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Cooling and rewarming of hands of military conscripts

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Summary
The key to successful cold weather operations is among others to maintain soldiers' manual dexterity and tactile sensation. Cooling of the hands leads to loss of manual dexterity, and reduces operational capacity. This descriptive study investigated whether cold weather exposure affects cooling rate and/or rewarming rate for soldiers' hands. Skin temperature changes following a standardized cold provocation test on the back of the hands were examined on two cohorts of conscripts at two particular time points; the first during the first week of basic military training and the second following participation in a winter exercise in Northern Norway. The results reveals a tendency in both cohorts for hands to rewarm slightly faster after the winter exercise compared to after the first week of basic training. No difference in rewarming rate between the two cohorts was found after the winter exercise. The findings reveal that it is worth considering future studies to determine whether a standardized cold provocation test of hands can distinguish soldiers who are more prone to loss of manual dexterity and tactile sensation, and thus have a reduced operational capability in the cold.

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Preface

The dataset presented in this note has been collected as part of a cooperative project between the Norwegian Armed Forces Joint Medical Services (Forsvarets Sanitet – FSAN), the Armed Forces Health Registry (FHR), UiT—The Arctic University of Norway (UiT) and the University Hospital of North Norway and was led by Professor Arne Johan Norheim of FSAN – data obtained during 2014–2015. This project is referred to in the note as the «Conscript study».

The authors would like to thank everyone involved in the Conscript study including the participants, those who collected the data and those who prepared the data for analysis. Special thanks to Tom Wilsgaard, Professor of Statistics in the Department of Community Medicine and Health Services at the UiT for introducing us to the contents of the dataset. Former research scientist at FFI Kristine Gulliksrud performed the statistical analyses upon which the note is based, while Nina Rones and Hilde K. Teien edited and wrote the note. Professor emeritus James Mercer (UiT) contributed to the report, both with the collection of thermographic data during the Conscript study and with a description of the method and quality control of the report's contents. Professor Arne Johan Norheim (UiT) was project leader for the original conscript study and contributed to all phases and processes of the study. He also assisted in describing the method and in quality assurance of this report.

The note was first published in Norwegian on 4 April 2022 (Rones, Teien, Gulliksrud, Mercer, & Norheim, 2022).

Kjeller, 1 November 2022
Nina Rones and Hilde K. Teien

1 Introduction

In the Norwegian Armed Forces, weapons and other materiel with high thermal conductivity are routinely handled outdoors during military training, exercises and operations throughout the entire year. Military activities can be conducted in the northern parts of the country, at sea, in the mountains and along the coast and are carried out regardless of weather conditions. Cooling factors as snow, rain, freezing temperatures and wind increase the risk of cold weather injuries (CWI) and there are often several different cooling factors present at the same time. Military activities in these kinds of conditions thus entail particular risk of developing CWIs, including hypothermia and/or non-freezing (NFCIs) and freezing cold injuries (FCIs). In addition, reduction of skin temperature can reduce manual dexterity and the ability to carry out manual work and/or tasks requiring the use of fine motor skills (Hassi & Rintamäki, 2002; Tipton, 2014). This has negative implications for military operative capability which is dependent upon personnel being able to handle weapons and other material with precision. Furthermore, NFCIs and FCIs can disturb the blood circulation, cause damage to the nerves and give rise to pain and lifelong cold sensitivity, not to mention the greater risk of re-injury in the same place. There is the additional risk that re-injury in the same place will be more serious the second time around (Jin et al., 2021). Thus, NFCI and FCI potentially impair the sufferer's quality of life and they can adversely affect the person's further career in the Armed Forces.

In order to avoid the negative consequences of CWIs in military personnel, the Armed Forces needs a greater understanding of the risk factors involved and the long-term effects. For example, more knowledge is needed of how exposure to cold contributes to the development of cold intolerance, as this is a condition necessitating greater vigilance afterwards. Other activities in which military personnel must handle equipment and materiel outdoors in all kinds of weather conditions also require further study. This report aims to contribute to the knowledge in this field.

Generally speaking, there are relatively few studies of how cold affects the health of soldiers. Earlier studies indicate that most FCIs in Norwegian military personnel are incurred by young conscripts during field exercises in the winter (81.1%) (A. J. Norheim & Borud, 2018). Furthermore, the literature shows that exposure to cold can lead to reduced blood flow in the hands and feet (Cheung, 2015) and a drop in body temperature. It is not known, however, to what extent blood flow and the regulation of temperature in the hands of young conscripts are affected by exposure to cold as experienced during basic training and participation in field exercises during the winter.

This study is based on the analysis of a set of data that FFI took over from FSAN and is part of a larger cooperative research project known as the «conscript study» (see Chapter 3)[1]. The data set consists of measurements of the skin temperature on the hands of two cohorts of national service

[1] The «Conscript study» is part of a cooperative project between FSAN, FHR, UiT and the University Hospital of North Norway, led by Professor Arne Johan Norheim at FSAN, where researchers have examined whether thermography, that is, infrared thermographic imaging, can be used in the diagnosis, follow-up and prevention of FCI in military personnel ((Arne Johan Norheim, Borud, Wilsgaard, De Weerd, & Mercer, 2018); see Chapter 3).

conscripts at Setermoen garrison[2], of which one cohort began military service in August and the other in January.

The skin temperature measures were generated from thermographic images (thermograms) that FSAN had taken of the hands of two cohorts of soldiers after exposing the conscripts' hands to a standardised cold provocation test in the form of cooling their hands by submerging them in cold water at two different time points, The first series of temperature measurements was taken at the time of enrolment in national service and the second after participation in a military exercise during winter. The aim of analysing the data set was to investigate whether there are changes in cooling and/or heating rate in conscripts' hands after participating in a winter exercise in the northern part of Norway.

1.1 Objectives

The objectives for analysing the data set was to answer the following questions:

- Were there detectable changes in the rate at which soldiers' hands cooled and rewarmed on the basis of temperature measurements taken at the time of their enrolment in national service and concluding upon completion of participation in a winter field exercise?

- Was there any difference between the two cohorts in the rate at which soldiers' hands cooled and rewarmed?

