Health and Performance Modeling for Tactical Insights: Case of the "Frozen Russian Soldiers" in Ukraine

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ABSTRACT

Biomathematical models to quantitatively describe human thermoregulatory and physiological responses have long been used to provide valuable information for mitigation of environmental stress injuries (e.g., hyper-, hypothermia, dehydration), mission planning, or analyzing post-event occurrences. However, these same methods and principles can be applied from a tactical perspective to provide strategically valuable insights of opponent status. This paper describes an outline to this approach using open-source information to assess health status with near-real time data. Specifically, this paper describes modeling and analyses used to quantify potential cold-related injuries to Russian forces in a convoy within Ukraine. In early March of 2022, media outlets began reporting that Russian soldiers in a stalled convoy were at serious risk of hypothermia and predicted these soldiers would face 'freezing to death' or would surrender within days. Using existing health and performance modeling, clothing data, and open-source intelligence, modeling and analyses were conducted within hours to quantitatively assess the conditions and provide scientifically-derived predictions. These predictions projected a significant increase in risks of frostbite for exposed skin as well as to toes and feet, with a very low (negligible) risk of hypothermia. Days following this modeling, media outlets confirmed these modeling predictions, reporting a steep rise in frostbite injuries to the feet of Russian forces. This example demonstrates what can be done today with existing mathematical physiology and how traditionally health-focused models can be used for tactical intelligence.

1.0 BACKGROUND

Mathematical models and artificial intelligence (AI)-based computational methods for predicting human thermal responses are generally used for preventing cold stress injuries [1], [2]. Computational models to account for human physiological and thermoregulatory responses along with data on the biophysical properties of clothing can be used to quantitatively model responses [1], [2], [3], [4], [5], [6], [7]. However, in contrast to their traditional use, these thermal modeling methods can be leveraged for providing tactical insights into the health status of opposition forces.

2.0 METHODS

At a minimum, modeling human responses requires inputs from four elements: 1) Environmental conditions, 2) The human, 3) Their activity level, and 4) Clothing properties. For this analysis, we have used USARIEM's existing thermal models [3], [4], [5], along with open-source estimates of the environmental conditions, made some assumptions regarding the 'typical' Russian soldier and their activity, and based on some observations used comparable clothing values to make predictions.

2.1 Modeling Cold Responses

2.1.1 Environmental Conditions

Current open-source weather forecasts were used to project conditions for the next 10 days in Kyiv, Ukraine; where estimates range for air temperature (Ta) are low of -8°C and highest of 8°C, relative humidity (RH) from 48 – 78%, and wind velocity 10 – 19 km/h (Weather.com). Our analyses showed a range of best and worst conditions (where 'best' is considered they are most stressed, and 'worst' is less stressful and likely uninjured).

2.1.2 Clothing Biophysics

Based on observational assessments of Russian cold weather clothing, there are some clothing properties with likely comparable values that can be used to make estimates [6], [7]. If the Russian military were using their complete (8 layer) cold weather clothing system (Figure 1; [8]), they would be fairly well protected from extreme cold exposure. Elements of most importance would be focused on extremities (hands, feet) and areas of soft tissue (e.g., cheeks). The element less known, and more important in these analyses are gloves and boots. From internet obtained images (Figure 2; [9]), it appears that the Russian military may be using these clothing systems to some extent, but not likely the complete sets (specifically using light gloves vs. cold weather mittens; while the boots from images seem to be light weight (not extreme cold weather boots). Public media also reported that Russian soldiers were trying to obtain Ukrainian military boots to replace their own inferior boots.

Figure 1: Russian military eight-layer extreme cold weather clothing system [8].

Figure 2: Internet-obtained images of Russian military wearing versions of cold weather clothing system [9].

2.1.3 Human Inputs

Simple assumptions can be made of the 'typical' Russian soldier. While information regarding the impact of additional potential physiological stressors (e.g., undernourished, dehydrated, sleep deprived) can be made based, the current analysis considers the 'simulated individual' is a healthy young male. Though it is important to note that these added stressors can have a significant impact on the thermoregulatory effectiveness as well as the added potential for fatigue.

