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Acute effects of cryotherapy on postural control

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HIGHLIGHTS

- ► The whole-body cryotherapy (WBC) increased postural sway in the for-aft plane only.
- ► Increased sway (INS) lasted for over 10 min.
- ► WBC decreased the COP frequency and entropy.
- ► The onset of INS preceded changes in postural strategies by at least 1 min.
- ► WBC caused lower automaticity, adaptability and complexity of postural control.

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ABSTRACT

To investigate the acute effects of whole-body cryotherapy (WBC) on postural control, we measured postural sway (COP) in a quiet stance with eyes open in four consecutive 20-second tests: before and 1, 6 and 11 min after the WBC. Twenty-four healthy young subjects aged 19.3 ± 0.9 were exposed to WBC (−110 °C) for 2 min. The time series recorded with a sampling rate of 100 Hz was used to evaluate postural performance (COP variability) and strategies (COP frequency and entropy). There were no differences between the pre- and post-WBC values of these measurements in the frontal plane; however, in the sagittal plane postural sway increased immediately after WBC ($p < 0.05$) and remained elevated throughout the experiment. Deteriorated performance brought about lagged changes in postural strategies, including a decrease in frequency and entropy. These changes remained sustained until the end of the experiment. In conclusion, the WBC caused a drop in complexity, adaptability, and automaticity in postural control, which accounted for specific constraints imposed on the postural system due to cooling.

1. Introduction

WBC is an increasingly popular modality to relieve pain and inflammatory symptoms [1,13,22]. In rehabilitation, it often precedes physical exercises because it facilitates muscle activity and enhances motor function. In sports, cryotherapy is commonly used in treating acute and chronic athletic injuries [21] and as a natural means to enhance training capacity [2,29]. Apart from the beneficial influence of WBC, its adverse effects on neuromuscular performance (NMP) need to be known by clinicians and athletic trainers [4]. This knowledge may help answer two important questions: (1) which exercises should be included and which avoided to benefit optimally from the changes in NMP that result from WBC and (2) are there any deleterious effects of WBC on NMP in athletes which might suggest postponing their participation in training and/or competition until full recovery?

One of the basic determinants of NMP is postural control, which is fundamental to fine performance in an unlimited variety of motor tasks. However, evidence about the influence of WBC on postural control is lacking. Although some authors have investigated the effect of exposure to cold on postural sway, the respective findings are limited to peripheral cooling or water immersion and are equivocal. Reduced ability to maintain balance was reported by Kernozek et al. [9] for a one-legged stance and by Piedrahita et al. [22] for dynamic balance. Probably the largest increase in postural sway was found by Mäkinen et al. [16] in subjects exposed to cold (10° C) for 90 min in a climatic chamber. On the other hand, Dewhurst et al. [5] demonstrated no change in four stability measures computed during four stance conditions after cooling the lower limbs by 3 °C. A similar effect – or even moderate improvement in postural control – was shown in two studies on marksmanship [11].

Despite contrasting findings regarding how exposure to cold affects postural control, understanding of the reason for these

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contrasts is similar across the studies. Different cooling modalities, durations, exposure temperatures, and body parts involved seem to be in the forefront of all possible causes [18]. Is it possible to establish a parallel between the neurophysiological results of being exposed to −110 °C for 2 min in a climate chamber as compared to 15 min standing in cold water? Thus, to advance our knowledge on the effects of WBC on postural control, more systematic studies are necessary that specifically address the latter cooling modality. We also believe that one additional reason for the previous, inconsistent findings was insufficient sensitivity of the stability measures employed in the reported studies to changes caused by exposure to cold.

