

CLASSIFICATION OF NON-FREEZING COLD INJURY IN PATIENTS: AN INTERIM REPORT

Clare M. Eglin, Frank St.C. Golden and Michael J. Tipton

Department of Sport and Exercise Science, University of Portsmouth, Portsmouth PO1 2ER, UK

Contact person: clare.eglin@port.ac.uk

INTRODUCTION

Non-freezing cold injury (NFCI) is a debilitating condition that can result in lifelong cold sensitivity, pain and sweating in the injured part, usually the feet (Francis and Golden, 1985). It is the most common form of non-combative related injury to afflict military forces operating in temperate and arctic environments. It is also common, at least in a mild form, in those participating in outdoor pursuits in cold/wet environments. The incidence of military personnel attending the Cold Injuries Clinic at the Institute of Naval Medicine, UK has increased 5 fold over the last 8 years (Oakley, 2009). Whilst this could be due to increased clinical awareness of NFCI, it could also reflect the increased recruitment of personnel of African and Caribbean origin in whom there may be an increased susceptibility to NFCI (Oakley, 2009).

One of the assessments used to determine the degree of NFCI is a cold sensitivity test (CST). Following an hour resting in 30°C air, the limb (usually foot, enclosed in a plastic bag to keep the skin dry) is immersed in water at 15°C for 2 min followed by spontaneous rewarming in 30°C air (Francis & Oakley 1996). The grading of cold sensitivity is based on the temperature of the coldest toe prior to immersion and 5 min post immersion, measured using infrared thermography. Previous studies have found that in a small population (n=6) of uninjured “normal” individuals, the response to the CST can be variable but this variability can be reduced by elevating core temperature slightly (0.2 to 0.3°C) by gentle exercise prior to the CST (Eglin et al, 2007). The exercise also increased the proportion of the uninjured individuals showing the expected “normal” response to the CST. This may be due to the removal of any confounding influence of central vasoconstrictor drive, leaving the peripheral response to the cold challenge as the primary determinant of the test result.

Whilst a slight elevation of core temperature appears to improve the sensitivity and reproducibility of the CST in “normal”, uninjured individuals (Eglin et al. 2007), the effect on patients with NFCI has not been examined. Furthermore, the CST is just one of the factors used to determine the degree of NFCI; thermal sensitivity and clinical assessment can also be undertaken. Thus, the results of a CST may not necessarily correlate with an independent clinical assessment. The aim of this study was to establish the responses of patients with NFCI to the CST with and without prior exercise, and to compare the resulting cold sensitivity grading with the NFCI classification determined by an independent clinical assessment.

METHODS

Ten patients (7 Afro-Caribbean males, 2 Caucasian males, 1 Afro-Caribbean female, mean age 28 ± 4 y) with previously diagnosed NFCI participated gave their informed written consent. Each

participant undertook two CSTs of their injured limb (foot or foot and hand), one in the morning and one in the afternoon. The order of the CSTs was counter-balanced. The participants refrained from caffeine and smoking for 3 hours prior to testing. The assessment was approved by a research ethics committee within the University of Portsmouth.

On arrival the participants, wearing trousers and a long sleeved top, entered a waiting room controlled at $30 \pm 0.5^\circ\text{C}$ at the level of the feet. Having removed their socks and shoes, they sat at rest for 72 ± 26 min in the REST condition, and for 34 ± 14 min in the EXERCISE condition. They then walked 15 m wearing slippers to another climatic chamber controlled at $30 \pm 0.5^\circ\text{C}$. In the REST condition the participants sat for a further 10 min prior to the CST. In the EXERCISE condition they performed light-moderate exercise for up to 12 min prior to the CST. The exercise consisted of either stepping at $22 \text{ steps}\cdot\text{min}^{-1}$ on a 20 cm step for 7-10 min (3 participants) or exercising on a cycle ergometer for 12 min at 71 ± 23 W. The intensity and duration of exercise varied between participants due to varying fitness levels and peripheral neural pain experienced on exercising, but aimed to elevate core temperature slightly (Eglin et al. 2007) and resulted in the onset of sweating in all participants. Following the rest or exercise period a Laser Doppler probe (MoorLab System, Moor Instruments, UK) was placed on the pad of the great toe of both feet using double sided tape to measure skin blood flow (SkBF). Two minutes of resting data were collected before commencing the CST.