2.1.4 Activity Level

Based on this analysis, the activity rate was considered as low (representative of sitting in a vehicle) (~116 W) [10], [11], [12], [13]. It is important to note that with the restricted ability for movement (e.g., in a vehicle such as a tank), the ability to maintain body heat (i.e., metabolic heat production) is significantly reduced.

3.0 RESULTS

3.1 In Vehicle

Modeled conditions were conducted for four scenarios with individuals resting/sitting in vehicle (116 W), in two air temperature conditions (Ta -8 and -20°C), with low wind penetration (60%RH and 1 km/hr wind velocity), and with both high and low hand and foot protection (Figure 3 and Figure 4).

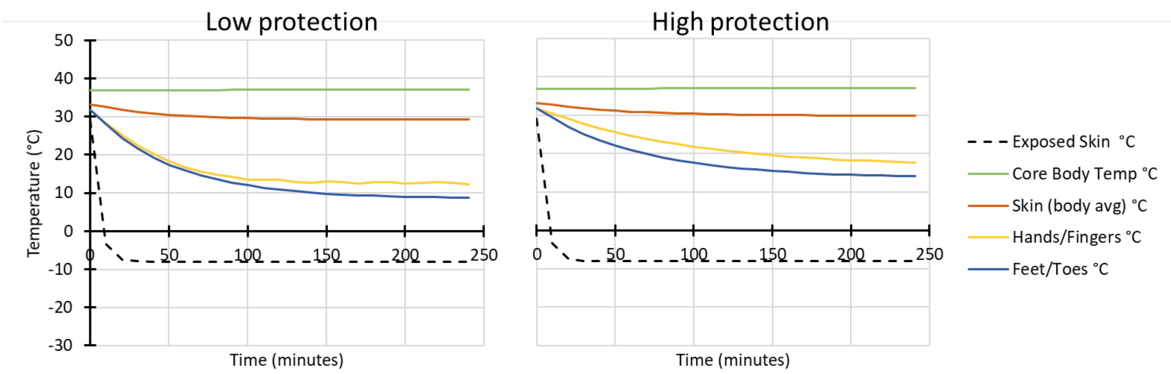

Figure 3: Modeled response for in vehicle: Ta -8°C, 60% RH, 1 km/hr wind velocity, while wearing low (left) and high (right) extremity protection (low protection included light gloves and all-weather boots (similar to Army light leather glove and temperate weather combat boots; high protection included mittens and cold weather boots similar to Army mittens and VB boots).

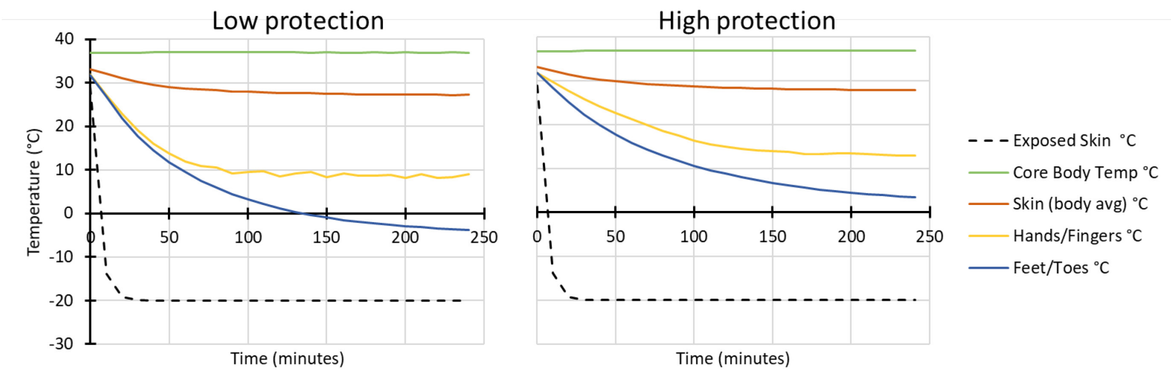

Figure 4: Modeled response for in vehicle: Ta -20°C, 60% RH, 1 km/hr wind velocity, while wearing low (left) and high (right) extremity protection (low protection included light gloves and all-weather boots (similar to Army light leather glove and temperate weather combat boots; high protection included mittens and cold weather boots similar to Army mittens and VB boots).