The purpose of this project was the assessment of postural performance and strategies in healthy young subjects before and after a standard WBC session. Postural performance was assessed by the traditional center-of-pressure (COP) measure, the COP variability whose higher values are commonly interpreted as deteriorated performance. Postural strategies were evaluated by means of the COP frequency and entropy. The sway frequency indexes the rate of exploratory actions in the equilibrium system accounting for the amount of activity required to maintain stability [15]. The latter parameter has been linked to processes which may play a role in postural behavior after exposure to cold, i.e., internal vs. external focus of attention and stiffness around the ankle joints. Specifically, increased sway frequency and stiffening strategy has often been reported during more demanding postural tasks and/or when attention is focused on external vs. internal performance measures. Sway entropy indexes the regularity of the COP, with higher values of entropy associated with more irregular time series. Lower values of sample entropy have been consistently attributed to an increased amount of attention invested in posture [3,24,27] and may be interpreted as an increase in the efficiency or “automaticity” of postural control [6].

Several authors have reported that cooling affects mechanisms which may be involved in postural control. This includes slowed transmission of afferent and efferent information [24,1], suppression of the tendon-reflex amplitude [19], and deteriorated function of proprioceptors located in muscles, tendons and joints [16], and ankle mechanoceptors [26,6]. Based on these reports, we hypothesized that WBC would adversely effect postural performance immediately after the cryotherapy due to an increased challenge to the CNS caused by some combination of the aforementioned factors. As postural strategies have been shown to respond to increased environmental or neuromotor demands, we also hypothesized higher activity of the postural system (higher sway frequency) and higher attentional involvement (lower sway entropy) following the WBC.

2. Methods

The group of 24 healthy students comprised of 15 women and 9 men participated after giving informed consent to the research protocol. Their mean age was 19.3 (±0.9), the mean body mass was 64.7 kg (±7.6 kg), and the mean body height 175.4 cm (±8.2 cm). None of the subjects had contraindications to whole-body exposure to cold. None of them reported musculoskeletal or neurological disorders and none reported physical injury at the time of the experiment.

Subjects were measured four times: just before the WBC (T0), 1 min after (T1), 6 min after (T6) and 11 min after WBC (T11) on a Kistler force plate in a quiet stance with eyes open. Balance measurement was made at a sampling rate of 100 Hz and the length of every trial was 20 s. The participants were instructed to stand still, with their feet parallel and 5 cm apart, and their gaze focused on a screen at eye level at a distance of 1.5 m away. The exposure to cold (WBC) lasted 3.5 min: 30 s in the vestibule of the climate chamber at a temperature of −60 °C and 3 min in the main chamber at a temperature of −130 °C.

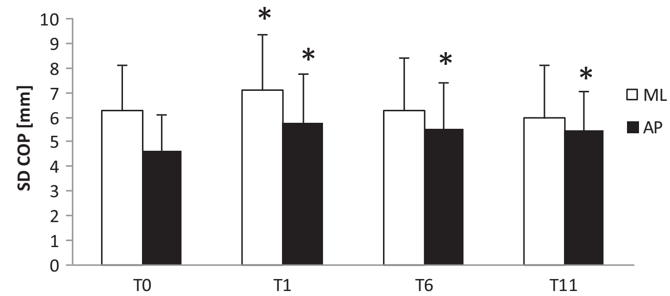

Fig. 1. Mean (±S.E.) of the COP variability. ML – frontal plane, AP – sagittal plane, T0 – baseline, T1 – 1 min after the WBC, T6 – 6 min after the WBC, T11 – 11 min after the WBC, SD COP – COP variability. *Statistically significant changes compared to the baseline, $p < 0.05$.

All subjects wore gloves, knee-length socks, special footwear with a thick sole and headbands to protect the outer ears. The men wore shorts while women wore bathing suits. Before entering the cryogenic chamber, subjects dried their bodies thoroughly with a towel to remove sweat. The subjects placed surgical masks over their faces just before entering the chamber to protect airways.

Postural balance was evaluated by three parameters based on the center-of-pressure time series (sway): variability, frequency, and sample entropy. For the estimation of postural frequency we used a measure [7] based on the ratio of mean sway speed and variability: frequency = mean speed/(variability × 2π). The mean speed was computed as the ratio of total sway path length to the period of measurement. Input parameters for estimating the sample entropy were based on the median value of the relative error [10], resulting in the selection of pattern length $m = 3$ and error tolerance $r = 0.03$ as optimal parameters for the time series (normalized to unit variance) of all participants and trials.