During the CST, the injured foot was placed in a plastic bag and immersed to the level of the mid-malleoli for 2 min in stirred water at $15 \pm 0.2^\circ\text{C}$. The foot was then taken out of the water, the bag removed and the subject remained resting in a recumbent position on a couch for 10-15 min to allow spontaneous rewarming. Five participants (3 Afro-Caribbean males, 2 Caucasian males) also had a CST on their hand (immersion to the level of the wrist) following the CST on their foot. The same procedure as with the foot was conducted, with no further rest or exercise carried out between the tests.

Skin temperature (T_{sk}) of the toe/finger pads of the immersed foot/hand were measured using a FLIR Systems A320G thermographic camera pointed at the soles of both feet/palm of both hands. Infra-red images were captured at 1 Hz to a remote computer and T_{sk} were later analysed prior to rest/exercise, prior to immersion and every minute during rewarming. SkBF was recorded throughout the CST and minute averages were calculated for 2 min prior to immersion, during immersion and throughout the rewarming period. A biological zero Doppler measurement was taken on completion of each CST by manually compressing the arterial flow to the great toe/thumb.

The grading of cold sensitivity was determined from the T_{sk} prior to immersion and following spontaneous rewarming at 5, 10 and 15 min post immersion according to the criteria used in the Cold Injuries Clinic conducted at the Institute of Naval Medicine, UK (Francis & Oakley, 1996; Eglin et al. 2007).

A clinical NFCI assessment of each participant was undertaken in the waiting room (30°C) by a clinician with 30 years experience of NFCI. The participants were interviewed to ascertain a detailed history (the circumstances leading to their NFCI, a description of the symptoms at the time of injury and the current condition/complaint). A physical examination was conducted to

determine the appearance, trophic changes, degree of hyperhidrosis, peripheral pulse, capillary filling, sensation and gait of the injured limb. The severity of NFCI was based on the findings from the history and examination and was derived independently of the results from the CSTs.

T_{sk} and SkBF data were analysed using Shapiro-Wilks test of Normality. T_{sk} of the finger pads prior to the foot CST and hand CST were compared using a Wilcoxon Signed-Ranks Test. A Pearson's correlation coefficient was used to investigate any relationship between participants change in great toe/thumb T_{sk} and change in SkBF following the cold challenge. Statistical significance was taken at the 5% level ($P < 0.05$).

RESULTS

On average, the patients were assessed 3.5 years (range 1 to 9.3 years) after the original injury. Typically the injury occurred as a result of prolonged (5 days to 3 weeks) exposure to cold/freezing and often wet conditions.

Feet

The clinical assessment of the degree of NFCI in the feet was different to the gradings obtained from the CSTs in all but two cases (CICP1 in REST and CICP7 in EXERCISE; Table 1). In four cases the EXERCISE CST gradings were closer to that of the clinical NFCI assessment, two of the REST CSTs were closer and the other 4 were the same (Table 1).

In 5 out of 10 of the assessments on the foot, the EXERCISE CST resulted in a milder cold sensitivity grading than the REST CST, 4 were found to be the same and one resulted in a more severe grading (Table 1).

Table 1. The NFCI classification for the foot based on the clinical assessment and the gradings from the REST and EXERCISE CSTs.

Participant	Clinical assessment	REST CST	EXERCISE CST
CICP1	Moderate	Moderate	Normal/Mild
CICP2	Moderate	Severe	Severe
CICP3	Mild	Normal/Mild	Normal/Mild
CICP4	Moderate	Normal-Mild	Moderate
CICP5	Moderate	Severe	Moderate – Moderate/Severe
CICP6	Mild/Moderate	Moderate/Severe	Moderate – Moderate/Severe
CICP7	Moderate	Normal	Normal
CICP8	Mild/Moderate	Normal	Normal
CICP9	Mild/Moderate	Normal/Borderline	Normal
CICP10	Mild	Moderate/Severe	Mild/Moderate

In the REST CST, the change in great toe SkBF (measured in LDU) and T_{sk} were correlated ($r=0.898$, $P < 0.001$) over 0 to 10 min following the cold challenge, but not between 0 and 5 min or 5 and 10 min. In the EXERCISE CST a correlation was found between change in SkBF and T_{sk} over 0 to 5 min ($r= 0.732$; $P=0.016$) and 5-10 min ($r=0.926$; $P < 0.001$) following the cold challenge.

