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INTEGRATING COLD WEATHER IMPACTS ON HUMAN PERFORMANCE INTO ARMY M&S APPLICATIONS

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ABSTRACT

Exposure to cold weather has deleterious effects on the performance of soldiers. Gross and fine motor skills as well as cognitive ability are all diminished by exposure to low ambient temperatures. Clothing and equipment that protect the solider from cold also encumber the soldier's movement and dexterity. Therefore, while the solider is protected from the cold, his or her performance is reduced in terms of both time to perform a given task and accuracy. Food and water consumption are also greatly increased by exposure to the cold. For Army simulations to accurately represent missions that occur in cold weather, these impacts must be accounted for, yet they seldom have been. This paper will briefly review the physiological mechanisms for degraded performance in the cold. A sample of the data available in the literature on cold weather impacts on humans will also be presented. Finally we suggest how these impacts might be incorporated in military models and simulations.

1 INTRODUCTION

In winter warfare the cold has often been responsible for greater losses than those inflicted by the enemy. History provides many examples where forces superior in training and numbers were unsuccessful in winter attacks. In 1812 Napoleon led the premier army of its time into Russia, a force superior to his opponent's. He lost half of his 680,000-man army, with more than two thirds of his losses to cold, combined with the hunger, exhaustion, and disease that often accompany cold exposure (Yeshnik 1988). Napoleon's failure to achieve his objective was arguably due to his failure as a commander (Swinzow 1993); however, clearly his losses were increased by his unprepared withdrawal in winter.

Other famous examples of winter warfare include the Russo-Finnish War of 1939, the Russians forces suffering heavy losses against the lesser-numbering but superior winter warriors and winter warfare tactics of the Finns. In this case the Russians learned, at great costs, valuable winter warfare techniques that they used against the German invasion in the winter of 1941-1942 (Swinzow 1993). The message from these historical examples is clear: those best prepared for the cold will win in winter battle, all else equal. Those who are unprepared will suffer major losses from the cold itself, let alone those inflicted by the enemy.

It can be argued that the winter warfare lessons from history are irrelevant in the technological battlefield of today. The historical difficulties presented by the cold may be of less significance, but the cold will present new impediments as well. Ultimately, the effects of the cold can not be ignored as long as humans, and to a lesser degree mechanical equipment, are exposed to the weather. In fact, the current vision for the Army of the future calls for a lighter, faster responding, and more flexible "Objective Force" that will be supported by a war fighting system called the Future Combat System (FCS). The FCS will rely less on the heavy armor of the current tanks, survivability will be derived from the "see first, shoot first" premise. Central to the success of these concepts is the dismounted infantry soldier, who will remain the most intelligent agent in the FCS. Thus, knowing and recognizing the limits of the soldier in his/her environment is essential.

DoD relies heavily on Models and Simulations (M&S) in order to reduce costs and also provide a superior force. Before the design of a new weapon system is contemplated, concepts are evaluated using M&S applications. Once a decision has been made in concept, specifics are determined again with heavy reliance on M&S. M&S applications are used extensively, almost exclusively in limited cases, in training. And ultimately M&S applications will be carried into battle. Currently most Army M&S applications ignore cold weather impacts on the soldier. Clearly, realistic outcomes in cold cannot be expected when its significant effects are ignored. In recognition of this, our laboratory has initiated a modest effort to synthesize what is known about the impacts of the cold on humans into a form suitable for inclusion in Army M&S applications. This paper covers some of our initial efforts, first presenting a brief review the physiological mechanisms for degraded performance in the cold. Examples of the data available in the literature on cold weather impacts on humans will also be presented. Finally, we suggest how these impacts might be incorporated in military M&S applications.

2 PHYSIOLOGICAL IMPACTS OF COLD ON HUMANS

The following is not intended to be a thorough or complete treatment of the physiological impacts of cold exposure on the human body. There are several references that the reader may refer to for a complete treatment (i.e. Marriott and Carlson 1996). The purpose of our brief review here is to lay a foundation of understanding of the mechanisms that precipitate the impacts.