[2] Setermoen garrison (68.9°N, 18.3°E) is located in Troms County, North-Norway, one of the coldest military campuses in the country.

2 Cold weather injuries and blood circulation

2.1 Cold weather injuries

CWI is the common term for any type of injury that is sustained as a result of being exposed to cold. It includes everything from FCIs, NFCIs, dangerous cooling/loss of heat from the body (hypothermia), snow blindness, injuries from avalanches, dehydration, malnutrition and carbon monoxide poisoning in heated bivouacs. The three most classic cold injuries are (A. J. Norheim & Borud, 2018):

- FCI which occurs when the temperature of the skin falls below the freezing point of the tissue. This type of injury only occurs in actual frost, never in cold weather with an air temperature over -0.55 °C.

- NFCI which occurs when the fingers and feet are exposed to moisture and low temperatures over a sustained period, but where the temperature is still above the tissue's freezing point. Most cold injuries occur in temperatures between 0 and 15 °C and is beyond the scope of this report.

- General cooling of the body (hypothermia) occurs when the body's core temperature falls below 35.0°C and is beyond the scope of this report.

2.2 Blood circulation and temperature in the hands

Heat is transported around the body by the blood and, as earlier studies have shown, there is a close correlation between skin temperature and blood circulation to the skin (Høiland, de Weerd, & Mercer, 2014; Stikbakke & Mercer, 2008).

Blood circulation in the skin is regulated primarily by control centres in the brain. Thermal information from peripheral thermoreceptors in the skin and inside the body (cold and warm receptors) are sent to the hypothalamus which then regulates the body temperature by reducing or increasing the blood flow in the muscles and skin (Kräuchi & Deboer, 2011; Morrison & Nakamura, 2011) and/or inducing other autonomic thermoregulatory responses such as shivering or sweating. To dissipate heat, the circulation of blood in the skin is increased by a widening of the diameter of the blood vessels (vasodilation). To prevent heat loss, the circulation of blood to the skin is decreased by reducing the diameter of the blood vessels; in other words, they constrict (vasoconstriction).

In hot environments, blood flow to the skin can be as high as 8 L/min and account for 60 percent of the cardiac minute volume. In cold environments, the blood flow to the skin can be very low, especially in the extremities and parts of the face, for example the nose. From a condition of maximum vasoconstriction to maximum vasodilation of the vessels in the fingers and toes, the blood flow can increase by a hundredfold (Giesbrecht & Wilkerson, 2006).

There are more sensory cells per cubic meter of skin on the hands than there are on any other places on the body and sensitivity to cold is much higher in the skin on the extremities (hands and feet) than it is on other more central parts of the body (Crawshaw et al., 2012; LeBlanc & Wilber, 1975).

In addition to vasodilation and vasoconstriction of the blood vessels, blood circulation in the body is also regulated through certain small blood vessels called arteriovenous anastomoses (AVA's). Circulation in the fingers and toes is largely governed by the function of these AVA's. AVA's are found in many of the organs and tissues in vertebrates, but they are usually few in number. The exceptions are certain areas of the skin, for example the fingertips and tips of the toes and in the mucous membranes of mammals and birds, where they can be quite numerous (Walløe, 2016).

AVA's may be considered a kind of direct connection (shunt) between the veins and arteries and they enable the transport of blood to the skin without having to pass through the network of capillaries where resistance is high (Walløe, 2016). When AVA's are in an open or vasodilated state, they can transport a much higher volume of blood to the skin to exchange heat with the environment than would have been possible through the capillaries. AVA's can thereby induce a great increase of heat exchange between the skin and the surroundings (Romeijn et al., 2012). In cold conditions, the opposite occurs. When it is cold, AVA's can close through powerful vasoconstriction to minimize the loss of heat from the skin to the surroundings.

To prevent tissue damage as a result of reduced blood flow through the fingertips, most people (though not all) have a mechanism whereby the blood flow to the fingers is opened at intervals of 5–10 minutes, called cold-induced vasodilation (*Cold-Induced Vasodilation*, CIVD) (Daanen, 2003; Lewis, 1930). This is also often described as the "hunter response" or the "hunter reflex".

The reduced blood circulation that may be observed in hands after NFCI and FCI is due to damage of the AVA's (Walløe, 2016). This means that even though it is the so-called «thermostat» in the brain (hypothalamus) that coordinates and regulates the circulation of blood in the body, there can be local deviations in the blood circulation that occur beyond the control of the "thermostat". These local variations can lead to a closing off of the blood flow to the extremities, despite the body being otherwise warm and the person not feeling cold (Daanen, 2003). Fingers and toes with closed off blood vessels/AVA's have a greatly reduced blood perfusion and are thus extremely vulnerable to NFCI and FCI.

Earlier studies have shown how the pattern of rewarming in the hands (and feet) after cooling takes place (Rasmussen & Mercer, 2004). Rewarming begins from the very end of the fingertips and continues in a proximal direction[3], not the opposite as one might expect (see Figure 2.1). In healthy individuals, the fingers warm up symmetrically according to this pattern. A typical sign of CWI is a deviation from this pattern of rewarming, for example a finger that has suffered FCI or some other CWI does not rewarm in the same manner as the other fingers do.

[3] Proximal means in a direction towards the center of the body (Kåss, 2020).