Hands

The T_{sk} of the finger and thumb pads prior to the foot CST and the hand CST were similar (REST: $33.4 \pm 4.2^{\circ}\text{C}$ v $34.3 \pm 3.9^{\circ}\text{C}$; EXERCISE: $35.5 \pm 2.1^{\circ}\text{C}$ v $36.3 \pm 1.2^{\circ}\text{C}$; $n=5$; $P>0.05$) indicating that performing a CST on the foot did not alter starting T_{sk} on the hand. One participant obtained the same NFCI classification/cold sensitivity grading of the hands from all three methods of assessment (Table 2). The EXERCISE CST resulted in a milder (2/5) or the same cold sensitivity grading for the hands as the REST CST (Table 2).

Table 2. The NFCI classification for the hand based on the clinical assessment and the gradings from REST and EXERCISE CSTs.

Participant	Clinical assessment	REST CST	EXERCISE CST
CICP5	Normal	Moderate	Mild
CICP6	Mild/Moderate	Moderate – Moderate/Severe	Normal
CICP7	Normal	Normal	Normal
CICP8	Mild/Moderate	Normal	Normal
CICP9	Mild/Moderate	Normal	Normal

Change in thumb SkBF and change in T_{sk} were not correlated following the cold challenge in either CST.

CONCLUSIONS

The aim of this study was to compare two methods of assessing cold sensitivity (the REST and EXERCISE CSTs) and to investigate how these CSTs compared with an independent clinical assessment of patients previously diagnosed with NFCI. The EXERCISE CST appeared to result in a cold sensitivity grading closer to the clinical NFCI assessment than the REST CST. However, the grading of cold sensitivity using either CST was not totally consistent with the NFCI classification; this might be expected as the CST assessment is specific to cold sensitivity and the NFCI assessment is a more global investigation normally (but not in the present study) incorporating cold sensitivity as only one consideration.

There are other explanations for the disparity between the results of the CSTs and the clinical assessment. In the CST it is assumed that the higher the starting T_{sk} and the greater the amount of rewarming of T_{sk} following cooling, the less severe the cold injury. Therefore if T_{sk} is low prior to immersion ($<32^{\circ}\text{C}$) and does not rewarm to 25°C within 5 min the cold sensitivity grading will be “Severe”. From a clinical perspective severe NFCI classification is made if there is a history of very severe exposure, blistering, gangrene, tissue loss, and/or permanent residual severe neurological damage. Thus, unless the individual has experienced these severe symptoms they will not be clinically classified as “Severe” regardless of their cold sensitivity, i.e. cold sensitivity is treated as a complication of cold injury that may vary between individuals but not always be related to the degree of the original NFCI.

In the present study, it was found that the CST sometimes resulted in a lower grading of cold sensitivity than the clinical assessment of NFCI (Table 1 and 2). The clinical assessment took into account the history of subjective cold sensitivity of the individual in their home or work environment and the impact this had on their daily routine/employability. In contrast, the CST is

conducted in an ambient temperature of 30°C; it is not attempting to test responses to a “normal” office or home environment that are closer to 21°C. Thus, being found to be “normal” at the higher ambient temperatures of the current CST does not mean an individual will have a “normal” response at home or work at the lower temperatures. The ambient temperature in the CST is maintained at 30°C (and mild exercise undertaken in the EXERCISE condition) to promote vasodilation prior to the cold stimulus. If a cooler ambient temperature was used, rewarming of the foot following the cold water immersion would take considerably longer and thus be impractical as a clinical test. (In the REST condition 5 participants’ foot T_{sk} failed to reach 32°C by the end of the rewarming phase even in an ambient temperature of 30°C). Also, lowering the ambient temperature would not necessarily help isolate what should be a local injury, as a low mean skin temperature will promote a general vasoconstrictor drive (Wyss et al, 1974). The above highlights the very great need to obtain values for “normal” (uninjured) individuals tested using the CST. In addition, it seems clear from the tests undertaken to date that these values should be obtained for different ethnic groups.

A relationship was found between change in SkBF and change in T_{sk} during the CSTs conducted on the feet. This suggests that between individuals increases in SkBF of the great toe are associated with an increase in T_{sk} . In the hands no such relationship was observed as in 3 out of 5 of the CSTs SkBF was maintained throughout the test whilst T_{sk} altered.

The results of this interim analysis suggest that the EXERCISE CST tends to result in a less severe grading for cold sensitivity than the RESTING CST. Furthermore, the EXERCISE CST seems to more often approximate the clinical assessment of NFCI than the RESTING CST (ratio of 2:1). As it stands, and with the classification currently employed, the CST is a useful tool for quantifying the degree of residual cold sensitivity following cold injury, its sensitivity is such that it is most effective at differentiating between the more serious degrees of cold sensitivity. Further testing and refinement should lead to the development of this diagnostic tool.

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