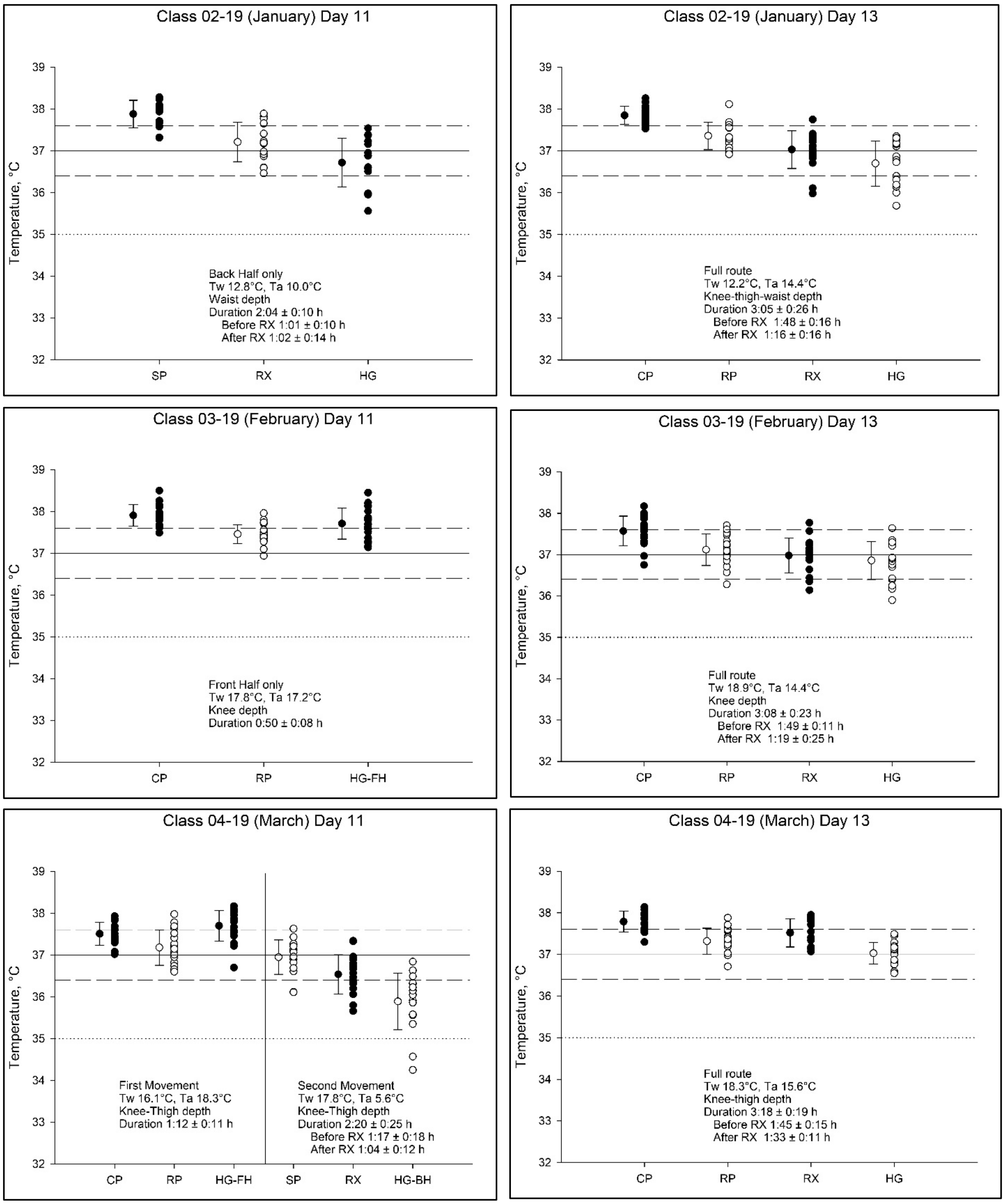
The conditions encountered on Day 11 and Day 13 of each class are shown on Table 4. The duration for completion of each waterborne movement is presented, along with the recommended time limit from the most closely matched immersion table category for Tw and depth. Also shown is the number of participants with a Tc below 35°C, which always occurred during or after a river crossing. Note that three waterborne movements span multiple categories, primarily due to water depth between Knee and Waist (JAN Day 13, MAR Day 11 and Day 13). Rounding up to a higher depth results in more conservative time limits. While it is reasonable to extrapolate between categories, no guidance is presented for this situation.

The mean ± SD and individual Tc at each landmark during swamp movements on Day 11 and Day 13 are presented in Figure 3. Actual conditions are noted on each graph, as well as the corresponding immersion table limits.