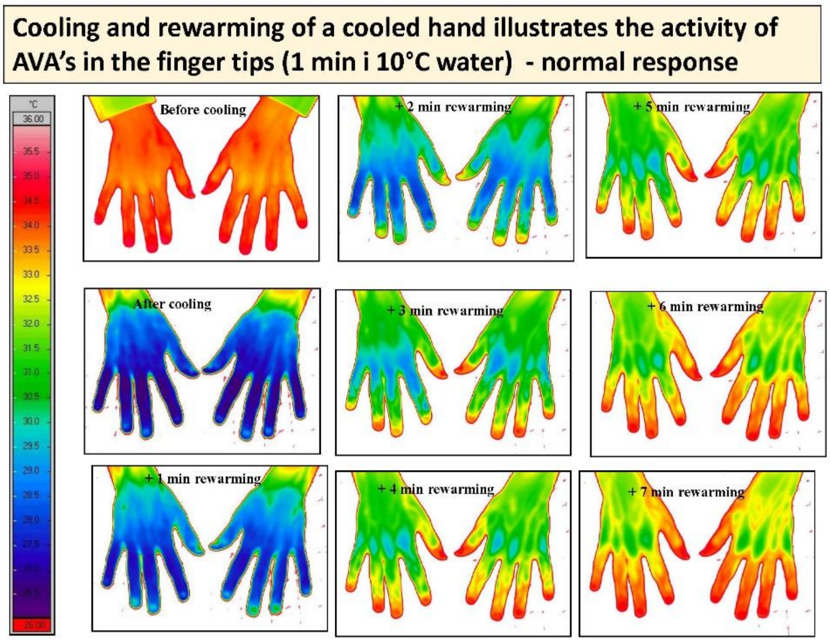

Figure 2.1 *Illustration showing the rewarming of hands after cooling, where red is warm and blue is cold (see the colour scale). The thermographic images clearly show that normal rewarming of the hands starts from the fingertips. This illustration is taken from a presentation held by Professor Emeritus James Mercer, University of Tromsø (UiT), at the Cold Weather Operations Conference (CWOC) from 2–4 November 2021 (Mercer, 2021).*

3 The conscript study

The «conscript study» was led by Professor Arne Johan Norheim and was carried out as a collaboration between FHR, the University of Tromsø – The Arctic University of Norway (UiT) and the University Hospital North Norway. The aim of the conscript study was to investigate whether thermography or thermal imaging, can be utilized in the diagnosis, follow-up and prevention of CWIs in terms of FCIs among Norwegian Armed Forces personnel (Arne Johan Norheim et al., 2018).

Behind the decision to carry out the conscript study was the fact that CWI, especially FCIs, occurred quite frequently during basic training and military exercises. These injuries have also proven to be quite difficult to diagnose and treat. This applies both to recognised but in particular, unrecognised FCIs where the patient has no obvious or recognisable symptoms. Furthermore, both recognised and unrecognised FCIs can have late effects in the form of greater sensitivity to cold as well as discomfort and pain in the hands and feet, impairing the sufferer’s ability to work and adversely affecting the person’s quality of life (Jin et al., 2021). To avoid such late effects, it will be important to be able to diagnose and chart the incidence of FCI properly (Arne Johan Norheim et al., 2018). One of the aims of better diagnostic techniques is to provide useful information to soldiers suffering from unrecognised primary FCIs, thereby assisting them in avoiding re-injury and perhaps more serious secondary FCIs (Arne Johan Norheim et al., 2018).

With these aspects in mind, the objective of the conscript study was to study variations in the proposed normal ability to rewarm the skin on hands using *Dynamic Infrared Thermography* (DIRT) (Pors-Nielsen & Mercer, 2010) in a cohort of young and healthy military conscripts (Arne Johan Norheim et al. (2018). In short, DIRT is a process in which thermographic images are generated after a standardised cooling test to show changes in skin temperature (blood circulation). An integral part of the study was to investigate the extent to which DIRT could be used in the diagnosis, follow-up and prevention of cold and frost injuries in military personnel.

3.1 Thermography (DIRT) in the diagnosis of cold injuries

Anything that is warmer than the absolute zero point (–273 °C) will emit infrared (IR) radiation. The more heat an object has, the more infrared radiation it emits[4]. Infrared heat radiation can be detected by cameras that are especially made for detecting IR radiation to allow the generation of thermographic images. A thermographic image consists of colours whereby each colour represents different areas of temperature on the object[5]. Used on people, the camera will produce an image of the surface temperature of the skin[6].

[4] More precisely, infrared radiation is proportional to the fourth power of the absolute temperature.
[5] A modern infrared camera can in principle register temperature with precision of 0.05 °C (Ammer & Ring, 2019), but in practice the precision is probably closer to 0.1 °C.
[6] The surface temperature of the skin depends on blood circulation in the outermost millimeters of skin and is regulated by complicated processes in the nerve system and in the brain.

DIRT is an indirect method of measuring blood circulation in the skin. However, measurements made using more indirect methods show that blood circulation in the skin, especially in the extremities, has a very close positive correlation to skin temperature (Stikbakke & Mercer, 2008).

From the coloured images generated by a modern infrared camera, also known as radiometric imaging, each colour on the thermographic image represents different temperatures (Ammer & Ring, 2019). With the aid of special computer programs, precise data on temperature can be extracted from these images, right down to a single pixel. This makes it possible to accurately compare average temperature in a specific area of the skin (region of interest or ROI) at different time points. These comparisons can be made both in real time and later with the help of thermographic images stored on a PC.

The use of thermography is promising, both for research and in clinical settings and results using it so far indicate that it can be a useful supplemental tool in clinical diagnostics (Kesztyüs, Brucher, & Kesztyüs, 2022). In the study of CWIs, it is proving useful, not only for detecting NFCI and FCI lacking overt symptoms, but also in gauging the incidence of recognized and unrecognized NFCI and FCIs (Imray, Grieve, & Dhillon, 2009).

An example of thermographic imaging (thermograms) of the hands, both before and at different time points after a standardised cold provocation test, may be seen in Figure 3.1.

