

Costs and Benefits of Training to Prevent Heat and Cold Injuries

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ABSTRACT

Preparation for deployment in hot or cold climates often involves training or acclimation in order to perform adequately in theater. The cost-benefit analysis of such preparation is rarely performed. Therefore, we compared heat acclimatization (in a natural environment) and heat acclimation (in climatic chambers) with no preparation for deployment in the heat using a simple model. For cold deployment, we compared a short training program and a selection procedure based on cold injury susceptibility with no preparation. The results showed that investment in an eight-day heat acclimatization program only becomes cost effective when the temperature in theater is rather high (>38°C for the chosen parameters). The benefits of training for operations in the cold and selection based on cold injury susceptibility generally outweigh the costs. Although the model is a simplification of reality, it may be a useful tool to assess the impact of measures to enhance operational effectiveness in heat and cold.

1.0 INTRODUCTION

The costs and benefits of training for deployment in hot or cold climates are not well documented. At the same time, heat and cold injuries continue to affect overseas deployment of armed forces despite concern about temperature-related effects. In this paper, we apply a cost-benefit approach to possible preparations for dealing with heat and cold strain. We perform an initial analysis that may serve as a guideline for military staff to support decisions on training programs.

Cost-benefit analysis (CBA) documents both the costs and effects of policy initiatives or collective action. The main advantage of CBA is its comparability: costs and benefits are expressed in monetary terms. Moreover, guidelines exist both at national and European levels which enable comparison of multiple CBA analyses. However, CBA suffers from a number of drawbacks, notably that not all effects of a policy can easily be expressed in monetary terms. One of these is the benefit of avoided injury. Because of its advanced level of standardization, we follow the Dutch national CBA guideline (Eijgenraam et al., 2000). To be sure, many other approaches exist, such as the European standard (European Commission, 2008).

The analysis is twofold: one related to heat stress and one to cold stress. It is well documented that heat acclimatization (in a natural environment) or heat acclimation (in an artificial environment) lead to physiological adaptations that reduce heat strain (Taylor & Cotter, 2006); the benefit of cold acclimation, meanwhile, is very limited in magnitude (Savourey, 1996). However, thermal behavior can be optimized for both heat and cold by transferring the appropriate knowledge to the military. For instance, preparation for military deployment to cold areas may comprise calculating the necessary clothing insulation to stay in thermal equilibrium (ISO 11079, 2007). In addition, it has been documented that exclusion of a limited subset of vulnerable soldiers from operations in the cold may lead to a reduction in cold injuries (Daanen & Van Der Struijs, 2005).

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Our cost–benefit analysis compares the hypothetical deployment of forces in hot and cold areas with and without any prior action. We compare projected costs and benefits of acclimatization (in a natural environment) and acclimation (in climatic chambers) to reference alternatives. The same analysis is performed for a situation with and without preparation for cold operations, using current knowledge in training programs and a situation with and without selection of vulnerable subjects for cold operation. Selection procedures for deployment in the heat are still controversial and, therefore, are not included in the analysis. The model was constructed in Microsoft Excel with the following independent variables: number of soldiers and trainers involved, salary of soldiers and trainers (in Euros), added value for a soldier (multiplication factor for salary to estimate the operational value), preparation duration (days), duration to full acclimation (days), duration of operation (days), ambient conditions (temperature in °C, relative humidity in % and wind speed in km/hr). The dependent variables are the costs and benefits expressed in Euros.

2.0 METHODS

2.1 Alternatives

All alternatives center on sending 800 military employees to areas with unfamiliar temperature circumstances for 120 days. Six alternative ways of dealing with extreme temperatures were modeled and assessed: no preparation for heat (NH), heat acclimatization (HA), heat acclimation (HAc), no preparation for cold (NC), cold training (CT), and cold selection (CS). The alternatives NH and NC can be described as reference alternatives: the simplest way of achieving stated policy intentions. The alternatives HA, HAc, CT, and CS are project alternatives: alternatives which involve strategic action at certain costs, directed at achieving societal benefits. Costs and benefits were calculated as differences from the reference alternatives. A limited set-up of the projects was chosen, assessing only a single preparation effort without aggregation of project years.

