The Risk Index for Frostbite

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ABSTRACT

The lowest skin temperatures during operations in the cold are generally observed in the human extremities. The hands are particularly vulnerable since they are difficult to cover when manual dexterity is required. Fortunately, cold induced vasodilation (CIVD) occurs at very low finger temperatures and this mechanism transports warm blood to the extremities. The magnitude of the CIVD-reaction differs considerably between subjects and there were some indications that those subjects with a fast CIVD reaction with high amplitude had a reduced risk for cold injuries. The purpose of this investigation was to monitor and describe the CIVD reaction in marines. Later, we evaluated whether marines in whom cold injuries occurred during operations in cold areas did have a poor CIVD response in previous tests.

In order to evaluate the magnitude of the CIVD response, 226 marines immersed their left middle finger in ice water for 30 minutes. The Risk Index for Frostbite (RIF) according to Yoshimura was determined on the basis of the finger skin temperature response. This index ranges from 3 (high risk) to 9 (low risk) dependent on the response time and response magnitude.

The calculated RIF was relatively good as compared to a Japanese male soldiers (7.0 ± 1.7 versus 5.7 ± 1.7). Unexpectedly, smokers had a better RIF-score than non-smokers had. The RIF-score was inversely related to pain.

One year later 54 marines obtained cold injuries during training in Norway. Twelve or them were in the measured pool of 226 marines. These twelve marines had a RIF of 5.3 ± 1.6, as compared to 7.1 ± 1.6 for the remaining marines. This was significantly different (t-test, t=-3.6, df = 209, p<0.001).

In conclusion, the RIF shows considerable differences between subjects and the RIF, determined in a simple lab test, may be related to the risk for cold injuries during operations in the field.

1.0 INTRODUCTION

It became clear during the occupation of Manchuria by Japanese forces in the Second World War that some soldiers were more prone to local cold injuries than others. Some Japanese scientists, like Prof. Shoji, related the occurrence of Cold Induced Vasodilation (CIVD) to the cold injury risk. CIVD is the paradoxical vasodilatory reaction of blood vessels to cold (<15°C). A considerable amount of heat is released that may prevent the occurrence of local cold injuries (Yoshimura and Iida, 1950). The CIVD-reaction is attributed to paralysis of the muscle wall around the arterio-venous anastomoses (Daanen and Ducharme, 2000; Daanen, 2004).

In 1950, Yoshimura and Iida developed a simple test to determine the risk for local cold injuries, using the CIVD reaction. The left middle finger was immersed in ice water for 30 minutes. The fingertip

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temperature was determined each minute using a small thermocouple at the fingertip. The water was well stirred and ambient temperature was set at about 20°C. A so-called Resistance Index for Frostbite (RIF) was calculated from the CIVD response.

The Royal Netherlands Navy wanted to know how the RIF of the marines would be related to factors like ethnicity and smoking behaviour and if the index was related to the actual occurrence of cold injuries in the field. TNO Defence, Security and Safety was asked to perform the measurements and report to the Royal Navy.

2.0 MATERIALS AND METHODS

2.1 Subjects

A total of 226 marines participated in the experiment (Table 1). Seven out of the 25 marines with 'other ethnicity' were Moroccan, nine Indonesian, four Afro-Caribbean and five with mixed ethnicity.

Table 1: Overview of the marine group under investigation.

	Mean	Standard Deviation
Age (years)	20	2
Body mass (kg)	77	7
Stature (cm)	182	7
Smokers (number: cigarettes/day)	0: 124; 0-10: 96; >10: 33	
Ethnicity	Caucasian: 201; other: 25	
Dominant hand	right: 190; left: 36	

2.2 Measurement Periods

The measurements were performed in the period from November 1999 to January 2001. The first location was in the open field, where the ambient temperature was lower than the other locations inside a building. Table 2 shows the measurement dates, location of measurements, number of marines involved and ambient temperatures.

Table 2: Overview of measurement periods.

Date (day-month-year)	Location	Number of marines	Ambient temperature (°C)
7-11-1999	Open area	20	11.5
11-1-2000	Building	14	19.3
12-1-2000 – 14-1-2000	Building	56	18.7
14-2-2000	Building	56	18.1
16-2-2000	Building	28	18.0
18-1-2001	Building	52	19.5
TOTAL		226	18.1

2.3 Protocol

The marines reported in groups of no more than 14. They were dressed in combat suits. Each marine received a long cup with ice cubes and cold water, which was stirred. The marines sat on the floor or on a chair with the cup at the level of the heart. They immersed their left middle finger in ice water for 30 minutes after application of a type T thermocouple at the fingertip (Tempcontrol T-T-28M, Voorburg, The Netherlands). The marines were asked to stir the ice water with their immersed finger. Ice was added to the cup when necessary. Every 5 seconds the skin temperature of the fingertip was measured and stored in a PC.