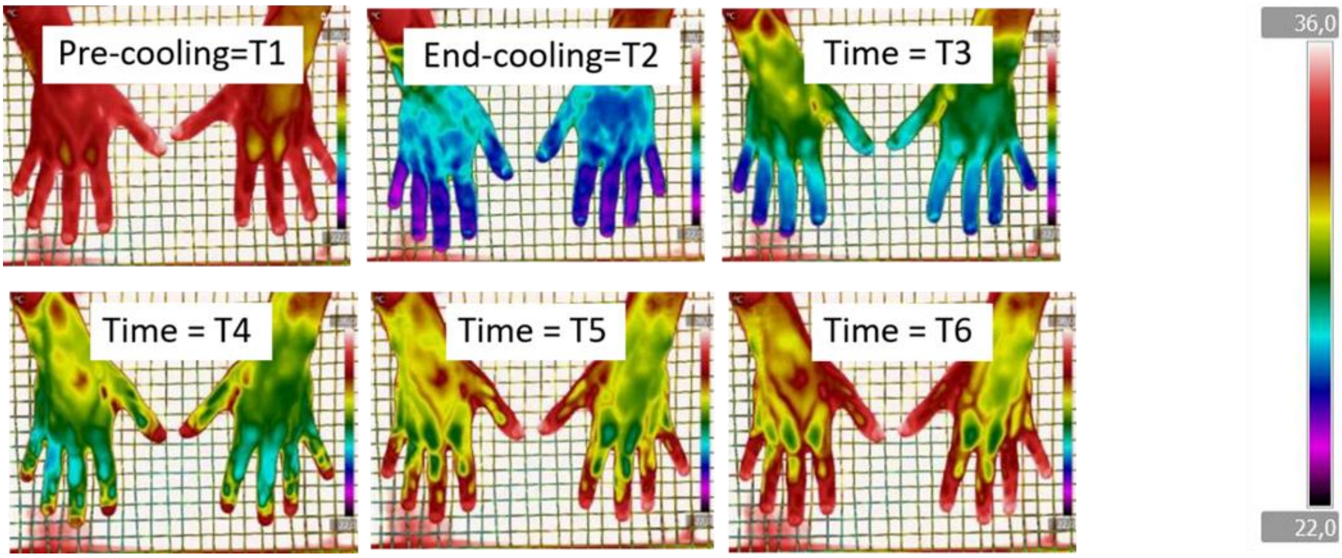

Figure 3.1 Dynamic Infrared Thermography (DIRT) of the external surface of hands showing how skin temperature changes before, immediately after and at four different time points during the rewarming phase following a standardised cold provocation test. The first image was made after acclimatisation and right before the cooling phase («Pre-cooling»). This image provides a baseline measurement prior to start-up with DIRT. The second image was generated immediately after the cooling phase («End-cooling»), with pictures taken every minute thereafter during the restitution phase. This illustration is taken from a presentation held by A.J. Norheim at the NATO HFM RTG-310 meeting in Paris on 27 September 2019 (A. J. Norheim, 2019).

3.2 Participants in the conscript study and collection of data

Ethics:

Permission to carry out the conscript study was sought and approved by the Regional Ethics Committee of Southern and Eastern Norway (Regional komité for medisinsk og helsefaglig forskningsetikk, Sør-Øst-Norge (REK sør-øst)) in 2014. Participation in the study was voluntary and informed consent was secured from all of the participants in the study. The Armed Forces Health Registry (helsedata.no) was in charge of handling the data and upon approval of the application to the Registry seeking permission for use. Only anonymous datasets were released for use in the study.

Participants:

The conscript study recruited 260 voluntary conscripts from two enrolments to national service in North Norway. Of these conscripts, 122 of the soldiers were enrolled to national service in the Armoured Tank Batallion (Panserbataljonen) in August 2014. The second cohort consisted of 138 soldiers who enrolled for service in the Artillery Battalion in January 2015. Both battalions are based at the Setermoen military garrison in the county of Troms (68.9°N, 18.3°E). This is one of the military garrisons with the coldest climate in the entire country and basic training of the soldiers was carried out there. In both the August and January cohorts the conscripts declared themselves willing to participate in the study during the first week of their service.

3.3 Thermographic measurements

3.3.1 Upon enrolment to national service

Over the course of the first week of service, blood circulation in both hands of the conscripts was measured using DIRT. The measurements were taken at three different test stations using three different kinds of IR cameras. The three IR cameras were calibrated using a standard black-body source and the variance between them was extremely small.

During the imaging process, the conscripts were asked to rest their hands on a nylon grid. A heat source of 40 °C (± 2 °C) was positioned 7 cm (± 0.5 cm) below the nylon grid to ensure sufficient thermal contrast in processing the images. See Figure 3.2, as well as Norheim et al. (2018) for a detailed description of the procedure and equipment used. The camera was mounted on a stand and pointed downwards towards the hands (see Figure 3.2). Thermographic images (measurements) were made of the dorsal side (outer side/back side) of the conscripts' hands at six different intervals after a 30-minute standardised acclimatization to the indoor room temperature of 23 °C (± 1°C). The first image was taken right after acclimatisation and right before cooling («pre-cooling»). This image provided the baseline measurement prior to start-up with DIRT. For the cooling phase, the conscripts' hands were placed inside a plastic bag reaching to the elbows to prevent moisture reaching the skin in the water bath. The hands were then immersed in water with a temperature of 20°C (± 1°C) for one minute, with the water covering the wrists. Immediately after the standardised cold provocation test, the hands were removed from the water, the plastic bag was removed and the hands were immediately positioned on the nylon grid with a heat source of 40 °C placed 7 cm below the nylon netting. Thermal images were generated continually throughout the entire rewarming phase.

Figure 3.2 Photographs of the thermal experiment using Dynamic Infrared Thermography (DIRT) which was carried out during the conscript study in August 2014 and January 2015: A) right before cooling («Pre-cooling»), B) during the standardised cold provocation test with hands placed in a plastic bag reaching to the elbows and submerged in water up to the wrists for one minute in water temperature of 20°C (± 1°C) and C) measurements every minute during the restitution phase (rewarming phase) for a total of four minutes with hands resting on a nylon grid. A heat source of 40 °C was placed 7 cm below the nylon netting. Photo: Arne Johan Norheim 2014/2015.

To facilitate analysis of the data from the study, pictures taken immediately before the cold provocation test («pre-cooling»), immediately after it («end-cooling») and thereafter images generated every minute during the restitution phase (rewarming) were used as the basis. For each one of these thermographic images, the average temperature of the pre-defined area of skin on the hands was determined with the help of the computer program (see description in section 3.1). In this case, the actual region of interest (ROI) on the skin was defined as the average skin temperature along a line over the skin area on the dorsal side of all fingers stretching from the centre of the fingernail to the base of each finger (interdigital fold) (see Norheim et al. (2018) for details).