Table 4. Conditions for each waterborne movement on Day 11 and Day 13

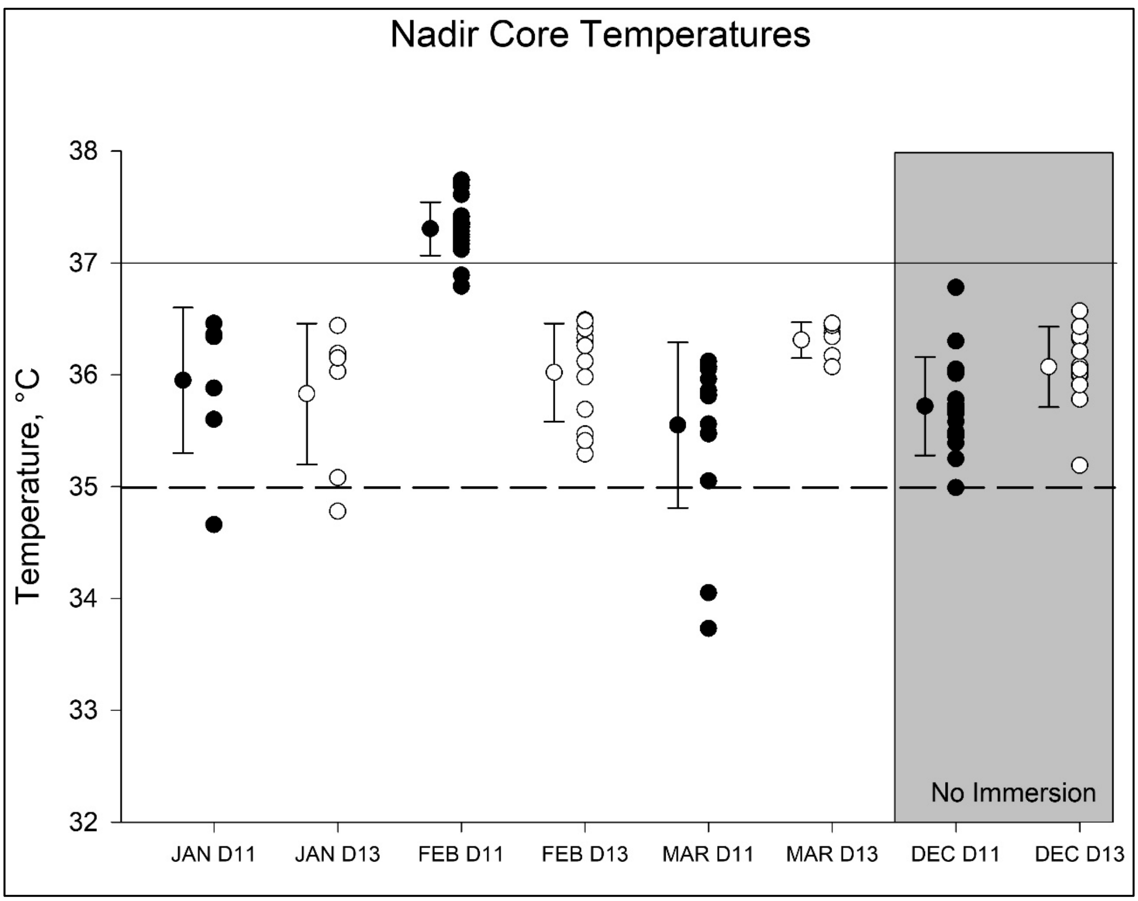
Class	Water Depth	Temperature		Duration	Table Limit	Tc < 35°C
		Water	Air			
JAN Day 11	Waist; River crossing	12.8°C (55°F)	10°C (50°F)	2:04 ± 0:10 hrs	Waist 2 hrs	One; Lifeguard
JAN Day 13	Knee-Thigh-Waist; River crossing	12.2°C (54°F)	14.4°C (58°F)	3:05 ± 0:26 hrs	Knee 5 hrs; Waist 1.5 hrs	One; at RX
FEB Day 11	Knee; No river crossing	17.8°C (64°F)	17.2°C (63°F)	0:50 ± 0:08 hrs	Knee 8 hrs	
FEB Day 13	Knee; River crossing	18.9°C (66°F)	14.4°C (58°F)	3:08 ± 0:23 hrs	Knee 12 hrs	
MAR Day 11	Knee-Thigh; No river crossing	16.1°C (61°F)	18.3°C (65°F)	1:12 ± 0:11 hrs	Knee 8 hrs	
	Knee-Thigh; River crossing	17.8°C (64°F)	5.6°C (42°F)	2:20 ± 0:25 hrs	Waist 3.5 hrs	Two; after RX
MAR Day 13	Knee-Thigh; River crossing	18.3°C (65°F)	15.6°C (60°F)	3:18 ± 0:19 hrs	Knee 12 hrs Waist 6 hrs	

Figure 3. Mean (SD) and individual Tc at each landmark during swamp movements on Day 11 and Day 13. Reference lines are presented at the mean neutral Tc (37°C) and range of neutral Tc (dashed lines), and at 35°C, the limit used in the immersion table.



