Foot Temperatures and Toe Blood Flow during a 12 km Winter Hike and Guard Duty

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ABSTRACT

Freezing and non-freezing cold injury occurs primarily in the toes. The cause of such an injury is a combination of low environmental temperature and decreased tissue perfusion. Cold-induced vasoconstriction enhances the rate of cooling of the tissue, and may cause irreversible damage depending on the final temperature of the tissue and duration of exposure to low temperatures. The risk of cold injury may be further potentiated by ischaemia caused by footwear. The present study evaluated toe temperatures and blood flow by an indirect method during a 12 km winter hike and guard duty. Subjects (10 males, 10 females) wearing a standard military issue winter clothing ensemble, participated in two separate trials. In one, they conducted a 12 km hike carrying a 20 kg backpack, on trails surrounding the Alpine military training facility Pokljuka (altitude 1360m). The hikes ranged from 3 to 4 hours. In the second trial, they conducted a 3 hr guard duty. During the 3-week study, the trails were covered with snow. The average (SD) ambient temperature during hikes and guard duties was 2.0 (3.8)°C. In both trials we monitored the skin temperature gradient between the calf and big toe ($\Delta T_{calf\text{-}toe}$). This proximal-to-distal skin temperature gradient is considered an index of toe perfusion. Core temperature was monitored in the gastrointestinal tract (Tgastro) with a radio pill. Average skin temperature (Tsk) was determined from measurements made with thermistors at four sites, and the data recorded on a 40-channel data logger situated in the backpack. Breath-by-breath oxygen uptake and heart rate were monitored with a portable oxygen uptake system. During guard duty, average (SD) Tgastro remained stable, Tsk decreased from 33.8 (0.5) to 29.0 (1.3)°C and Ttoe from 27.7 (3.6) to 15.4 (2.3)°C. During the hike, Tgastro increased significantly from 37.2 (0.23) to 38.18 (0.42)°C. Tsk was maintained at approximately 32°C in both trials, and Ttoe increased from 27.4 (3.5) to 31.2 (5.4)°C. $\Delta T_{calf\text{-}toe}$ increased from –0.83 (0.59) to 14.7 (15.9) during guard duty, and decreased from –0.8 (3.7) to –1.7 (3.4) during the hike, indicating vasoconstriction during guard duty and vasodilatation during the hike. Peripheral vasodilatation, presumably as a result of the elevated core temperature, maintained average skin temperature constant during the 12 km hike, and increased toe temperature. In contrast, the low activity during the guard duty resulted in a stable core temperature, and peripheral vasoconstriction. The reduction in toe perfusion resulted in substantial decreases in toe temperature. Should this toe temperature prevail for a longer period, the risk of non-freezing cold injury would be imminent.

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1.0 INTRODUCTION

Toe and finger temperatures are dependent primarily on perfusion, since metabolically generated heat in the digits is minimal. Small changes in blood flow will induce substantial variations in the toe and finger tissue temperature. The vasoconstriction-induced decrements in digit temperature are exacerbated by a cold and wet microenvironment. Depending on the tissue temperature-time profile, such exposures may ultimately lead to freezing and non-freezing cold injury. The aim of the present study was to evaluate the risk of such injuries during regular winter hikes and guard duty.

2.0 METHODS

Twenty subjects (10 males and 10 females) participated in the study. They were all members of the Slovene Armed Forces. Subjects were familiarized with the experimental protocol and were aware that they could terminate their participation in the experiment at any time. The experimental protocol was approved by the National Ethics Review Committee (Republic of Slovenia).

Each subject participated in two trials. In one, they were requested to conduct a 12 km hike, while carrying a 20 kg load in their backpack. The hike was conducted on the trails surrounding the Alpine military training facility in Pokljuka (altitude 1360 m). The trails were covered with snow. In parts, the trail was well trodden, in others it was covered with fresh snow. The maximum change in elevation during the hike was approximately 100 m. The hike required between 3 to 4 hours, depending on the snow conditions. In the second trial, subjects were requested to conduct a 3-hour guard duty. During both trials they wore standard issue winter clothing ensembles.