In order to be included in the study and its ensuing progression, the conscripts-were medically screened for at the time of enrolment. No one was excluded on the basis of the medical examination, but two conscripts in the August cohort and three conscripts in the January cohort were dropped from the study due to a lack of follow-up data. The dataset utilised by Norheim et al was thus based on thermographic images from 255 national service conscripts, of which 120 persons came from the August enrolment to the Armoured Tank Battalion and 135 from the January enrolment to the Artillery Battalion. Twelve percent of the participants were women. The average age of the participants was 22.5 years and they had an average body mass index (BMI) of 23.79 kg/m^2.

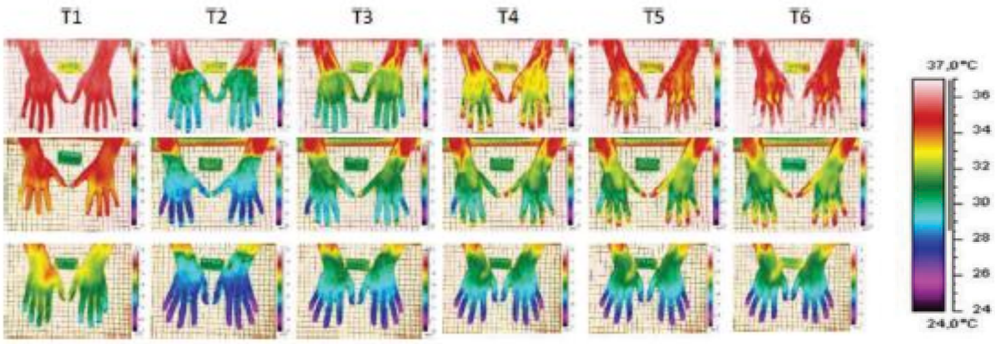

Figure 3.3 The figure shows an example of different rewarming patterns discovered during the DIRT-study of conscript hands. These images show the hands of three individual recruits from the August cohort. The upper row shows a rapid rewarming pattern, the middle row shows an intermediate rewarming capability while the lower row shows the hands of a slow responder. The thermographic images were made at six different time points: one before and one immediately after the mild cold provocation test, and thereafter images taken at one-minute intervals in the course of the four-minute rewarming phase. This illustration is taken from Norheim et al. (2018), p. 5.

According to Norheim et al., (2018), the series of thermographic images taken at the time of enrolment show that there was considerable individual variation in the rate at which the hands of the conscripts rewarmed. Furthermore, it was discovered that the participants could be grouped according to how quickly their hands rewarmed: slow, intermediate or rapid responders. See Figure 3.3 for example from the August cohort, where it was found that 72 percent of 120 participants were completely rewarmed after four minutes, 18 percent were partly rewarmed, while rewarming was delayed in the remaining 10 percent. The latter findings were associated with a low average temperature on the hands before the cold provocation test.

The results from the conscript study were intended from the outset to form a basis of data on which to develop a r*isk assessment scale* for use in determining who is at the greatest risk of incurring FCIs. The risk of injury by FCI was defined into four levels of risk (Risk 0, 1, 2 and 3), as shown in Figure 3.4 (A. J. Norheim, 2016). The distribution of the soldiers is redefined according to the percentages in Figure 3.3, to meet the intentions according to proposal of a risk-assessment given in Figure 3.4.

However, no other research of this type has been done on large groups of healthy young people. Hence, this data set is rather small to allow the introduction of such a scale for use in selection (A. J. Norheim, 2016) as shown in Figure 3.4.

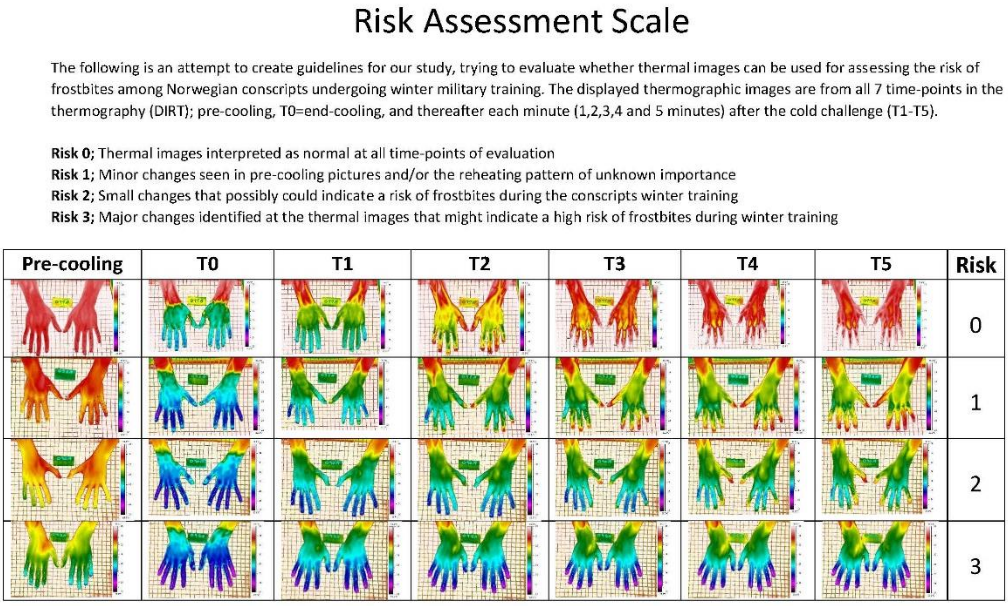

Figure 3.4 Risk assessment scale. This illustration is taken from a presentation held by A.J. Norheim at the European Congress of Aerospace Medicine – 2016 (A. J. Norheim, 2016).

Figure 3.5 shows the rewarming pattern and the risk of sustaining FCI undergoing military winter training for all 255 participants in the conscript study according to the four levels in the *risk assessment scale* (A. J. Norheim, 2022).