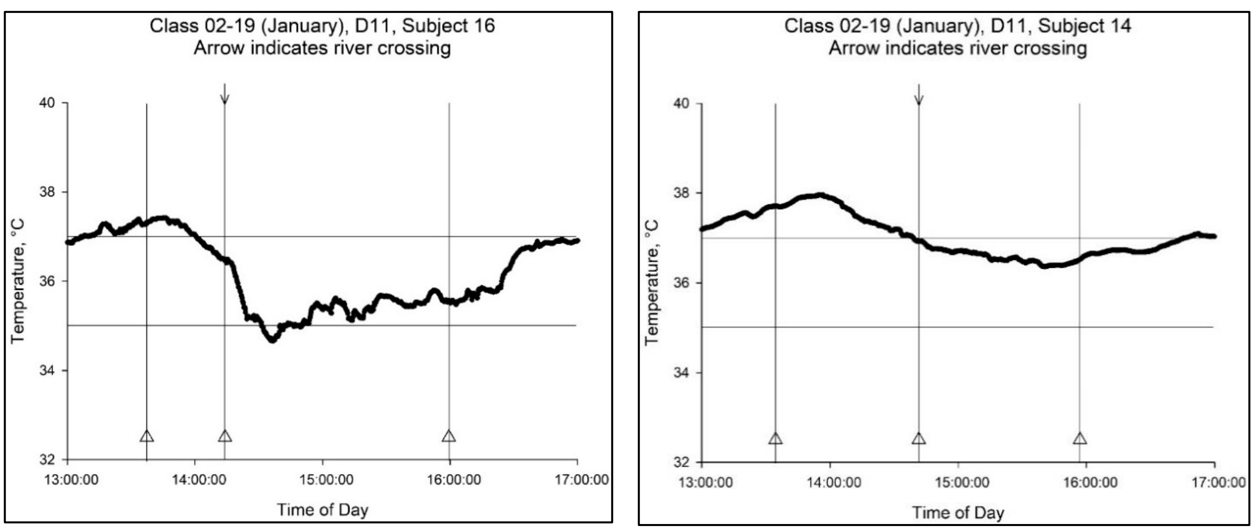
The lowest temperatures measured on Day 11 and Day 13 in each class are shown in Figure 4. Overall, there were four cases when a student's core temperature (Tc) fell below 35°C, all occurring at or after a RX. The duration below 35°C ranged from less than 5 min for one student on JAN Day 13, to 11 min for a lifeguard on JAN Day 11, to over 100 min for two students on MAR Day 11, during the second swamp movement. Data from the DEC class are also presented, although no swamp movement was conducted. For this class, since there was no water immersion, the nadir Tc typically occurred during sleep.

Figure 4. Mean (SD) and individual data for the lowest (nadir) measured Tc on Day 11 and Day 13 during waterborne movements (except DEC)



To conduct river crossings some individuals, including swim teams, rope bridge teams, and lifeguards, are in the river water longer than the time to cross the river once the rope bridge is constructed. Some are in the water for the time it takes to erect the rope bridge, while others remain in the water as the entire platoon crosses. River water is typically deeper than the average depth of the swamp, and river current can increase rate of heat loss. This is illustrated in Figure 5, where the lifeguard on JAN Day 11 (Subject 16, Panel A) was one of the first to reach the river and cross, then remained in the water, experiencing a fall in Tc that continued for the duration of the platoon river crossing. In contrast, individuals who moved through the swamp, crossed the river and continued into the swamp, even if they were then static while awaiting the rest of the platoon, experienced little fall in Tc (Subject 14, Panel B).

Figure 5. Illustrations of Tc in two individuals from JAN Day 11. Panel A shows the Tc of a lifeguard. Panel B shows the Tc of a typical student.



The lowest measured Tc overall occurred on MAR Day 11, during the second swamp movement which began in the evening and continued into nighttime as air temperature fell below 10°C (50°F). Figure 6, Panels A and B show two students with Tc < 35°C, illustrating the rapid fall in Tc after crossing the river.