The HA alternative entails preparing the involved soldiers in a warm environment for eight consecutive days supervised by trainers (one trainer per 20 soldiers), assuming their bodies will adapt to warm circumstances, thereby fostering productivity and decreasing the share of injury cases compared with the reference alternative (almost 20%) by half. HA and HAc include heat training, which is information to optimize behavior in hot climates. It is assumed that working in a warm environment without prior action reduces general productivity by 2% for every °C above 25°C for 10 days, after which productivity returns to normal levels. Preparation reduces the initial productivity drop by half. The HAc alternative applies the same approach, only using climate chambers for acclimation (for eight days), instead of outdoor acclimatization.

The CT alternative involves cold preparation in a cold environment supervised by trainers (again, one trainer per 20 soldiers) for half a day, reducing performance loss and cold injury. The CS alternative attempts the same by selecting those soldiers who appear the most prepared for cold environments using a simple test protocol.

2.2 Costs and benefits

Because of the limited size of the alternatives in terms of time and investment, we abstained from identifying indirect effects. The following costs and benefits were assessed by comparison with the reference alternatives:

Costs

- Attributed salary costs
- Medical treatment costs
- Costs of climate chambers
- Salary of trainers

Benefits

- Production minus performance loss
- Production minus loss due to injury

Production loss was estimated by the societal added value of soldiers. Added value is an economic term describing the surplus of what a firm earns over its inputs (machinery, edifice rental, and so on). Theoretically speaking, this value should exceed salary costs, because it would not be rational to hire soldiers. Unfortunately, due to the public nature of military investments, no added value figures for armies exist in economic statistics. The army does not earn money in the form of cash; instead, it is assumed to provide and maintain societal security. For the sake of simplicity, we assumed that the added value (benefit) of soldiers equaled 1.5 times their salary costs.

2.3 Risk assessment

The decrease in productivity in the heat was set to 2% for every °C above 25°C (Seppanen, Fisk, & Faulkner, 2004). This estimation is based on industry data, since no data on military productivity declines were found and may lead to an overestimation of the cost for the military. For fully acclimatized or acclimated subjects, the increase in core temperature is estimated to be about 50% less than non-acclimated subjects. This was calculated using the THDYN model (Lotens, 1993) with individual adaptations in set-point and gain of sweating (Havenith, 1997). Therefore, productivity decrease was set to 1% for acclimatized or acclimated subjects in ambient temperatures higher than 25°C. It was assumed that acclimation benefits took eight days to be achieved and that the benefit disappeared after 10 days of in theater operations in the heat, since everyone has now been naturally acclimatized.

In the cold, productivity decrease is based on manual dexterity decrease, one of the most important causes of performance decrement in the cold. First, the wind chill equivalent temperature (WCET) is calculated from ambient temperature and wind speed. The performance decrement equals $-0.162 * WCET * \text{exposure duration}^{0.38}$ (Daanen, 2009), in which WCET is in °C and exposure duration in minutes. It is assumed that productivity loss is 10% less for instructed or selected soldiers, due to more adequate behavior in the cold or better finger blood flow in the cold.

The main costs are soldiers' salaries. When an acclimation or training program was executed prior to deployment, the salary costs were adjusted accordingly. In addition, the salary of trainers was included in that case and the cost of the climatic chambers for acclimation.

Heat and cold injuries result in two costs: inactivity of the soldier and medical costs.

For the hot environment, the injury risk was based on a combination of ambient temperature and relative humidity (RH) (Leithead & Lind, 1964). The risk for heat-related death was imminent when the $(10) \log$ of ambient temperature * 373 + relative humidity (in %) exceeded 608. For every two points above 608,

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the risk for heat injury is estimated to increase by 1%. Again, the percentage is divided by 2 when subjects are fully acclimated.