2.1 The Body's Response to Cold Exposure

The initial response of the body to cold is to preserve heat by reducing heat loss. By reducing the skin temperature, the potential for heat transfer is corresponding reduced. To reduce skin temperature, the blood supply to the skin and extremities is reduced by vasoconstriction. With continued exposure to cold this mechanism is partially offset by subsequent vasodilation as the body's protective mechanism against cold injury, i.e. frostbite. With prolonged cold exposure these two mechanisms fall into an alternating rhythmic pattern and the skin temperature oscillates (Marriott and Carlson 1996). Vasoconstriction reduces the sensitivity of touch in the hand, as will be discussed later, as well as increasing blood pressure.

To cope with increased heat losses the body also increases its metabolic heat production rate. The increase in appetite that accompanies cold exposure results in increased metabolic heat output from digestion. However, these increases are modest. Involuntary shivering can increase metabolic heat rate by as much as four times the normal resting basal rate. Beyond that, voluntary exercise can increase heat production at maximum by four or more times the maximum shivering rate (Marriott and Carlson, 1996).

Dehydration is another significant problem resulting from extended cold exposure. There are three principal mechanisms responsible for dehydration with cold exposure. The first is cold-induced diuresis (CID). CID has been well documented in many research studies. There is not complete agreement on the cause or causes; however, many feel that elevated blood pressure is largely responsible (Freund and Sawka 1994).

The second principal mechanism of dehydration in cold is increased respiratory water losses. Cold air has little capacity for water vapor and frequently is at very low humidity levels in subfreezing temperatures. When cold air is drawn into the body, it is warmed and its capacity to hold moisture is greatly increased. In becomes, in essence, saturated with moisture in the body, and this moisture is carried from the body upon exhaling and drawing in more dry air. Not only is respiration a significant source of water loss in the cold, it's also a significant source of heat loss, as the air being exhaled carries with it both latent and sensible heat from the body.

The remaining principal source of water loss from the body is through sweating. Sweating is controllable if clothing can be ideally matched to ambient temperature. However, the widely varying rates of metabolic heat generation resulting from varying amounts of activity as noted earlier, make it very difficult to maintain an appropriate clothing match under all ambient conditions and activity levels encountered. Sweating cannot only be a significant source of moisture loss in cold, if the moisture is allowed to become trapped in clothing, the insulating value of the clothing can be drastically reduced, resulting in increased potential for cold injuries.

It should also be noted that decreased intake of fluids often accompanies the increased loss of water experienced with cold exposure. Both the difficulty in obtaining and maintaining unfrozen sources of fluids and a loss of thirst can be responsible for decreased fluid intake.

2.2 Performance Impacts

The performance impacts of physiological effects discussed above can be divided into three categories: physical impacts, cognitive impacts, and emotional impacts. Physical impacts include diminished dexterity, strength, endurance, and maximum ability to perform work. Dexterity losses, for example, result from reduced sensitivity in the extremities, due to vasoconstriction, as well as stiffening of the joints and muscle strength loss. Losses in dexterity have been documented in a number of studies largely using standardized tests. The results of one effort that looked at performance for multiple finger skin surface temperature was presented by Yeshnik (1988). The data from this study has been reproduced in Figure 1 below. Performance at three different tasks was investigated in this study. The tasks had varying degrees of strength and dexterity requirements. The hand dynamometer required the most strength and endurance, while the "large nut" assemble task required more dexterity than the hand dynamometer but less dexterity than the "fine screw" assemble task.

The results show that the performance impacts are greater for the tasks requiring more dexterity as opposed to strength, but in all cases the performance degradation is very significant. When hand skin temperature is reduced from 77.5 °F to 49 °F, task efficiency drops about 35% for the task requiring the least dexterity and the most strength. For the task requiring the most dexterity and the least strength, the task efficiency drops by about 60% under the same circumstances.