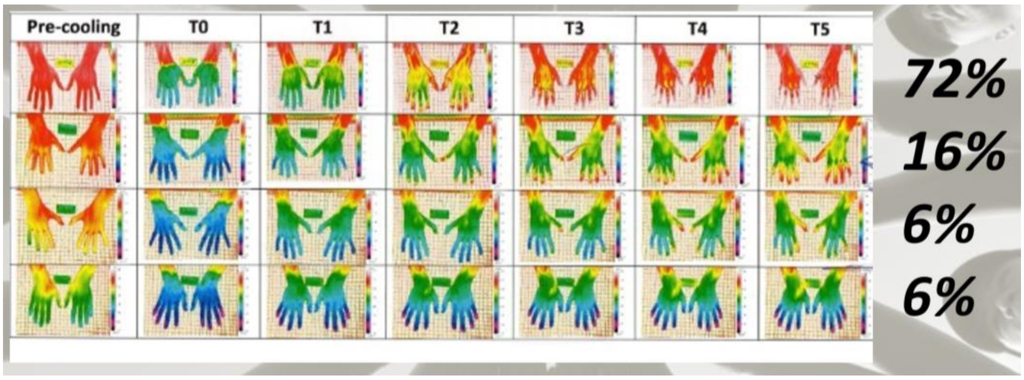

Figure 3.5 This illustration shows an example of the different rewarming patterns as discovered in the DIRT images of the hands of all the participants in the conscript study. The figures to the right of the illustration show the proportion of conscripts (n = 255) with varying rewarming patterns as assessed according to the four levels in the Risk Assessment Scale. This illustration is taken from the presentation held by A.J. Norheim at the European Congress of Aerospace Medicine – 2022 (A. J. Norheim, 2022).

3.3.2 After the winter exercise

In addition to the thermographic measurements made at enrolment, Norheim et al. also carried out thermal imaging immediately after a winter exercise. All of the measurements and thermal imaging were done at Setermoen garrison. Both the August- and the January cohorts participated in the winter exercise. Hence the study would include and cover two cohorts with differing timespans from enrolment to exercise, with the possible implication of dissimilar adaptation and military experience/training with respect to cold weather prior to carrying out a winter exercise.

The thermographic images collected after the winter exercise were generated according to the same procedure as at enrolment (see Section 3.3). The thermography after the winter exercise was carried out in the same room, under the same conditions and utilising the same study procedures as were utilized during the measurements taken at enrolment.

The datasets from the conscript study make it possible to study whether there are differences in the rate of cooling and rewarming from the first time point (at enrolment) to the second measured time point (after the winter exercise). This has not been examined before and FFI took over the datasets in order to study it.

4 FFI’s processing and analysis of the dataset from the conscript study

The dataset taken over and analysed by FFI in this study is the measurements of skin temperature from the thermograms generated by Norheim et al. (2018) of the hands of 255 conscripts who participated in the conscript study (see Chapter 3). The aim of the FFI analysis was to investigate whether there were any identifiable changes in cooling and/or heating rate in the conscripts’ hands from the first time point to the second one.

Some of the voluntary conscripts lacked consistent measurements throughout the study, from the time of enrolment to completion of the winter exercise. This was due to failure to show up for one or more tests, graduation from service or transfer to another division. There were 67 conscripts who lacked a complete set of thermograms from the different measurement time points, so they were excluded from further analysis.

A total of 188 voluntary conscripts were included in FFI’s analysis. There were 95 people in the August cohort and 93 in the cohort from January.

Statistical analyses were carried out using Microsoft Excel (Redmon, USA) and IBM SPSS (IBM SPSS Statistics, version 26, IBM Corp., Armonk, NY, USA) (n = 188). The following analyses were carried out:

- The rate of increase for each individual participant
- Paired sample T-test
    - Tests of differences in the rate of rewarming between the January and August cohorts after the winter exercise
    - Tests of differences in the rate of cooling before and after the exercise for both the January and August cohorts
- Independent T-test for rewarming and cooling rate differences between the two cohorts after the winter exercise.

In order to study the rate at which the hands rewarmed, a rate of increase was calculated for the temperature curve from the time point «end-cooling», here specified as T0[7], to the completion of the rewarming phase, here given as T4, see Figure 4.1. This was done for every single participant using the Excel function LINEST. (Here the rate of increase refers to the slope of the skin temperature curve). It provides two columns of rates of increase, one before and one after the winter exercise. A paired sample t-test was run on this data in SPSS. The analyses for the January and August cohorts were carried out separately due to differences in pre-cooling skin temperature between the cohorts,

[7] Different notations for time were used for the various time points of thermography in the illustrations available to us for presentation in Chapter 3 (Figure 3.1. and Figure 3.2 versus Figure 3.4. and Figure 3.5). In FFI’s dataset and in the analysis, the following time notations were used: Precool, T0 = immediately after cooling («end-cool»), thereafter T1 for one minute after cooling, T2 for to minutes, T3 for tre minutes and T4 for after four minutes after cooling. These are the same time notations that are used in the dataset FFI took over, along with Figure 3.4 and Figure 3.5 except that we did not have results from measurements taken after 5 minutes (T5 in the two figures).

respectively 32.8 ± 1.4 °C and 34.2 ± 1.4 °C. Consequently, a comparison between the two cohorts was not carried out for the baseline measurements.

The same analysis was performed to study the rate of cooling as was done for the rate of rewarming, but then for the curve from *precool* to the time point T0, see Figure 4.1.