3.2 Outside Vehicle

Modeling was also conducted for six conditions outside at low work rate (137W), in three air temperature conditions (Ta 5, -8, and -20°C), with exposure to wind (60%RH and 17 km/hr wind velocity); and both low and high hand and foot protection (Figure 5, Figure 6, Figure 7).

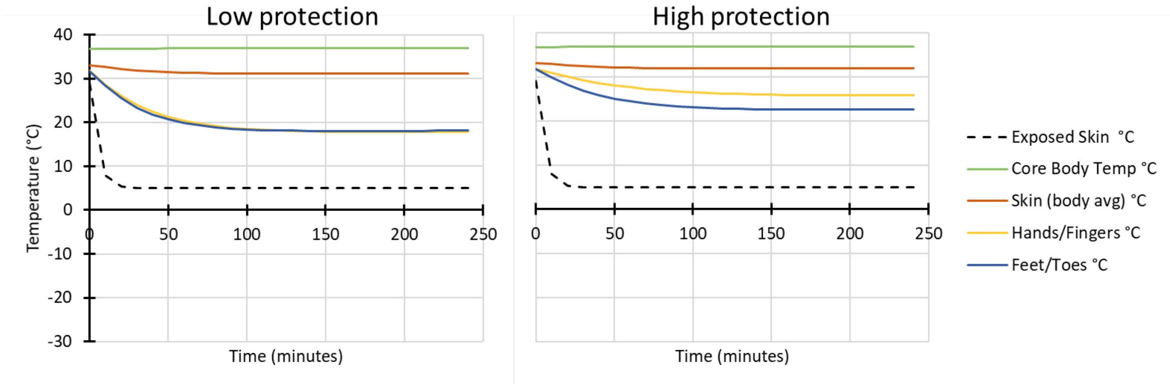

Figure 5: Modeled response for outside: Ta 5°C, 60% RH, 17 km/hr wind velocity, while wearing low (left) and high (right) extremity protection (low protection included light gloves and all-weather boots (similar to Army light leather glove and temperate weather combat boots; high protection included mittens and cold weather boots similar to Army mittens and VB boots).

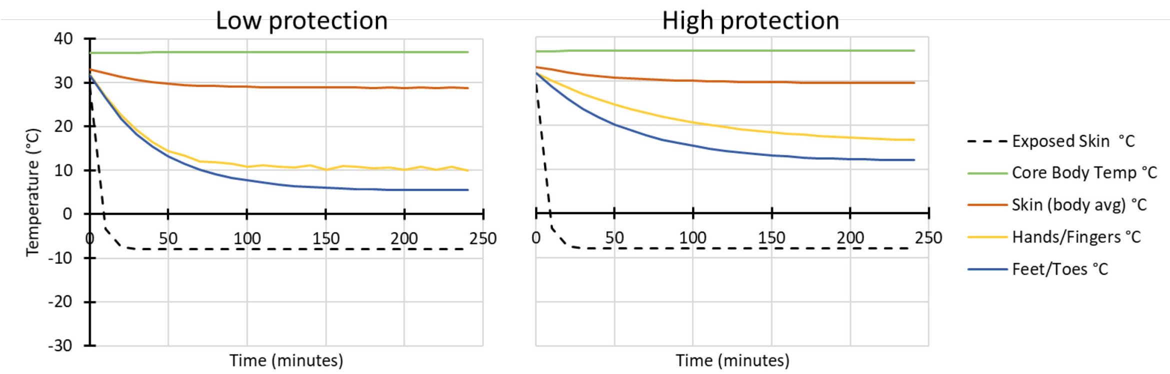

Figure 6: Modeled response for outside: Ta -8°C, 60% RH, 17 km/hr wind velocity, while wearing low (left) and high (right) extremity protection (low protection included light gloves and all-weather boots (similar to Army light leather glove and temperate weather combat boots; high protection included mittens and cold weather boots similar to Army mittens and VB boots).