Figure 6. Illustrations of Tc in two individuals from MAR Day 11

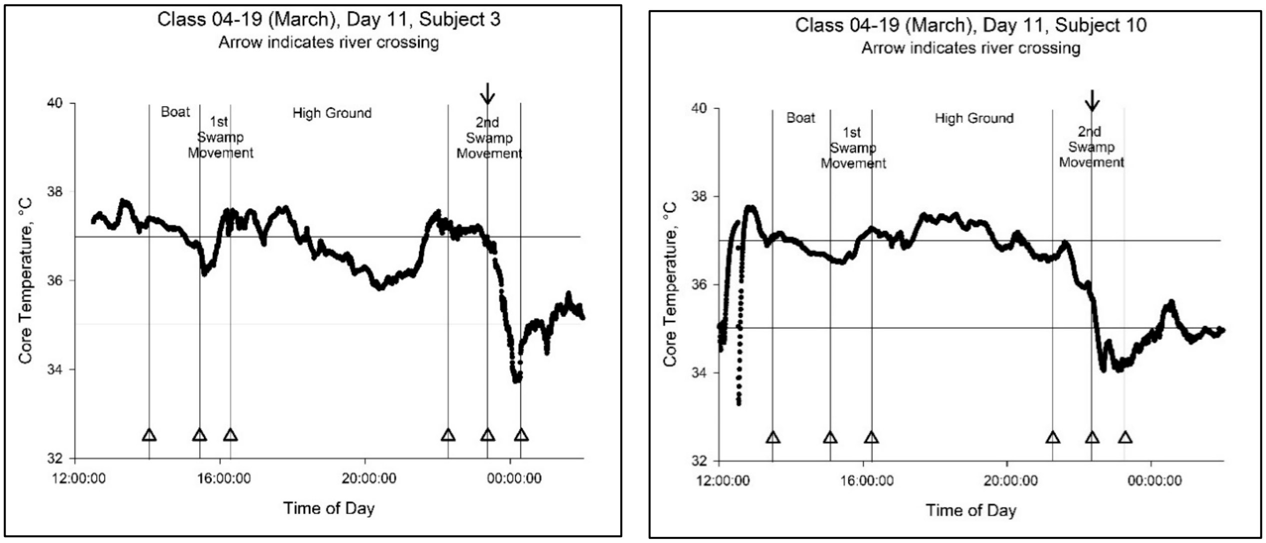
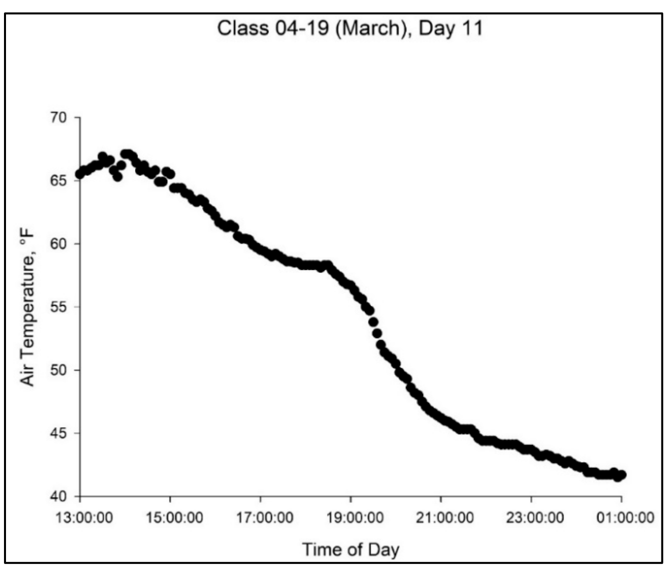


Figure 7 shows the air temperature, which decreased by ~13.9°C (25°F) between the front half swamp movement that had occurred earlier in the day and the second swamp movement with the river crossing in the evening. The dramatic difference between the change in Tc during the first part of the second swamp movement and the change in Tc after the river crossing suggest that the low air temperature combined with wet clothing could be an important factor. The immersion table does not provide adjustments for low Ta. The 17.8°C Tw indicated a time limit of 3.5 hrs, reduced to 2.5 hrs "if raining." The mean duration of this swamp movement was 2:20 hrs