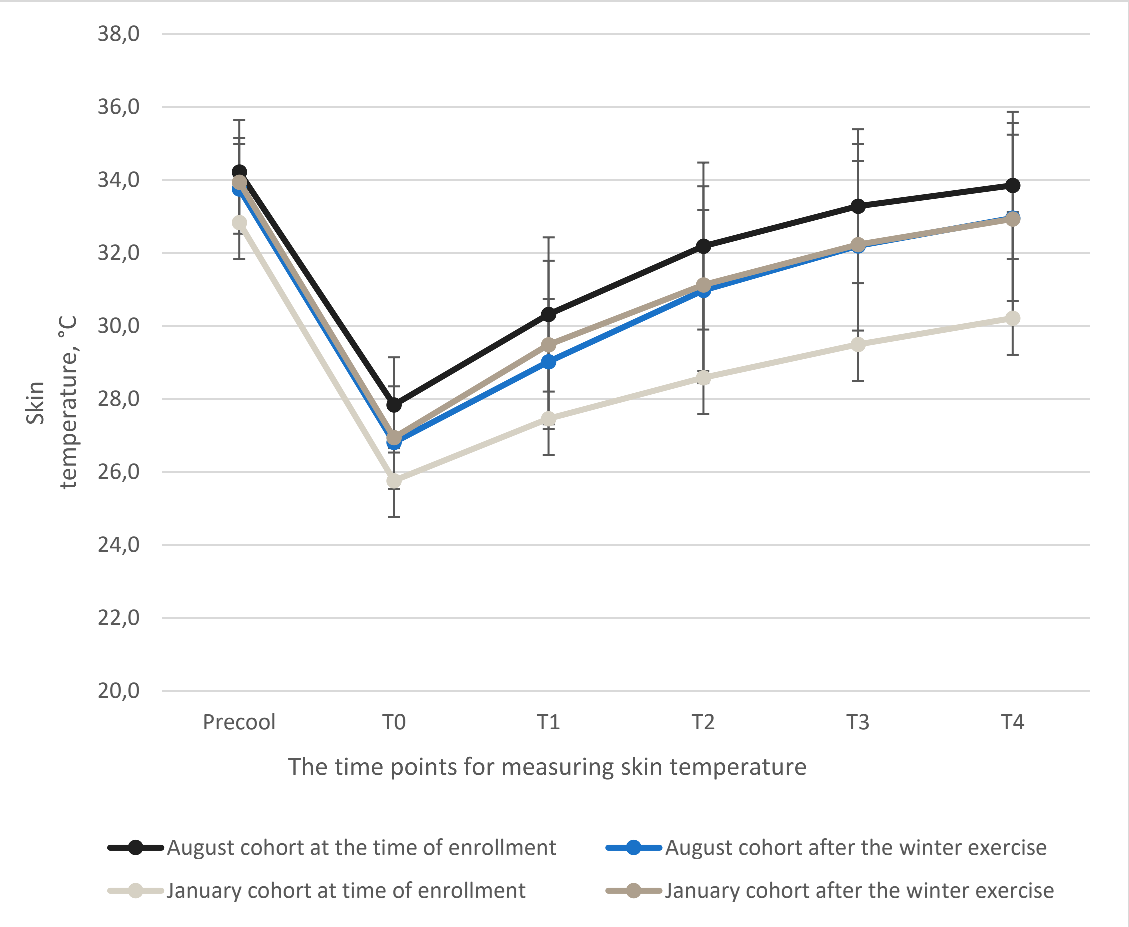

Figure 4.1 The graphs in the diagram illustrate changes in skin temperature on the hands of the August and January cohorts as measured with the use of a thermal imaging camera. The images were generated at the time of enrollment and after the winter exercise. Measurements of skin temperature on the hands were taken both at enrollment and after the winter exercise and the work was done in a series of six different time points: before cooling of the hands in the water bath (Precool), immediately after cooling (T0), after one minute (T1), after two minutes (T2), after three minutes (T3) and after four minutes (T4).

5 Results

5.1 Rewarming

There were a statistical significant increase in rewarming rate from enrolment to after the winter exercise for both the August and the January cohorts, respectively p = 0.002 and p = 0.018 (Table 5.1).

The increase in rewarming rate in the August and January cohorts after the exercise shows no statistically significant difference between the cohorts, p = 0.3 (Table 5.2).

In other words, there is a tendency towards increased rewarming rate in the hands after the cold provocation test that was carried out right after the winter exercise, compared to the test that was carried out at enrolment (Table 5.1). This applied to both the August and the January cohorts. Otherwise, we found no difference in the rate of rewarming between the two cohorts (Table 5.2).

Table 5.1 Rewarming rate in the August and January cohorts at enrolment and after the winter exercise.

Cohort	Rewarming rate at enrolment (°C/min)	Rewarming rate after the winter exercise (°C/min)	P-value
August	1.49 ± 0.41	1.54 ± 0.48	0.002*
January	1.09 ± 0.63	1.47 ± 0.48	0.018*

Notes: January cohort 2015: n = 93. August cohort 2014: n = 95. Values are mean ± standard deviation.
* = significant difference between measurements at enrolment and after the winter exercise, p < 0.05.

Table 5.2 Difference in rewarming rate between August and January cohort after the winter exercise.

Cohort	Rewarming rate after winter exercise (°C/min)	P-value
August	1.54 ± 0.48	0.3
January	1.47 ± 0.48	

Notes: January cohort 2015: n = 93. August cohort 2014: n = 95. Values are mean ± standard deviation.

5.2 Cooling

The cooling of the skin temperature at the hands at enrolment and after the winter exercise shows statistically significant differences for the August cohort ($p = 0.036$), but not for the January cohort ($p = 0.67$) (Table 5.3).

In other words, it appears that the hands of the August cohort cooled faster after tests carried out following the winter exercise than they did at enrolment. We did not observe a similar change in the rate of cooling from the first to the second time point for the January cohort (Table 5.3).

Table 5.3 Cooling of hands at enrolment and after the winter exercise for both the August and the January cohorts

Cohort	Cooling rate at enrolment (°C/min)	Cooling rate after winter exercise (°C/min)	P-value
August	–6.38 ± 1.10	–6.95 ± 0.96	0.036*
January	–7.08 ± 0.86	–7.00 ± 0.88	0.67

Notes: January cohort 2015: n = 93. August cohort 2014: n = 95. Values are mean ± standard deviation.
* = significant difference between measurements at enrolment and after the winter exercise, $p < 0.05$.

6 Discussion

6.1 Rewarming

The findings that the hands of conscripts from both cohorts warmed up a little faster right after the winter exercise than they did at enrolment suggests that participation in the winter exercise led to a more rapid expansion of the blood vessels in their hands, thereby affording increased protection against NFCIs and FCIs. However, there are small differences and in the series of thermographic images Norheim et al. observed there were great individual variations in the speed at which the hands of conscripts rewarmed (Arne Johan Norheim et al., 2018). Hence without further study and more measurements it is not possible to draw any final conclusions. It would be useful to continue conducting thermal imaging during winter exercises to be able to strengthen or reject the hypothesis. According to Norheim et al. (A. J. Norheim, 2016), the original plan was to use the results from the conscript study to form the basis for the development of a «*risk assessment scale*», which could be used to determine who was most vulnerable to incurring NFCIs or FCIs. However, this data set is still too limited to be able to do this (A. J. Norheim, 2016).