The cold injury was based on the WCET. The Canadian meteorological office indicates that injuries occur for WCET values lower than -28°C. For every degree lower, the risk is estimated to increase by 1%. Again, instructed or selected soldiers are expected to have a 10% lower risk for cold injuries.

The initial assumptions for the model calculation were that 800 soldiers were deployed for 120 days to a hot (40°C, 50% relative humidity [RH]) area with or without eight days of acclimatization or to a cold (-25°C, wind 5 km/hr) area with or without half a day instruction or a selection test to determine cold injury susceptibility (Daanen & Van Der Struijs, 2005). The costs per medical treatment were set at 5,000 Euros (http://www.ey.com/NL/nl/Newsroom/News-releases/PR_Gemiddelde-kosten-per-ziekenhuisopname-zijn-toegenomen_050711).

3.0 RESULTS

3.1 Heat

The salary costs were 6,838 kEur for 120 day deployment of the soldiers and the estimated value was thus 1.5 times the salary or 10,258 kEur (Table 1). Without heat preparation, 1,667 kEur was lost due to productivity loss (16%), 1,099 kEur due to heat injury non-deployment (11%), and 791 kEur due to medical costs (8%) totaling 3,557 kEur (35%).

With heat acclimatization the salary costs increased by 486 kEur due to the eight extra days for preparation. However, productivity loss, deployment, and medical costs dropped to 1,539 kEur, 1,015 kEur, and 396 kEur, totaling 2,950 kEur (29%). Therefore, heat acclimatization provides an extra net benefit of 122 kEur.

Table 1 Costs and benefits of deploying 800 soldiers for 120 days in warm circumstances (40° C) with and without prior preparation (8 days).

	No heat preparation (NH)	Heat acclimatization (HA)	Heat acclimation (HAc)
Costs	<i>x € 1 000</i>		
Salary of military	6,838	7,294	7,294
Medical costs	791	396	396
Climatic chambers	0	0	16
Salary of trainers	0	31	31
Benefits			
Production (value added)	7,491	7,704	7,704
- loss due to production	(1,667)	(1,539)	(1,539)
- loss due to casualties	(1,099)	(1,015)	(1,015)
Net benefit (benefits minus costs)	-138	-16	-32

Source: TNO

The disadvantage of heat acclimatization is that it remains unknown as to whether the local weather is such that adaptations to heat can be achieved. There is a risk that it may rain for instance or that the temperature is too high to be active or too low to acclimate. This risk is not present when heat acclimation is performed in climatic chambers. This risk reduction has an estimated extra cost of about 16 kEur.

The model enables the calculation of different scenarios. For instance, the effect of the duration of the deployment can be estimated, or the impact of climate. Figure 1 shows the effect of ambient temperature only on the net difference in costs and benefits of heat acclimatization over no preparation, *ceteris paribus* (keeping all other parameters constant). It is clear that heat acclimation only confers a benefit when deployment occurs in hot regions.