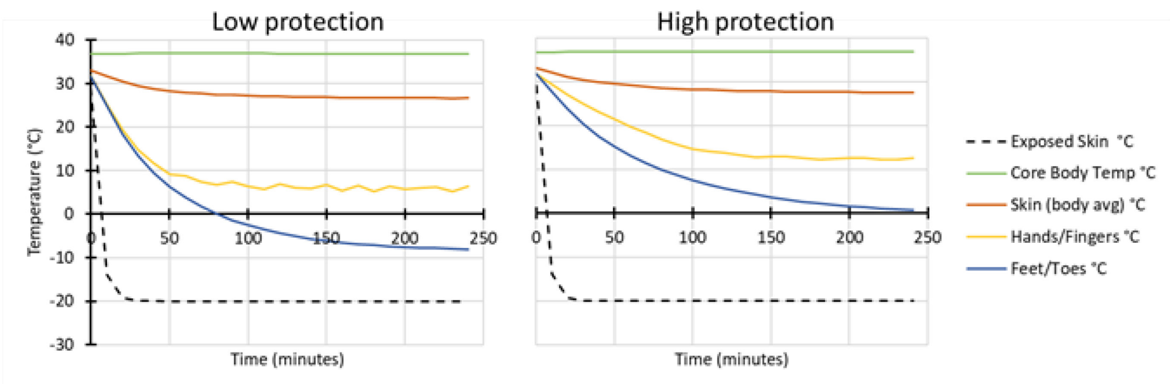

Figure 7: Modeled response for outside: Ta -20°C, 60% RH, 17 km/hr wind velocity, while wearing low (left) and high (right) extremity protection (low protection included light gloves and all-weather boots (similar to Army light leather glove and temperate weather combat boots; high protection included mittens and cold weather boots similar to Army mittens and VB boots).

3.3 Threshold Points

Determining threshold points for the onset of cold related injuries is complicated due to individual variability in responses to cold and the complexity of conditions in which they occur [2], [14]. Cold responses have higher individual variability when compared to those seen in heat-related injuries. Frostbite injuries occur when skin tissue begins to freeze. Traditionally 0°C is considered the freezing point of water, while the freezing point of skin is generally understood to be marginally lower due to things such as electrolyte levels within the tissue [14]. Additionally, observed freezing points have been seen as high as -0.6°C and as low as -4.8°C [14], [15]. Hypothermia includes a broad category of cold injuries clinically described as the point at which core body temperature drops below ~35°C [16].

From a modeling and simulation perspective, thresholds have been set for loss of dexterity at ~8°C, onset of pain to begin at ~5°C, and frostbite (<1°C) [2], [14]. Table 1 and Table 2 show the predicted times to reach general skin temperatures thresholds both within the vehicle (Table 1) and outside (Table 2).

Table 1 shows that individuals remaining in the vehicles in these conditions are at risk of frostbite to exposed skin in both the -8 and -20°C conditions (within 10 minutes of exposure). While in the -8°C conditions individuals are at low risk of dexterity loss, pain, or frostbite of any covered extremities with both low and higher thermal protective clothing (gloves and boots) (>250 minutes).

In the vehicle at -20°C conditions in the lower thermal protection settings, individuals are at increased risk of numbness (~65 minutes) and the onset of pain (~130 minutes) for feet and toes, and increased risk of loss of dexterity of the hands and fingers (~205 minutes). In these same conditions with higher insulation protection, individuals were still predicted to be at an increased risk of numbness (~130 minutes) and onset of pain (~185 minutes) for the feet and toes.

Table 1: Predicted times to reach thresholds within 250 minutes of exposure while in the vehicle.

Temperature (Ta)	Condition	Body Part	Numbness / Dexterity loss (8°C)	Pain (5°C)	Frostbite (<1°C)
-8°C	Low protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	N/A	N/A	N/A
	High protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	N/A	N/A	N/A
-20°C	Low protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	205 min	N/A	N/A
		Feet/Toes	65 min	130 min	N/A
	High protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	130 min	185 min	N/A

Table 2 shows that individuals outside in 5°C conditions are at low risk of frostbite to covered areas and even for exposed skin (>250 minutes). However, there is a risk of numbness to exposed skin in both low and high total body thermal protection (<10 minutes) and an increased risk of an onset of pain for both low (<10 minutes) and high thermal protection (~40 minutes). There is an increased risk of numbness, pain, and frostbite to exposed skin in both the -8 and -20°C conditions (all within 10 minutes of exposure).