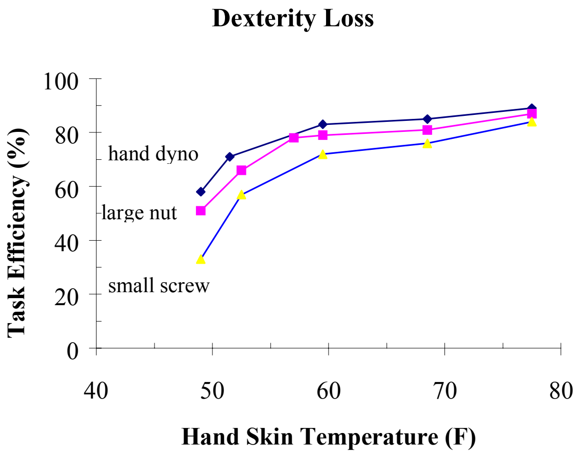

Figure 1: Dexterity versus Skin Temperature

Impacts on cognitive performance have not been studied as extensively as dexterity impacts. The mechanisms causing reduced cognitive performance are also not as well understood. It is believed that both lower body core temperature and dehydration contribute to reduced cognitive capacity. Vaughan and Strauss (1975) conducted a study of diver performance after 3 hours of exposure to 60 °F (15.5 °C) and 40 °F (4.5 °C) water. They attempted to correlate diver performance with a measure of body heat content; however, their results where inconclusive in that regard. Their results do demonstrate performance decrements when comparing the cold water exposure to the warmer water exposure; Figure 2 is based on these results. The results of Vaughan and Strauss (1975) show substantial performance degradation for the colder water exposure condition. While time to complete simple arithmetic computations was not increased, accuracy fell off by about 11%. For navigation problem solving accuracy was similarly affected with a decrement of approximately 9%. For the vigilance monitoring task of target detection, only a slight decrease (3%) in the number of targets detected was observed, yet the mean latency time until detection increased by approximately 26%. Taken in total these tests indicate significant cognitive performance degradation from this level of cold exposure.

The emotional impacts of cold exposure are more difficult to quantify, yet they have been reported by many observers of winter warfare and other forms of cold exposure. Again the mechanism of dehydration has been postulated as a cause (Marriott and Carlson 1996). Reported emotional impacts include reduced discipline, loss of vigilance, loss of appetite, and changes in disposition. Any of these impacts can be absolutely devastating to an army's performance, even in the complete absence of the other more discernable performance degradations discussed above.

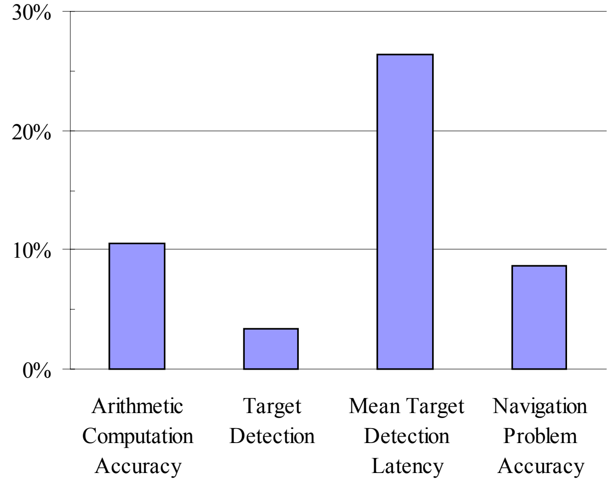

Figure 2: Cognitive Performance Loss in Divers Exposed to 40 °F Water for 3 Hours Versus 60 °F Water

3 INCORPORATING HUMAN PERFORMANCE IMPACTS INTO M&S APPLICATIONS

Assuming that sufficiently creditable data on cold weather impacts on human performance can be found, incorporation of impacts into M&S applications requires a number of other issues to be addressed. First consider that the impacts would need to be quantifiable based on the environmental conditions available from the M&S applications, for example air temperature, humidity, and precipitation. However, most existing performance data are based on parameters like skin temperature or body core temperature. Heat transfer models of the human body, of which a number exist (e.g. Lacombe and Peck 2000), could in theory be used to bridge this gap.