The data collected were tested for normal distribution and homogeneity of variances. After log transformation of the non-normally distributed data, all dependent variables were subjected to a repeated (four tests referred to as TIME that elapsed from the baseline to each consecutive test) analysis of variance in the anterior–posterior (AP) and medial–lateral (ML) plane separately. Selected pairwise comparisons were explored using follow-up contrast analysis. Statistical significance was set at $p < 0.05$.

3. Results

The COP standard deviation (SD) displayed the main effect of TIME on both planes: $F(3,69) = 2.76$; $p < 0.05$ in the ML and $F(3,69) = 2.88$; $p < 0.05$ in the AP plane. However, the follow-up analysis showed that in the ML plane only test T1 resulted in higher sway SD ($p < 0.05$) when compared to the baseline (Fig. 1). In contrast, in the AP plane all three tests performed after the WBC indicated higher sway SD ($p < 0.05$) than the baseline value (Fig. 1).

The main effects of TIME were similar with regard to the postural strategy measures. There was no main effect in the ML plane, while in the AP plane TIME significantly affected sway entropy and frequency ($F(3,69) = 5.52$, $p < 0.05$; and $F(3,69) = 3.71$, $p < 0.05$, respectively). These results indicated that the ML postural control was robust to the cold exposure in contrast to the AP plane where the consecutive tests showed decreased values in the latter two parameters. The follow-up analysis revealed, however, that these changes were present during the T6 and T11 tests only ($p < 0.05$), without any detectable changes during the T1 test (Figs. 2 and 3).

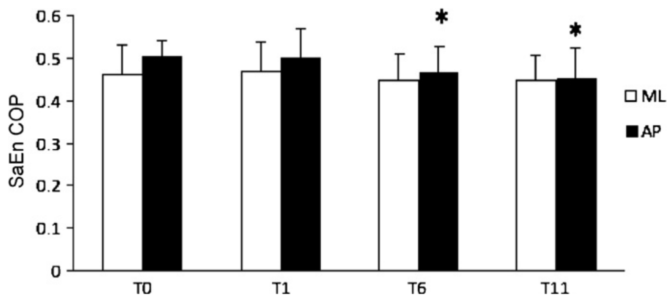

Fig. 2. Mean (±S.E.) of the COP sample entropy. ML – frontal plane, AP – sagittal plane, T0 – baseline, T1 – 1 min after the WBC, T6 – 6 min after the WBC, T11 – 11 min after the WBC, SaEn COP – COP sample entropy. *Statistically significant changes compared to the baseline, $p < 0.05$.

4. Discussion

The purpose of this study was to investigate the immediate effect of WBC on postural performance and strategies in healthy young subjects. In short, two findings are of particular interest. Firstly, the sway amplitude on the AP plane increased 1 min after WBC and remained elevated during T6 and T11 tests post-cooling. It led to changes in postural strategies as indicated by the decrease in sway frequency and entropy. However, the onset of the latter changes did not occur simultaneously with the deterioration in performance – they turned up somewhere between the T1 and T6 test following the WBC. Secondly, there were no differences in the ML plane between any of the sway measures post-cooling and their respective baseline values. Taken together, besides the unmistakable effect of cooling on postural stability in the AP plane, these findings raise the following questions: (1) why were the postural reactions to WBC exposure different in the AP and ML planes, (2) what was the reason for the time lag between the changes in performance and strategies, and (3) what was the purpose of changing postural strategies in the AP plane?