We found no difference between the cohorts in rewarming rate after the winter exercise (Table 5.2), so there seems to be little probability that the change in the rate of rewarming at enrolment and after the winter exercise Table 5.1 can be ascribed to seasonal variations.

6.2 Cooling

The conscripts carried out their basic training at Setermoen garrison in the county of Troms. This garrison is one of those with the coldest climate in Norway. Hence it cannot be excluded that a half year longer military service or certain other variations in military basic training might explain the finding that it was the hands of the conscripts in the August cohort that cooled the most rapidly during the cold provocation test as measured between the first and second time point (Table 5.3). However, the measurements in connection with the winter exercise were neither planned nor designed with a view to explaining the reason(s) for the results we report above. Consequently, it is difficult to explain what might be the cause of the changes we observed in the physiological responses.

6.3 Design of the study/method for the conscript study and the winter exercise

The main purpose for the study of conscripts carried out by FSAN was to investigate variations in the ability of the skin on hands to rewarm after having been subjected to cold with the help of thermographic imaging. Upon taking over this dataset FFI’s aim was to try and determine whether there were variations in the rate of cooling and/or rewarming of the hands of the two cohorts of conscripts after participation in a winter exercise.

It is known, for example, that peripheral blood circulation and consequently the temperature of the hands, are influenced by a number of factors, both internally in the body (as for example stress and lack of sleep) and external factors from the surroundings (Fernández-Cuevas et al., 2015).

Detailed information about the winter exercise and the various conditions during it, as for example the duration of the exercise, the weather and external temperatures, the soldiers' food intake, the intensity of the exercise, sleep quantity and quality, degree of exhaustion, stress level and the degree to which the hands and feet were exposed to cold weather, wind and moisture during the exercise is absent. Nor do we know if the two cohorts followed the same program during the entire exercise, or if they were subject to the same stress factors, even though both cohorts were part of the same winter exercise. Consequently, we cannot assess how these conditions may have affected the results.

We have, however, identified several aspects that may have had some influence on the measurements and the database and thereby the result. These include:

- Different stress loads during the winter exercise;
- Seasonal variations and differing ability to acclimatise to the season at the time of the first measurement;
- Differences in the basic military training and the duration thereof, related to differences in cold weather training and exposure to other cooling episodes;
- Deviations from the test protocol at the various time points of measurement.

Furthermore, the study was designed with two cohorts with two different enrolments, with the ensuing baseline measurement carried out at different time points and at different times of the year.

The first measurements for the August cohort were taken in August one week after enrolment, while the first measurements for the January cohort were taken in January one week after enrolment. Thus, the two cohorts may have acclimatised differently at the time point of the first measurement, where the August cohort was measured having acclimatised to the summer half-year and the January cohort acclimatized to the winter half-year. The degree to which the skin's cooling rate and its rewarming capability varies with acclimatisation to the different seasons is a point that might be worth pursuing in a new study.

As described above, there was also a difference between the August and the January cohorts with respect to the length of military cold weather training they had undergone before re-testing after the winter exercise. The two cohorts had respectively six months and eight weeks of military training and other exercises behind them, meaning that the August cohort may have been through more episodes entailing exposure to cold between the first and the second measurements than the January cohort. This may account for the more rapid drop in temperature we observed in their hands after the winter exercise then at enrolment.

The effects of seasonality and the differences of time between the first and the second measurements may also have influenced the results we observed in this study more than the actual winter exercise itself (the exposure to cold weather).

Deviations from the test protocol during the study are also possible. However, extensive effort has been made to ensure the internal validity of the data, including standardization of procedure and conditions at the time of the measurements. See Norheim et al. (2018) for details, as well as the instructions on standardised preparations for participating soldiers. Participants received instructions on food intake and were advised to avoid any unnecessary exposure to cold and physical activity. The compliance to these instructions is unknown.

Nor can it be ruled out that the time of day the before and after measurements for the given dataset were carried out may have had an impact on the data. The measurements taken at enrolment were carried out in the time period from 0800–2000 over a period of several days. This might have influenced the measurements, as it is known that the blood circulation can vary over the course of the day. Changes in the blood circulation to the skin follow the circadian rhythm, with generally increased vasodilation occurring in the evening and increased vasoconstriction in the morning. This increase in vasodilation is most likely explained by an increase in the sleep hormone melatonin (Kräuchi, 2007). Changes to the circadian rhythm in connection with the exercise were not investigated in this study.

The use of three different kinds of IR cameras during the measurements might also have influenced the data. However, quality assurance on the technical side was ensured by calibrating the three cameras on a daily basis against a standard black-body source and the variance between them was considered to be minimal. (See Norheim et al. (2018) for details).

7 Conclusion

From the analysis of the existing data set it appeared that the hands of the soldiers rewarmed a little faster after the cold provocation test that was carried out immediately after the winter exercise compared to the test that was performed at enrolment. This finding applies to both the August and the January cohorts. We found no difference between the two cohorts in the rate of rewarming after the winter exercise. However, it would appear that the rate of cooling was greater in the August cohort in the test that was carried out after the winter exercise compared to the measurements from the test performed at enrolment in August. We did not observe a similar change in the rate of cooling from the first to the second time point of measurement in the January cohort.

The aim of this study was to investigate whether there were any identifiable changes in cooling and/or heating rate in the conscripts' hands from enrolment to after the winter exercise. The study was not designed to explain the cause(s) of these findings. In order to achieve a better understanding of how exposure to cold weather and seasonal acclimatisation influences the capability for cooling and rewarming in the body's extremities, further standardized studies must be carried out that register and control for the different factors that can have bearing on the results. It might also be useful to continue performing thermal imagery measurements to investigate the cooling of hands during military exercises in the wintertime, for example.

The importance of this work for the Armed Forces is to determine the extent to which the following responses to a standardised cold provocation test of hands can distinguish between soldiers with an impaired or strengthened operative capability:

- *More rapid cooling of hands* with slow rewarming may indicate increased risk of NFCI and FCI which could thereby compromise operative capability

- Slow cooling with *more rapid rewarming of hands* may indicate a smaller chance of sustaining NFCI and FCI and strengthened operative capability.

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