Figure 7. Air temperature during MAR Day 11



Influence of Initial Tc

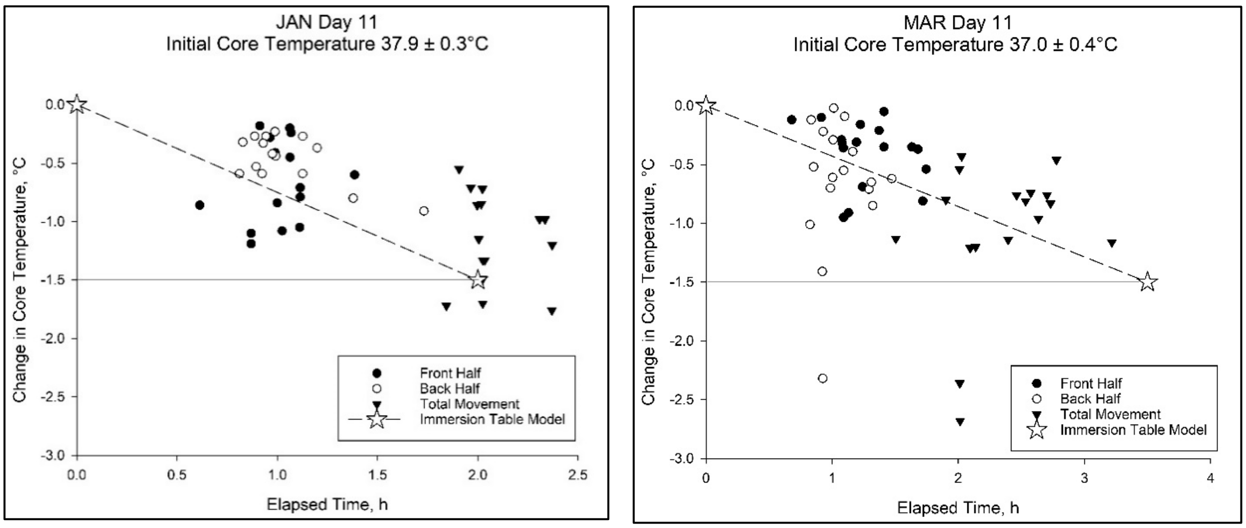
Waterborne movements begin either by preparing boats for launch and paddling to a rally point, or with an approach march to the starting point. Both of these activities raise Tc due to increased metabolic activity. Once swamp movement begins, both the thermoregulatory drive to return body temperature to the neutral zone and a higher gradient for heat loss (higher body heat content relative to the environmental conditions) can contribute to a faster fall in Tc than the model would predict. The model simulations to create the immersion table began at a neutral Tc of 37.0 (98.6°F). This is a typical resting temperature for humans, and temperatures within the range of 36.5 to 37.5°C (97.7 to 99.5°F) would be considered neutral.

Evaluation of the Immersion Table

There were three waterborne movements that were similar to categories of the immersion table for water temperature, depth, and duration. One fell into a single category of the immersion table and was at the limits for depth, temperature, and time. On JAN Day 11, the total swamp movement was 2:04 ± 0:10 hrs for the waist deep immersion at Tw of 12.8°C (55°F), the lowest Tw of the category (55 - 59°F). The Tc at waypoints shown on Figure 3 indicate that Tc remained above the target of 35.5°C for this population, reaching 36.7± 0.6°C (98.1°F ± 1.0°F) at the end of the movement. This suggests that the immersion table limit for this category (2 hrs) may be too conservative, had the exposure been a single continuous swamp movement without added risks such as a river crossing, or static roles during immersion. However, Tc before entering the swamp was elevated (37.9± 0.3°C), and the fall in Tc (-1.2 ± 0.4°C) was similar to the fall in Tc (-1.5°C) predicted by the model which began at a neutral Tc. The change in Tc for JAN Day 11 is presented in Figure 8, Panel A, for each individual during the front half, back half, and total swamp movement, along with the model-predicted change. This suggests the model was not too conservative, although the river crossing and wet clothing likely increased risk relative to a single continuous partial immersion.

The second waterborne movement that could be used to evaluate the immersion table was MAR Day 11 during the second swamp movement. The Tw was 17.8°C (64°F), and reported depths were knee and thigh. This resulted in a time limit of 8 hrs for Knee depth and 3.5 h for Waist depth. Students began the second swamp movement at a neutral Tc (37.0°C) and at the end of the 2:20 ± 0:25 h swamp movement Tc was 35.9 ± 0.7°C, for a fall in Tc of 1.1 ± 0.6°C. Figure 8, Panel B shows the change in Tc for each individual during the front half, back half, and total swamp movement, along with the model-predicted change for Waist depth. The immersion table limit appears to be appropriate, had the movement lasted an additional hour, although it is likely that several individuals would fall below 35.5°C. There are two factors that could influence the rate of heat loss on this occasion. First, it was the second waterborne movement of the day, with the previous one conducted several hours earlier and objectives on high ground conducted in between. Consecutive immersions could increase risk. Second, the immersion table does not consider Ta below Tw, but the fall in Ta during the nighttime swamp movement likely contributed to the rate of heat loss after the river crossing.

Figure 8. Change in Tc is presented for each student during JAN Day 11 (Panel A) and the second swamp movement on MAR Day 11 (Panel B). The model-predicted change is also indicated for reference.