4.1. Differences in postural control between the AP and ML plane

In agreement with our hypothesis, WBC deteriorated postural performance. Although the COP variability increased in both planes immediately post-cooling, it was only the AP plane where this increase was significant and substantial (26%), compared to 13% in the ML plane. These inter-plane differences are consistent with the examination of postural sway after a 90-minute exposure to 10 °C [16]. However, despite some similarity in the acute effects on both planes, the elevated sway amplitude was sustained only in the AP plane during at least 10 min post-WBC, displaying no tendency to decrease, while in the ML plane sway returned to its baseline value before T6. One possible explanation for this inter-plane difference may be the higher cooling effects of the body at the ankles and knees, which are mainly responsible for AP sway, than in the lower part of the trunk, where the hip abductors and adductors controlling sway in the ML plane are located. This concurs with Westerlund et al. [30] who presented data on thermal responses immediately after WBC and reported the lowest skin temperature at the calf (5 °C) and thigh (8 °C) while the back skin measurement indicated a larger value (13 °C).

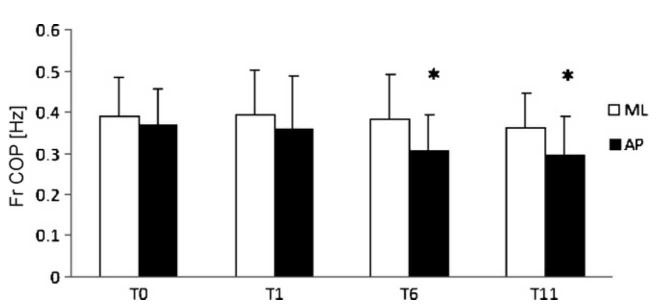

Fig. 3. Mean (±S.E.) of the COP frequency. ML – frontal plane, AP – sagittal plane, T0 – baseline, T1 – 1 min after the WBC, T6 – 6 min after the WBC, T11 – 11 min after the WBC, Fr COP – COP frequency. *Statistically significant changes compared to the baseline, $p < 0.05$.

The explanation for inter-plane differences in our results, which is based on the skin cooling effects only, may be too simplified. The input signals to the postural system are being sent from several receptors that are located in tissues under the skin, and Jutte et al. [8] showed that the coefficient for determination between skin and intramuscular temperatures was low (21%). Thus, the thermal processes in the subcutaneous tissue may significantly differ from the direct skin temperature measurements. Furthermore, Westerlund et al. [30] reported that recovery of skin temperature was rapid during the first 2–3 min, gaining around 2/3 of the value lost due to cooling. Assuming a direct relationship between the temperature of tissues of interest (receptors) and postural performance, and between these receptors and the skin temperature, one might expect the recovery of AP sway amplitude to occur a few minutes later than in the ML plane. However, this was not the case, which indicates that more complicated neuromuscular factors may be responsible for sustained deteriorated performance in the AP plane. For instance, because of different stability conditions in the AP (pivoting around ankle joints requires constant control) and ML planes (there is always a definite area of stability extending between the two supporting feet), the AP control may be more vulnerable to sensorimotor challenges. Accordingly, postural behavior after application of the cold stressor might qualitatively differ between the planes after reaching some level of postural threat, i.e., a level which is still acceptable in the ML plane would trigger additional defense in the AP plane (e.g., changes in postural strategies documented in this study).

4.2. Time lag between the onset of changes in postural performance and strategies

Before discussing the possible reciprocal relationship between deterioration of postural performance and changes in postural strategies which occurred due to the WBC in the AP plane further, it is imperative to point out that there was a delay between the onset of the two events. Postural strategies started to change some time after the deterioration in performance was observed. Assuming that reduced performance was already present at the moment of getting into the cryo chamber and taking into account the timing of the experimental procedures, a rough estimate of this period was about 80 s at the least. This is a novel finding that may affect planning of experimental protocols and data interpretation in future studies. In previous work it has always been implicitly assumed that changes in performance and strategies take place simultaneously. Our data indicate that such an assumption may be false and lead to obvious mistakes in making related inferences. The results of this study tell us that even if changes in sway entropy in response to some experimental factors were not manifested, there would still be a chance to detect these changes after some reasonable amount of time. Much in a speculative way, we see no reason to ignore the hypothesis that under some circumstances the reverse may be possible, i.e., the change in strategies may precede the change in performance, yet we believe that this time lag should not appear in many simple experiments and interfere with the respective findings because of motor synergies which, if available, are called upon simultaneously with the postural need. However, it certainly warrants further investigations in studies involving novel, not yet experienced challenges to posture. When the CNS has no available response to such a challenge, it must turn to other means for help, and motor feedback is probably the best candidate.