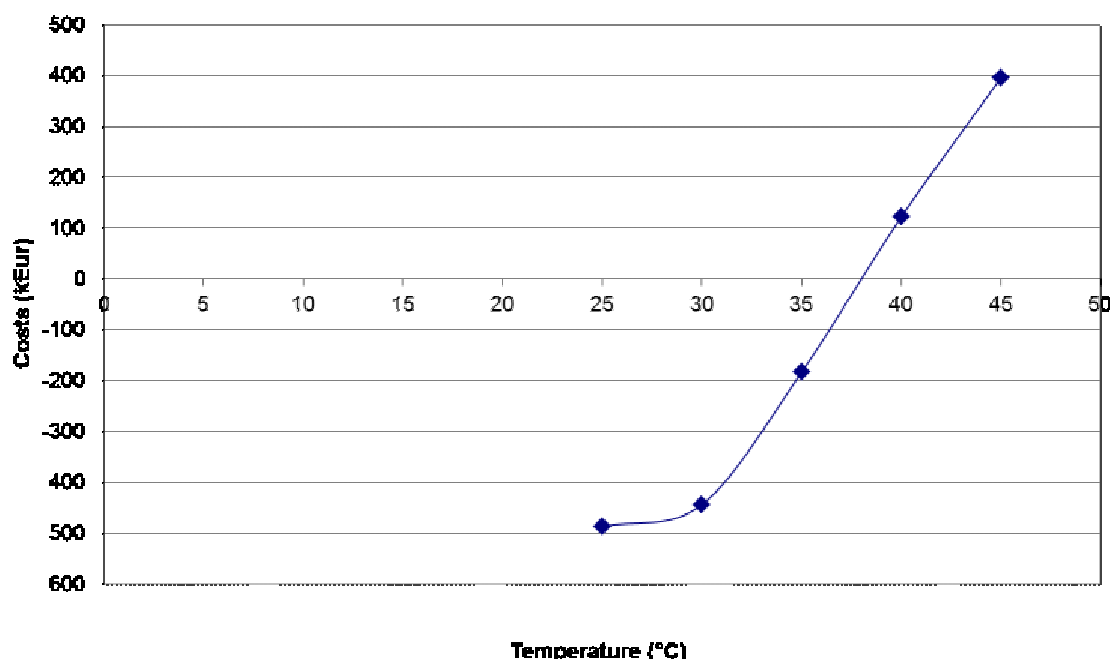


Figure 1. Net benefit of heat acclimatization over no preparation for heat in kEur. Ambient temperature is plotted on the horizontal axis (in °C). Please note that net benefits of heat acclimat(izat)ion only occur when ambient temperature in the country of deployment exceeds 38°C.

3.2 Cold

The salary costs were 6,838 kEur for a 120-day deployment of the soldiers, identical to the starting point in the heat (Table 2). Without any preparation for cold, 2,359 kEur was lost in productivity losses (23%), 200 kEur due to cold injury non-deployment (2%), and 78 kEur due to medical costs (<1%), totaling 2,637 kEur (26%).

The training course that deals with cold is only 30 kEur in salary costs. Productivity loss, deployment, and medical costs dropped to 2,123 kEur, 180 kEur, and 70 kEur, totaling 2,373 kEur (23%). Therefore, cold training provides an extra net benefit of 234 kEur. Selection of subjects confers an extra benefit of about 18 kEur, because the selection test only takes a few hours, including instruction and debriefing. The disadvantage, however, is that about 10% of the soldiers with a high cold injury risk can not be deployed and that a replacement has to be found in the pool of other soldiers.

Table 2. Costs and benefits of deploying 800 soldiers for 120 days in a cold climate (-25° C) with and without prior preparation (0.5 days) or selection (0.2 days).

	No cold preparation (NC)	Cold preparation (CT)	Cold selection (CS)
Costs	<i>x € 1 000</i>		
Salary of military	6,838	6,867	6,850
Medical costs	78	70	70
Climatic chambers	0	0	0
Salary of trainers	0	2	1
Benefits			
Production (value added)	7,699	7,955	7,955
- loss due to production	(2,359)	(2,123)	(2,123)
- loss due to casualties	(200)	(180)	(180)
Net benefits (benefits minus costs)	782	1,016	1,034

Source: TNO

4.0 DISCUSSION

Table 3 shows the differences between the project alternatives and the reference. Deployment of the military under the selected hot climate features higher net social cost than deployment in the selected cold climate. The major reason for this appears to be the high rate of warm injury cases. These cases affect the cost-benefit ratio unfavorably in two ways: they increase medical cost and decrease value added. Moreover, heat acclimation involves climate chamber costs, making it a relatively unattractive alternative to heat acclimatization. It should be noted, however, that transport and energy costs have not been included in the analysis. Cold circumstances, on the other hand, cause higher loss of productivity, because dexterity shows a strong decrement in the cold (Daanen, 2009). Cold preparation requires lower trainer salary than heat preparation, since it can be effectively done within a day.