A second difficulty in incorporating human performance factors into M&S applications is relating performance degradation from the specific tasks used to develop the performance data to the many varied and complicated tasks that must be addressed in an Army simulation. Methods that address this issue by breaking large tasks down into smaller tasks and ultimately into some fundamental task set have been applied to M&S applications already, i.e. the IMPRINT model of Allender et al. (1997). In the implementation used by IMPRINT, the most elemental tasks are ultimately decomposed into "taxons," which represent the fundamental human sensory, cognitive, and motor skills. The weights of the various (nine) taxons can be assigned for each task. For example, the task of acquiring a target might consist predominately

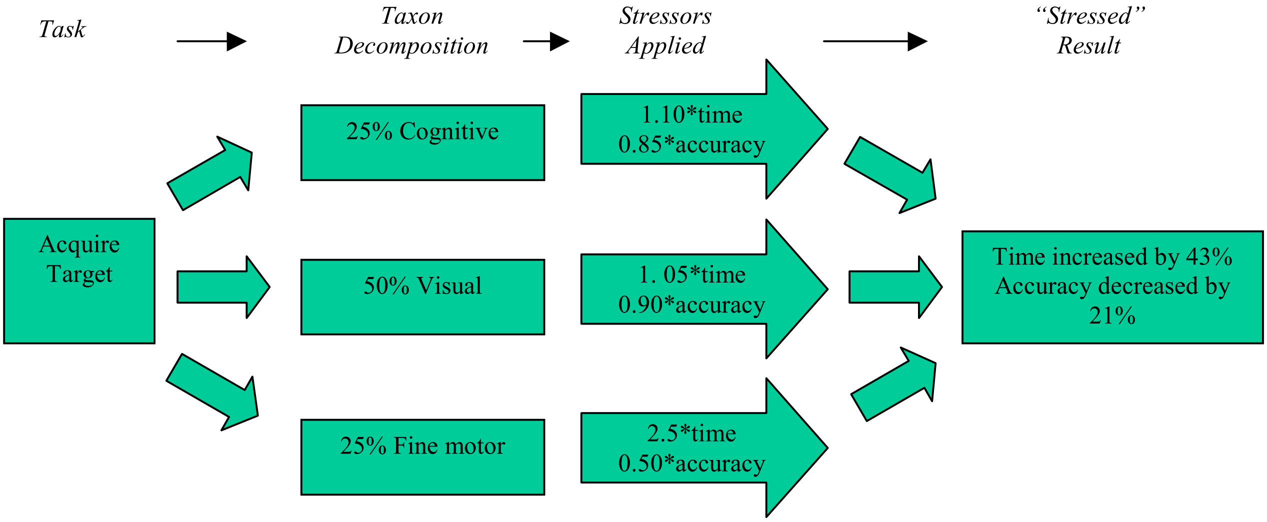

Figure 3: A Fictitious Example of Taxon/Stressor Method

of the visual and/or auditory taxons. The impact of "stressors" can be assigned a time or accuracy performance degradation factor against the taxons. Figure 3 provides a simple example using purely arbitrary stressors and task decomposition. Using the approach of Allender et al. (1997) requires that cold weather stressors be determined for all applicable taxons. These should be a function of the environmental conditions, i. e. temperature, wind, humidity. Both time and accuracy stressors should be allowed, as is the case of the formulation as implemented in IMPRINT. Yet another important factor that must be considered with respect to cold weather exposure is an energy level indicator for the body, as nutritional requirements are significantly increased by cold weather operations.

4 CONCLUSIONS

Clearly, cold weather can have serious impacts on humans exposed to it. For M&S applications to be realistic and have realistic outcomes, these impacts must be included when cold weather operations are being simulated. While some quantitative data exist on impacts to humans exposed to cold, little presents itself in a form useful for M&S applications. From our initial survey of the literature we conclude that sufficient data are perhaps available for at least a "first generation" compilation of stressors to be developed. Significant analysis and a substantial degree of interpretation of the existing data will be required to reach useful results.

Once impacts are known, then the significant undertaking of applying them rationally to the tasks of interest to military M&S applications remains. The taxon/stressor method used by IMPRINT (Allender et al. 1997) appears to be very general and would allow for maximum flexibility as well as rigor in addressing performance impacts. Any model that uses a workload and performance management scheme similar to IMPRINT will require such a decomposition of tasks. Thus, there should be sufficient need, outside of assessing cold weather impacts, to ensure the availability of task decompositions. For this reason it seems prudent that efforts be directed towards that approach.

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