The third waterborne movement that could be used to evaluate the immersion table was JAN Day 13, when Tw was 54-55°F, which is the break point between two categories. Depths encountered were Knee, Thigh, or Waist, depending upon the actual route of each student, again spanning two categories of the immersion table for depth. This resulted in immersion table time limits of 1.5 to 2 hrs for Waist depth, and 5 to 7 hrs for Knee depth. Actual duration was 3:05 ± 0:26 hrs. The Tc at the end of the movement was 36.7 ± 0.5°C. The Tc at the beginning of this movement was elevated (37.3 ± 0.3°C), resulting in a fall in Tc of 0.7 ± 0.6°C. These data suggest that the immersion table would have been conservative if all students had been immersed to the waist; however, within each platoon only some students reported that depth, with the others reporting knee or thigh depth. Given the rate of fall in Tc over 3 hrs, extrapolating the time limit between depths may be appropriate. Whether the reported depth was consistent through the entire swamp movement, vs a brief deeper immersion, is an important factor when evaluating whether to use the time limit of the greater depth or to extrapolate between depths.

Influence of Wet Clothing

One way to assess whether wet clothing contributed to a higher rate of heat loss is to examine the rate of change in Tc before and after a river crossing. There were two instances where the initial Tc was similar both before and after the river crossing.

During FEB Day 13, the fall in Tc was similar between front half and back half, suggesting wet clothing due to the river crossing was not an important contributor to heat loss under those conditions. During MAR Day 13, conditions were similar, but there was a greater fall in Tc after the river crossing. The Tc had increased slightly during the front half movement, and it may be that it was the higher initial Tc at the start of the back half that contributed to the higher rate of fall in Tc, rather than wet clothing. Indeed, the highest rate of heat loss was from the highest initial Tc (JAN Day 11, front half).

In contrast, the second highest rate of heat loss was from the lowest initial Tc (MAR Day 11, second swamp movement, back half). This occurred despite a higher Tw; however, Ta was 5.6°C (42°F). On this movement, most (65%) students had a greater fall in Tc after the river crossing. The only other movement that occurred at a Ta as low as 50°F was JAN Day 11, where heat loss on the back half was at the third highest rate. Table 5 summarizes the change in Tc for each swamp movement.

Table 5. Initial Tc and change in Tc during swamp movements involving a river crossing

Class, Day	Tw	Ta	Initial Tc (°C) Rate of Change (°C/h)	
			Front Half	Back Half
JAN Day 11	12.8°C (55°F)	10°C (50°F)	37.9 -0.65	37.2 -0.45
JAN Day 13	12.2°C (54°F)	14.4°C (58°F)	37.3 -0.19	36.9 -0.26
FEB Day 13	18.9°C (66°F)	14.4°C (58°F)	37.1 -0.09	37.0 -0.09
MAR Day 11	17.8°C (64°F)	5.6°C (42°F)	37.0 -0.32	36.5 -0.61
MAR Day 13	18.3°C (65°F)	15.6°C (60°F)	37.3 +0.1	37.5 -0.32

CONCLUSIONS AND RECOMMENDATIONS

This was the first study to measure Tc of Ranger School students during waterborne movements conducted in winter months. Data were obtained during 3 winter classes, encompassing conditions of Tw between 12.2 and 18.9°C and water depth ranging from Knee to Waist. The combinations represented most categories of the immersion table. Of 57 volunteers who completed waterborne movements, Tc fell below 35°C for four students (7%), all of which occurred after a river crossing, i.e., brief immersion to the neck. On a separate day of techniques training, Tc fell below 35°C for five students (9%) after either the first or second river crossing. Since all cases where Tc fell below 35°C occurred after a river crossing, the brief (<1 min) neck-deep immersion and wet clothing afterwards likely contributed to body heat loss and should be evaluated as additional risk factors.

The water immersion guidance, risk assessment and mitigation measures used by the 6RTB were appropriate for the conditions encountered in this study. There was large variability among individuals for temperature response during waterborne movements, which also is observed during laboratory studies of cold water immersion. While group means may suggest the immersion table limits are conservative, risk assessment needs to consider the more susceptible individuals. No individual whose core temperature fell to 35°C (95°F) was an outlier with respect to anthropometric measurements (e.g., weight, height, body fat). Only one individual had a Tc < 35°C on more than one occasion (MAR Day 4 and Day 11). During Ranger School there may be additional risk factors for rate of body cooling during cold water immersion, including fatigue, sleep deprivation, underfeeding, or negative energy balance. In addition, the particular task of an individual may play a role, such as lifeguards who are static and exposed to longer immersion in moving water during river crossings.

The immersion table is based on a thermal model that calculated change in heat storage from a neutral state, and derived the immersion limit from the elapsed time when Tc reached 35.5°C, a 1.5°C decrease. In general, the immersion table is intended to mitigate hypothermia, i.e., risk of reaching 35.0°C (a 2.0°C decrease in Tc); however, a target Tc of 35.5°C was used when modeling conditions for Ranger School students who are known to have less robust thermoregulatory responses to cold (Young, Castellani et al. 1998). The current study shows that Ranger School students began all swamp movements at an elevated Tc, with the exception of MAR Day 11 on the second swamp movement. For this reason, when evaluating the immersion table, the change in Tc is more appropriate than the Tc at the end of the movement, since it reflects more closely the rate of heat loss under those conditions.