Since core temperature is known to influence the CIVD-response (Daanen et al., 1997; Daanen and Ducharme, 1999), the oral temperature was measured in a subsample of 94 marines. This was done using a thermistor with a RD-temp datalogger (Omega Technologies Ltd, Broughton Astley, UK). The subject put the thermistor in the sublingual pocket and was asked not to talk or to breathe through the mouth.

Every 5 minutes the marines rated their pain experience on a scale according to Borg (1998).

2.4 Resistance Index of Frostbite (RIF)

The Resistance Index of Frostbite (RIF) was calculated according to Yoshimura and Iida (1950). Three variables were used:

- The lowest finger skin temperature prior to the CIVD response (T_{min}).
- The onset time of CIVD (t_{onset}).
- The mean finger skin temperature from minute 5 to 30 (T_{mean}).

Yoshimura and Iida (1950) constructed a scoring system for each variable: 2 points if the score was close to the average of their reference group of 100 Japanese subjects; 1 point if the reaction was considerably worse and 3 points if the reaction was considerably better (Table 3). This system is also used in the current experiment. The values are derived from each individual CIVD response. The onset time was determined by eye by two investigators and omitted if disagreement occurred.

Table 3: Scoring system of Yoshimura and Iida (1950) to determine the Resistance Index of Frostbite (RIF). T_{min} stands for the minimal finger skin temperature, T_{mean} equals the average finger skin temperature and t_{onset} corresponds to the time at which CIVD starts. All points are added so that the RIF score ranges from 3 (weak reaction to cold) to 9 (strong reaction to cold).

Number of points	1	2	3
T_{min}	< 1.5°C	1.6 – 4.0°C	> 4.1°C
t_{onset}	> 12 min.	8 – 11 min.	<7 min
T_{mean}	< 4.0°C	4.1 – 7.0 °C	> 7.1°C

2.5 Cold Injuries

In 2002 a group of 1080 marines went to Norway for training in the cold. A part of this group consisted of marines who had performed the finger immersion test. When cold injuries occurred during training, a medical doctor checked the marines and the location and severity of the cold injury were recorded. The RIF-values of the marines that acquired cold injuries and participated in the immersion test were compared to the RIF values of the other marines in the immersion test.

2.6 Data Processing

The relation between RIF and ethnicity, Body Mass Index (BMI) and smoking behaviour was investigated using regression analysis (Statsoft, 2000). A t-test was used to identify differences on the RIF-index between the marines with cold injuries and the remaining group.

3.0 RESULTS

3.1 RIF

The RIF-values of the 20 marines tested in the open air did not differ from the RIF-values determined inside, and were therefore included in the analysis.

In 16 out of 226 subjects, the CIVD response was too ambiguous to determine the onset of CIVD. This may have been due to continuous heat transfer to the water (Purkayastha et al., 1993) or because the finger was accidentally removed from the water in the cup. The RIF-distribution of the remaining 210 marines is shown in Fig. 1. The average is 7.0 and the standard deviation is 1.7.