During the trials, skin temperature was measured with thermistors embedded in heat flux sensors (Wuntronic Mess-, Steuer- und Regelgerate GmbH, Munchen, Germany) at five sites (arm, chest, thigh, calf and back). In addition, toe temperature was measured with a copper-constantan thermocouples. Temperature data was stored by a 40-channel portable Almemo Data Logger (Ahlborn Mess- und Regelungstechnik GmbH, Holzkirchen, Germany) situated in the backpack. Breath-by-breath oxygen uptake was monitored by a Cosmed model K4 b^2 (Pavona di Albano, Italy) portable oxygen uptake system, which also measured and stored the ambient temperature, relative humidity and pressure. Core temperature was monitored with a gastrointestinal (Tgastric) radio pill (VitalSense Integrated Physiological Monitoring System, Minimitter Co., Inc., Bend, OR, USA), which was ingested half an hour before the hike. We also monitored the skin temperature gradient between the calf and big toe (ΔTcalf-toe), considered to be an index of toe perfusion. (Stoen and Sessler, 1990).

The subjects conducted the trials in pairs. Thus, on any given experimental day, 2 subjects performed the 12-km hike, while 2 subjects were on guard duty.

Following the completion of the trials, data was downloaded from the data acquisition system, oxygen uptake system and the core temperature recorder onto a PC for later analysis.

3.0 RESULTS

During the 3 week study, average (SD) ambient temperature at the onset of the trials was 2.0 (3.8) °C, and ranged from -6 to 8.2 °C. Relative humidity was 68 (21)% and barometric pressure 871 (5) mbar.

During the 12 km hike, oxygen uptake was maintained between 1.0 and 1.5 $L.min^{-1}$ with average (SD) midway in the hike being 1.35 (0.75) $L.min^{-1}$. Oxygen uptake midway during guard duty was 0.2 (0.12) $L.min^{-1}$.

As can be seen in Table 1, guard duty posed the greatest risk for cold injury of the feet. Toe temperature decreased from 27.2 (3.6) to 14.4 (2.3) °C. The reduction in toe perfusion is reflected in the increase in ΔTcalf-toe (°C) from -0.83 (0.59) to 14.7 (15.9) °C by the end of the 3 hour trial. Gastric temperature remained unchanged during guard duty.

In contrast to the guard duty trial, core temperature increased during the Hike, concomitant with a fairly stable skin temperature, maintained at approximately 32°C. As a consequence of the vasodilatation in the toe (ΔTcalf-toe=-0.8 (3.7)°C at the onset of the hike, and -1.7 (3.4) after 3 hours), toe temperature increased from 27.4 (3.5) to 31.2 (5.4) °C after a 3 hour period during the hike.

Table 1: Core (Tgastric), average skin temperature (Tskin) and toe temperature (Ttoe) at the beginning and end of a 3 hour guard duty and 12 km hike.

	Start	***End***
Guard duty		
Tgastric (°C)	37.25 (0.33)	37.18 (0.35)
Tsk (°C)	33.8 (0.5)	29.0 (1.3)
Ttoe (°C)	27.7 (3.6)	15.4 (2.3)
ΔTcalf-toe (°C)	-0.83 (0.59)	14.7 (15.9)
12 km hike		
Tgastric (°C)	37.20 (0.23)	38.18 (0.42)
Tsk (°C)	32.5 (0.7)	32.0 (2.1)
Ttoe (°C)	27.4 (3.5)	31.2 (5.4)
ΔTcalf-toe (°C)	-0.8 (3.7)	-1.7 (3.4)

4.0 CONCLUSIONS

Peripheral vasodilatation, presumably as a result of the elevated core temperature, maintained average skin temperature constant during the 12 km hike, and increased toe temperature. In contrast, the low activity during the guard duty resulted in a stable core temperature, and peripheral vasoconstriction. The reduction in toe perfusion resulted in substantial decreases in toe temperature. Should this toe temperature prevail for a longer period, the risk of non-freezing cold injury would increase.

In addition to determining appropriate biophysical properties of footwear for cold weather, evaluation of footwear should also assess the consequence of the combined effect of cold and vasoconstriction on digit temperature.

5.0 REFERENCES

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