Considerations for applying immersion tables to field conditions

The water immersion table currently presents categories with time limits based on Tw and depth. It assumes individuals are walking while carrying a 35 kg load during a continuous partial immersion while the upper body remained dry. While there is an adjustment in duration “if raining,” rain was assumed to reduce clothing insulation value, but did not account for increased heat loss due to conduction or evaporation related to wet clothing. Since all cases of Tc < 35°C occurred after a river crossing, the impact of these routes of heat loss should be investigated and integrated into future guidance.

Whether an individual is moving or static influences body heat storage and the resulting change in Tc, through the contribution of metabolic heat production. Ranger School students during this study carried a heavier load (~45 kg) than the immersion table assumes, but they were also periodically static. Expanding the immersion table to include static as well as active conditions would improve the application of the guidance to a broader range of scenarios.

The Ta was assumed to be either the same as Tw or neutral (~20°C), which is a typical Ta during laboratory studies against which the models were validated. The data from MAR Day 11 suggest that Ta can be a significant factor for body heat loss when clothing is wet. Currently the model does not consider river crossings which saturate all clothing, but future guidance should consider whether there is a threshold Ta below which wet clothing poses increased risk.

The immersion table was originally developed for Ranger School students who are known to have less robust thermoregulatory responses to cold due to the stressors of the course and the accompanying body composition changes. For other populations the time limits may be conservative; however, Warfighters in field conditions may experience stressors of high physical exertion, negative energy balance, and weight and body fat loss.

Risk Mitigation

The immersion table presents safety limits as a tool for protecting groups of individuals. While group mean ± SD may not suggest a higher risk of hypothermia for a particular condition, individual data must also be considered since individuals vary in physiological responses to, and tolerance of, cold stress. The weak link rule suggests that one hypothermia case is often followed by others. Moreover, a hypothermia casualty increases risk by requiring resources to treat and evacuate. Guidance is intended to protect the most susceptible individuals. Risk mitigation provides measures to minimize the chance of injury and allow successful completion of missions.

Resources for treatment and evacuation may vary in different scenarios. For example, on Day 4, waterborne techniques are conducted in a central area, medical staff are on site, and hypothermia mitigation measures (fires, dry clothing) are available. The format can be adjusted to minimize time spent standing still between crossings, reduce heat loss by donning an outer layer of clothing, or have platoons move over land to the next RX. The activities are conducted during daylight, with students easily able to see each other and to be observed by leadership. Cadre undergo the same exposure, wearing the same clothing and therefore are aware of the thermal stress of the environment. Environmental risk mitigation includes several aspects, including limiting water immersion time; modifying environmental exposure by moving out of the wind and into the sun; limiting further heat loss by changing into dry clothing or donning outerwear to limit evaporative and conductive heat loss related to wet clothing; increasing metabolic heat production upon reaching high ground; and/or using adjuncts, such as warming fires, heat packs, etc.

In contrast, many of these resources are not readily available during the waterborne movements on Days 11 and 13. Nighttime operations reduce the effectiveness of relying on visual assessment of hypothermia. Mitigation may include adjusting time schedules or planning for more conservative time limits. All cases of Tc < 35° in the present study occurred after a river crossing. For roles that require longer immersion in the river, such as lifeguards or rope bridge teams, rotating these roles would reduce risk by limiting the duration for any single individual.

Assessing Water Depth

The immersion table depth measurements are presented as anatomical sites, which should be referenced to anatomical locations on the shortest person. A simpler way to portray these depths would be to use anthropometric data for the 1st and 99th percentiles of landmarks on military personnel (ANSUR database, http://www.openlab.psu.edu/ansur2/) (Gordon, Blackwell et al. 2014). This allows objective measurements to be used to determine which category of the immersion table to use, rather than subjective descriptions. All landmark measurements overlap, with the exception of Knee. It would be reasonable to round up to the next landmark at 50% of the height of the landmark below. For example:

1. Knee: up to 56 cm (22")
2. >56 cm (99th percentile) round up to Crotch
3. >84 cm (33") round up to Waist
4. >104 cm (41") round up to Chest
5. >127 cm (50") round up to Neck

Boat Movement

Boat movements are not represented by the immersion table, since preparation only involves wading into the water to push the boat off shore. Once boat travel begins, any cold stress is primarily due to air temperature, not water immersion. In the present study, Tc remained at or above neutral temperature during boat movements. While boat movement is unlikely to pose a risk for hypothermia, as Ta falls below ~10°C (50°F), vasoconstriction induced by body heat loss reduces blood flow to the extremities. Finger cooling may be associated with discomfort and reduced manual dexterity. This could be mitigated by use of gloves during the boat movement, and by increased physical activity upon reaching land. Paddlers are at less risk due to exercise; gunners and navigators may be at higher risk due to their static positions. Hypothermia is unlikely to occur with air exposure alone. Evidence is provided by the 1996 study where students at the end of Ranger School were exposed to cold 10°C (50°F) air, clothed in only shorts, shoes, and socks, sitting still for up to 4 hrs. Voluntary withdrawal occurred at core temperatures of ~36.0°C (96.8°F) after 2 to 4 hrs.