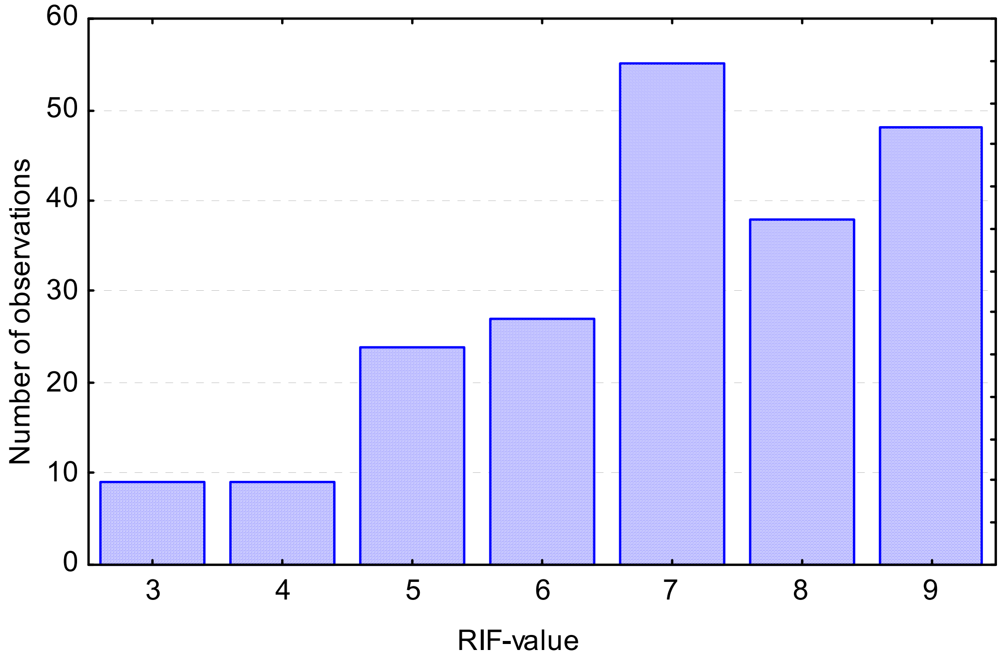

Fig. 1: Resistance Index of Frostbite (RIF)-values for 210 marines. A RIF of 3 to 4 is classified as a weak reaction, 5 to 7 as average and 8 to 9 as strong (Yoshimura and Iida, 1950).

3.2 RIF and Smoking

Since one marine did not fill in his smoking behaviour, the number of marines for the analysis was 209. Surprisingly, the 114 non-smokers had an average RIF-score of 6.7 ± 1.7, while the 95 smokers had a higher RIF-score of 7.4 ± 1.5 (t-test, t=3.0, df=207, P=0.0003). There was a positive correlation between RIF and the number of cigarettes smoked per day (r = 0.17, P=0.013).

3.3 RIF and Ethnicity

The Caucasians had a higher RIF-score (7.0 ± 1.6) than the other ethnicities (6.4 ± 2.1), but the difference was not significant.

3.4 Pain

The pain score was maximal 5 minutes after immersion and decreased with time (Fig. 2).

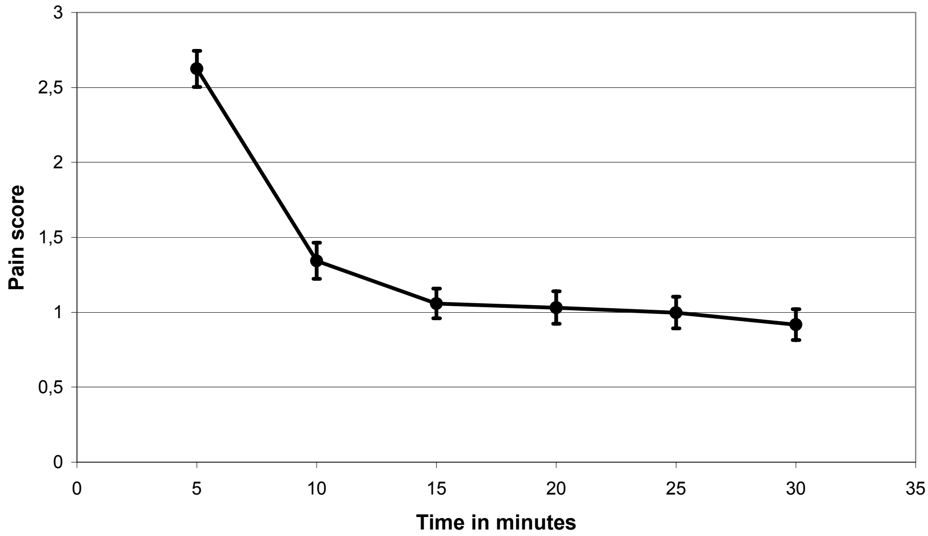

Fig. 2: Pain score during finger immersion in ice water.

Pain was well correlated to the RIF-score: the lower RIF, the higher the pain score ($P<0.001$). The correlation was strongest after 10 minutes of immersion (-0.44), followed by 15 minutes after immersion (-0.38).

3.5 Core Temperature

The impact of core temperature on CIVD response is well documented. Therefore the core temperature was determined in 94 marines using sublingual temperatures. The average was 36.8 ± 0.2°C. There was no significant relation between core temperature and RIF-score ($r = -0.08$).

3.6 Cold Injury Occurrence during Operation in the Cold

In the winter of 2001/2002, 1080 marines participated in cold training in Norway. A total of 57 cold injuries were observed in 54 marines, which was exceptional and probably related to the extreme cold during the cold training period. The severity and location of the cold injuries of the total group is shown in Table 4.