In the ML plane the situation was simple: a brief deterioration in performance did not cause any changes in postural strategies as it was probably treated by the CNS as a transient disturbance without any appreciable threat to the postural system. On the other hand, the larger and, more importantly, sustained deterioration in AP performance seemed to account mainly for deficits in sensory input due to the thermal stressor. Cooling probably affected the normal function of several sensors which contribute to postural control [26], impaired joint position sense [20], and slowed down neural transmission [25], which may have resulted in a temporary sensory mismatch. At the same time, the CNS remained silent as if it had not been affected by the exposure to WBC. It was not until some time elapsed that changes in the sway entropy and frequency started to become evident.

The selection of this particular strategy (less automatic and more deliberate control with slower postural adjustments) concurs with research on the effects of sensory deprivation on postural control. For example, standing on foam has been shown to decrease the AP sway frequency and entropy [12,28]. Similarly, patients with chronic whiplash injury [14] and those recovering from strokes [24] had lower COP sample entropy than the control group, as did sedentary subjects compared to athletes [27]. Another line of evidence that seems helpful in understanding our results is constrained action hypothesis, which predicts that an internal focus on body movements interferes with automatic processes and consistently shows lower frequency of postural adjustments for internal vs. external focus of attention [17]. Taken together, the latter studies provide evidence that lower entropy and frequency of the COP signal are associated with some constraints imposed on the postural control system and may represent compensatory reactions in an effort to maintain postural control in challenging conditions. In our subjects who were exposed to WBC, these constraints probably resulted from deteriorated proprioception and delays in central integration due to slower neural transmission, both rendering the postural system less complex and less efficient. It is possible that these transient deficits needed more conscious control, which accounted for allocation of attention resources to the postural task, as seen in the decreased sway entropy. The detrimental changes in somatosensory afferents, which are known to be the fastest source of input to the postural control system, might have reduced the high frequency component in the COP leading to a decrease in the mean COP frequency.

Based on these results, it is practically impossible to suggest a plausible explanation for the delay between changes in postural performance and strategies. However, differential cooling effects of the skin and underlying tissue could mean that changes could be delayed until some time after cryotherapy, when heat transfer cools the underlying tissue, or when cooled blood from the skin returns to underlying tissue. It may be also speculated that the rapidly increased neural activity due to cooling and re-warming may interfere with sensors that provide inputs used for postural control. This interference may increase the detection threshold or add some noise to the postural system due to physiological, psychological (apprehensive behavior resulting in decreases in performance [21]), and/or other reasons related to task prioritization. As a result, the larger AP sway amplitude after WBC was not recognized as having an excessive value that requires correction and no change in strategies was needed. It was only after this temporary interference disappeared that postural sway exhibited lower values of entropy and frequency.

References

[1] A.A. Algafly, K.P. George, The effect of cryotherapy on nerve conduction velocity, pain threshold and pain tolerance, British Journal of Sports Medicine 41 (2007) 365–369.

[2] G. Banfi, G. Lombardi, A. Colombini, G. Melegati, Whole-body cryotherapy in athletes, Sports Medicine 40 (2010) 509–517.

[3] F.G. Borg, G. Laxaback, Entropy of balance – some recent results, Journal of NeuroEngineering and Rehabilitation 7 (2010) 38.

[4] J.T. Costello, A.E. Donnelly, Cryotherapy and joint position sense in healthy participants: a systematic review, Journal of Athletic Training 45 (2010) 306–316.