1) This assumes clothing is dry. Wet clothing would increase heat loss and risk of hypothermia.

2) The primary risk due to boat movement in cold air is extremity cooling. This could result in impaired manual dexterity until students rewarm, such as with physical activity.

3) Individuals who are not paddling (gunner, navigator, RI) may become colder.

Future

Thermal models are increasingly being made more widely available in the form of mobile applications. This allows users to predict time limits for actual conditions, rather than being constrained by the categories on a table. Future developments in the thermal models used for risk assessment during water immersion could eliminate the need to extrapolate between depths or temperatures, and allow Ta to be considered independently of Tw. Research to support these developments include experiments to determine heat loss due to wet clothing during cold air exposure. Metabolic rate is an important input to thermal models due to heat production during physical activity. This is difficult to predict for field conditions that involve moving through water over uneven terrain or muddy ground. Future research should include measurement of metabolic rate during waterborne movements. This would improve model predictions by allowing metabolic rate to more closely match activity level. These developments could greatly enhance the risk assessment conducted by leadership, and reduce risk of hypothermia for Warfighters.

SUMMARY

1. The immersion table in TB MED 508 was developed using certain assumptions in predicting body temperatures during cold water immersion.

   a. The table was developed for men of similar age, nutritional status, weight, and adiposity as the average Ranger student at the end of the course

   b. The level of physical activity was assumed comparable to walking with a 35 kg (77 lb.) load over swampy (uneven) terrain.

   c. A Tc of 35.5°C was used by the model to determine time limits, since Ranger School students are known to have blunted thermoregulatory responses to cold.

   d. The immersion table presents limits for a single continuous immersion.

   e. The upper body was assumed to be dry, except for the “if raining” adjustment.

   f. The air temperature was assumed to be the same as water temperature or neutral (~20°C).

2. Three conditions observed during waterborne movements in Ranger School are not accounted for by the immersion table.

   a. Prolonged static periods

      1) The immersion table was modeled for a metabolic rate estimated to be equivalent to moving slowly though swamp terrain carrying 35 kg. When students are static, such as between the two river crossings on Day 4 or after a river crossing during a swamp movement as students wait for the rest of the unit to cross, the model / table may overestimate Tc since it assumes greater metabolic heat production.

      2) Prolonged static periods, such as waiting for the entire platoon to arrive by boat while the first to arrive are standing in water; awaiting set-up of the rope bridge for river crossing; waiting for the entire platoon to cross a river; and waiting between the two river crossings on Day 4 (techniques). Metabolic rate and therefore heat production is considerably lower when individuals are static vs active.

      3) Note that measurements in the current study (Table 2 on page 5) indicated an average skin-out carried load of about 45 kg.

   b. River crossings and wet clothing afterwards

1) Although the duration of a river crossing is short (< 1 min), clothing over the entire body becomes wet. Beyond the "if raining" reduction in insulation mentioned above, conductive heat transfer to wet clothing, evaporative heat loss from wet clothing, and heat loss due to wet skin could all increase above the calculations for dry clothing.

2) Prolonged standing in water with a current, such as a lifeguard for a river crossing, could increase heat loss during to longer duration of immersion and higher rate of heat loss to moving water.

3) Lower air temperature than water temperature. Below about 10°C (50°F), wet clothing, such as after a river crossing, may increase risk due to greater conductive and evaporative cooling.

4) The mean measured load carried was 45 kg (99 lbs), which would increase metabolic rate.

5) The limited duration for the condition "if raining" should be considered as part of risk assessment. This condition was modeled with degraded clothing insulation and wet skin.

6) Depending on Ta, wet clothing could increase rate of heat loss through conductive heat transfer from skin to wet clothing, and evaporative heat loss from wet skin and from wet clothing.

c. Air temperature lower than water temperature.

1) While cold air exposure alone is unlikely to be a concern for hypothermia, cold air when clothing is wet may pose greater risk.

2) Ranger School guidance specifies "air or water" temperature for risk assessments of waterborne movements. Heat loss to water is much greater than heat loss to air. While this approach provides additional safety when cold air could increase heat loss, such as when clothing is wet after river crossings, it would be unnecessarily conservative when clothing is dry. Future research to identify air temperature thresholds for increased heat loss due to wet clothing will improve guidance under conditions when air temperature is lower than water temperature.

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