Twelve or them were in the measured pool of 210 marines with a clear CIVD response. These twelve marines had a RIF of 5.3 ± 1.6, as compared to 7.1 ± 1.6 for the remaining 198 marines (Fig. 3). This was significantly different (t-test, $t=-3.6$, $df = 209$, $p<0.001$). Three subjects had 2nd degree injuries of the feet, three other had 2nd degree injuries of the hands. Three subjects had 1st degree injuries of the hands, and two had 1st degree injuries of the feet. One subject had 1st degree injuries of hand and feet.

Table 4: Severity and location of the 57 cold injuries in 54 marines.

	Hands	Feet	Head	TOTAL
1st degree	7	30	2	39
2nd degree	7	11	0	18
TOTAL	14	41	2	57

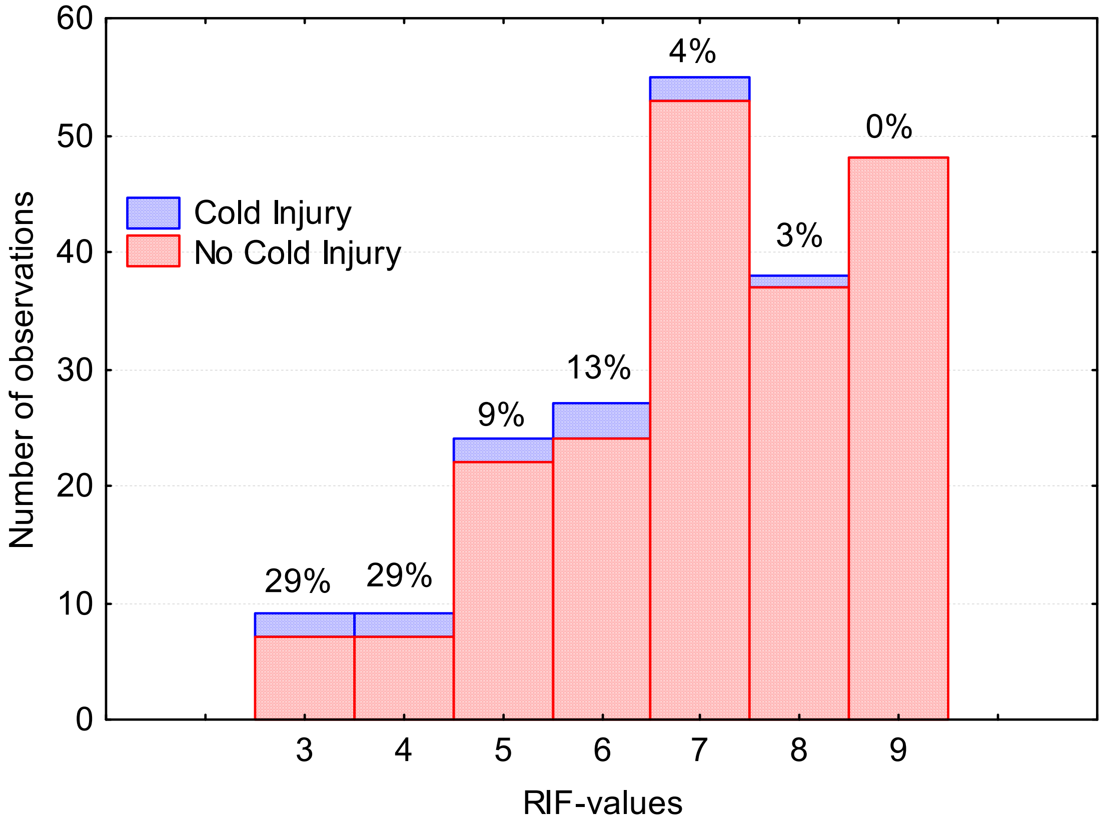

Fig. 3: Resistance Index of Frostbite (RIF)-values for twelve marines who acquired cold injuries compared to the other 198 measured marines. The percentages denote the percentage of cold injuries that occurred for each RIF-value.

4.0 DISCUSSION

4.1 RIF-Scores

The mean RIF-value of Japanese soldiers was 5.7 ± 1.7 (Yoshimura and Iida, 1950); as compared to the value of 7.0 ± 1.7 in the current experiment. The Dutch marines seem to have a relatively good protection against local cold injuries. This may be due to the excellent physical condition and health and food status (Daanen, 2003). Hirai et al. (1970), however, observed that Japanese had a faster and more pronounced CIVD-reaction than Caucasians. The difference disappeared when subjects were living in the same area.