While outside at -8°C, individuals are at an increased risk of numbness to the feet and toes (~95 minutes) in the lower thermal protection condition; otherwise, there is low risk of numbness, dexterity loss, pain, or-frostbite with both low and higher thermal protective clothing (gloves and boots) (>250 minutes).

Exposed to the -20°C conditions individuals are at risk of numbness, onset of pain, and frostbite of the feet and toes in both low (~45, ~55, and ~75 minutes) and higher (~95, ~130, and ~220 minutes) thermal clothing conditions. While there is still an increased risk of loss of dexterity to the hands (~65 minutes) in the low thermal conditions.

Table 2: Predicted times to reach thresholds within 250 minutes of exposure while outside.

Temperature (Ta)	Condition	Body Part	Numbness / Dexterity loss (8°C)	Pain (5°C)	Frostbite (<1°C)
5°C	Low protection	Exposed skin	<10 min	<10 min	N/A
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	N/A	N/A	N/A
	High protection	Exposed skin	<10 min	40 min	N/A
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	N/A	N/A	N/A
-8°C	Low protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	95 min	N/A	N/A
	High protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	N/A	N/A	N/A
-20°C	Low protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	65 min	N/A	N/A
		Feet/Toes	45 min	55 min	75 min
	High protection	Exposed skin	<10 min	<10 min	<10 min
		Hands/Fingers	N/A	N/A	N/A
		Feet/Toes	95 min	130 min	220 min

4.0 DISCUSSION

4.1 Predictions Based on Available Data

We made predictions about cold injury risks to Russian soldiers in their current situation as described by media sources, and on the basis of what we could establish regarding the environmental conditions, the soldiers, their activity levels, and their clothing. For this analysis, we used USARIEM's existing thermal models, along with open-source estimates of the environmental conditions, made assumptions regarding the 'typical' Russian soldier and their activity, and based on some observations used comparable clothing values to make predictions. Based on these best estimates, the soldiers in this convoy were not likely to become hypothermia casualties but were likely to suffer freezing cold injuries to their feet or any exposed skin (e.g., face), especially if temperatures dipped as low as the forecast of -20°C. After the fact, the temperature did not dip that low.

4.2 Limitations of the Current Computational Methods and Shift Towards Artificial Intelligence (AI)

Better predictions could be made if the available artificial intelligence (AI) tools were expanded with new data and rationally based algorithms. In this respect, high priorities would be to quantify the effects of fatigue and chronic underfeeding on cold response, established qualitatively by USARIEM in a series of studies with Winter Ranger students following four 1994 hypothermia deaths in training at Fort Benning, and to include cold-wet effects [17]. Another priority would be to expand the clothing biophysics database with characteristics of Russian (and/or other peer- or near-peer) military uniforms.

4.3 General Observations on the Value of this Predictive AI Capability

The AI-based physiological prediction demonstrates what can be done today with existing mathematical physiology. These AI-prediction capabilities compress the information response timeline from weeks to hours. This capability is based on 70 years of Army efforts to systematically expand environmental physiological predictions. Initially, this required urgent seat-of-the-pants human studies. When the Army wanted to send heat acclimated soldiers from Fort Knox into the Aleutian Islands in 1943, the Armored Medical Research Laboratory (AMRL) was asked to provide clothing requirement predictions [18]. Uniformed physiologists rushed to conduct experiments with two soldiers in various clothing sets walking on treadmills in a cold room to develop clothing guidance within a few weeks and they provided best available advice with limited understanding of the variability and other factors. Similar human studies produced data for design guidance for cooling and ventilation requirements in the Sherman tank. However, these early data formed the start of mathematical physiology that continues at USARIEM today to provide ever improving predictions of soldier health and performance outcomes in extreme conditions, using AI tools that can predict complex physiological interactions in minutes-hours.

Disclaimer

5.0 REFERENCES

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