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Table 3. Extra costs and benefits of project alternatives (differences from reference alternatives), in € 1000

	Heat acclimatization (HA)	Heat acclimation (HAc)	Cold preparation (CT)	Cold selection (CS)
COSTS	<i>x € 1.000</i>			
Salary of military	456	456	29	11
Medical costs	-396	-396	-8	-8
Climatic chambers	0	16	0	0
Salary of trainers	31	31	2	1
BENEFITS				
Production (value added)	213	213	256	256
- loss due to production	(-128)	(-128)	(-236)	(-236)
- loss due to casualties	(-85)	(-85)	(-20)	(-20)
BENEFITS - COSTS	122	106	233	252

Source: TNO

The favorable scores are reflected in the cost and benefit differences of the project alternatives to the reference alternatives. The preparation effort in case of heat deployment requires a significant additional salary allocation; however, the reduction in medical costs is considerable. Compared to the reference alternative, heat acclimatization appears to be the most attractive. For deployment in cold circumstances, cold selection appears to be the most attractive option. In addition, CT and CS may be offered in combination.

It has to be noted that our cost-benefit model is highly simplified, which is an inherent flaw. Important limitations include the omissions of transport and energy costs. Inclusion of these aspects in the analysis would have required more explicit assumptions on location and means of transport during deployment and preparation. The estimated monetary values are highly unpredictable. It would be interesting to apply ex post analysis to the matter, instead of the current ex ante analysis, especially since evidence-based heat and cold preparation represent comparably new approaches to the deployment of armed forces in foreign countries (Manshanden et al., 2011). Since we did not add up relative costs and benefits over a number of future or past years, we cannot compare the influence of discounting and inflation on the costs and benefits (e.g., on wages).

It is important to emphasize that the cost-benefits analysis should not exclude the ethical and legal duty-of-care aspects. Even when the costs of acclimatization exceed the financial benefits, it may be imperative that the physiological benefits of acclimation not be withheld for the soldiers.

Heat and cold injuries and performance loss figures were determined using temperature models, but were not empirically tested. Heat injury was linked to temperature and humidity and cold injury and cold productivity to temperature and wind speed. However, productivity loss in the heat was analyzed with a simpler model based on temperature only, since no other data were available. Recent observations may offer an alternative to Seppanen's formula, but only relate to manual performance in the heat (Zhao, Zhu, & Lu, 2009). Again, the approach is empirically limited. The same applies to the costs of hospital admission, which were set at 5,000 Euros, but might differ significantly in the real world. Wage differences were calculated using 26,000 Euros as the average salary for a soldier and 35,000 Euros for a trainer. Of course, real wages will differ enormously and are highly dependent on public decisions on budgeting. The assumption that a soldier is worth 1.5 times his or her salary cannot be tested in terms of revealed preference, due to the highly public character of armed forces deployment: the product is subject to both non-excludability (nobody can be excluded from the security benefits of deployment) and non-rivalry (the use value of one individual of the service provided by the military does not come at the expense of another individual's use value). For further reading on cost-benefit analysis methodology, the reader is referred to Eijgenraam et al. (2000) and European Commission (2008).

The aim of the paper was to take a first look at the relative sizes of costs and benefits of heat and cold preparation actions. This fits the role of cost-benefit analysis in strategic decision making: multiple proposals for realizing strategic goals can be evaluated in a very general way to filter out the most relevant alternatives. These alternatives can then be analyzed in more detail. Taking the first step is what this paper attempts to do, inviting discussion on improved deployment of the military in differing climates, which appears to be a growing trend.

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