4.2 Smoking

The general experience in the Royal Netherlands Navy is that smokers have a higher risk for local cold injuries. The results, however, show that smokers have a better CIVD-reaction than non-smokers. It is important to realize that smoking was not allowed during training in the cold. Smoking is known to lead to instantaneous vasoconstriction, and we speculate that the vasoconstriction reaction due to cold may be blunted in smokers.

4.3 Ethnicity and CIVD

Generally, has Afro-Caribbeans have an impaired CIVD-response as compared to Caucasians (Iampietro et al., 1959). These ethnic differences cannot be subscribed to ambient factors, they remain for instance when people from the Negroid race move to colder areas. Eleven percent of the marines were non-Caucasians. The CIVD-reaction of this group did not differ significantly from the Caucasians. Strikingly, four out of nine marines with a RIF-value of 3 were non-Caucasian: an African, an Indonesian and two Moroccans.

4.4 Pain

The pain score correlated well with the RIF-score. This was surprising because the pain was scored in a group and social control was expected to dominate. Marines do not easily call events painful. Pain is known to depend on the phase of the CIVD-response (Kreh et al., 1984). The vasoconstriction phase is most painful, and during vasodilation pain decreases. Five minutes after immersion, most subjects are expected to be in the vasoconstriction phase and therefore their pain score is high. During immersion, core temperature generally decreases slightly due to the heat loss to the water and the CIVD magnitude decreases subsequently. Regression analysis showed that subjects experiencing strong pain after 10 minutes of immersion had a worse CIVD-reaction and thus may have a higher risk for local cold injuries. Thus, pain can be seen as an effective warning signal.

4.5 Core Temperature

When core temperature drops, CIVD magnitude also decreases. In the experiment, no relation was observed between sublingual temperature and RIF. This observation may be explained by the fact that core temperature and core temperature threshold for hand blood flow varies considerably between subjects. Generally, only comparisons within subjects show significant results.

4.6 RIF-Values and Cold-Injuries

Scientific evidence for the validity of RIF-scores as an indicator for cold injury risk is scarce. Iida (1940) and coworkers immersed a fingertip in –10°C cooling liquid for 10 minutes. Freezing occurred only in absence of vasodilation. The best validation is to determine the RIF-scores of a large group of people and to check afterwards if people with cold injuries had different RIF-scores than those without. This study was a first attempt. Only 12 subjects were both in the experiment and acquired cold injuries. Even though this group is small, the hypothesis that cold injuries are related to CIVD-response could not be rejected.

In the discussions during the experiments we noticed that marines with low RIF-values were generally aware of the increased susceptibility to local cold injuries. It is not unlikely that these subjects behave more careful in cold areas than subjects with a good CIVD-response. Still, we observed in our study that the group with cold injuries had a worse CIVD-reaction (lower RIF-values) than the reference group.

In extreme cold and windy climates, freezing cold injuries occur extremely fast, even before CIVD can occur (Wilson en Goldman, 1970). In this case RIF-values cannot be considered as a good indicator of cold injury risk.

4.7 Reproducibility of the RIF

Yoshimura and Iida (1950) investigated the reproducibility of the RIF-score by measuring the CIVD reaction of 5 subjects every 2 to 4 days. The maximal variation was ± 1 point (SD 0.26). This can be considered as a good reproducibility. Daanen (1997) investigated the CIVD-reproducibility in eight subjects and observed a standard deviation in t_{onset} of about 1 minute and a standard deviation in T_{min} of 0.7°C. Variation within subjects was always smaller than variation between subjects.

4.8 Conclusion

The vascular response to immersion of a finger in ice water was measured in 226 marines. The Risk Index for Frostbite (RIF) was calculated from the finger skin temperature. The RIF was high as compared to a similar study in Japanese soldiers which indicates that the Dutch marines may have a lower risk to acquire local cold injuries. Unexpectedly, smokers had a better RIF-score than non-smokers. No differences were observed between ethnic groups. Subjects experiencing pain after 10 minutes of immersion had a worse RIF-score and are thus thought to have a higher risk for cold injuries. Twelve marines acquired cold injuries during operation in the cold. These marines had significantly worse RIF-scores than the other tested marines. This study therefore shows that the RIF, determined in a simple lab test, may be related to the risk for cold injuries during operations in the field.

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