[5] S. Dewhurst, P.E. Riches, G. De Vito, Moderate alterations in lower limbs muscle temperature do not affect postural stability during quiet standing in both young and older women, Journal of Electromyography and Kinesiology 17 (2007) 293–298.

[6] S.F. Donker, M. Roerdink, A.J. Greven, P.J. Beek, Regularity of center-of-pressure trajectories depends on the amount of attention invested in postural control, Experimental Brain Research 181 (2007) 1–11.

[7] A.C. Geurts, B. Nienhuis, T.W. Mulder, Intrasubject variability of selected force-platform parameters in the quantification of postural control, Archives of Physical Medicine and Rehabilitation 74 (1993) 1144–1150.

[8] L.S. Jutte, M.A. Merrick, C.D. Ingersoll, J.E. Edwards, The relationship between intramuscular temperature, skin temperature, and adipose thickness during cryotherapy and rewarming, Archives of Physical Medicine and Rehabilitation 82 (2001) 845–850.

[9] T.W. Kernozek, J.F. Greany, D.R. Anderson, D. Van Heel, R.L. Youngdahl, B.G. Benesh, C.J. Dburall, The effect of immersion cryotherapy on medial-lateral postural sway variability in individuals with a lateral ankle sprain, Physiotherapy Research International 13 (2008) 107–118.

[10] D.E. Lake, J.S. Richman, M.P. Griffin, J.R. Moorman, Sample entropy analysis of neonatal heart rate variability, American Journal of Physiology – Regulatory, Integrative and Comparative Physiology 283 (2002) R789–R797.

[11] M. Lakie, F. Villagra, I. Bowman, R. Wilby, Shooting performance is related to forearm temperature and hand tremor size, Journal of Sports Sciences 13 (1995) 313–320.

[12] C.J.C. Lamoth, R.C. van Lummel, P.J. Beek, Athletic skill level is reflected in body sway: a test case for accelometry in combination with stochastic dynamics, Gait and Posture 29 (2009) 546–551.

[13] U. Lange, C. Uhlemann, U. Müller-Ladner, Serial whole-body cryotherapy in the criostream for inflammatory rheumatic diseases. A pilot study, Medizinische Klinik 103 (2008) 383–388.

[14] P. Madeleine, M. Nielsen, L. Arendt-Nielsen, Characterization of postural control deficit in whiplash patients by means of linear and nonlinear analyses – a pilot study, Journal of Electromyography and Kinesiology 21 (2011) 291–297.

[15] B. Maki, P. Holliday, G. Fernie, Aging and postural control: a comparaison of spontaneous- and induced-way balance tests, Journal of the American Geriatrics Society 38 (1990) 1–9.

[16] T.M. Mäkinen, L.A. Palinkas, D.L. Reeves, T. Pääkkönen, H. Rintamäki, J. Leppäluoto, J. Hassi, Effect of repeated exposures to cold on cognitive performance in humans, Physiology and Behavior 87 (2006) 166–176.

[17] N.H. McNevin, C.H. Shea, G. Wulf, Increasing the distance of an external focus of attention enhances learning, Psychological Research 67 (2003) 22–29.

[18] M.A. Merrick, L.S. Jutte, M.E. Smith, Cold modalities with different thermodynamic properties produce different surface and intramuscular temperatures, Journal of Athletic Training 38 (2003) 28–33.

[19] J. Oksa, H. Rintamäki, S. Rissanen, S. Rytky, U. Tolonen, P.V. Komi, Stretch-H-reflexes of the lower leg during whole-body cooling and local warming, Aviation, Space, and Environmental Medicine 71 (2000) 156–161.

[20] R. Oliveira, F. Ribeiro, J. Oliveira, Cryotherapy impairs knee joint position sense, International Journal of Sports Medicine 31 (2010) 198–201.

[21] S.M. Patterson, B.E. Udermann, S.T. Doberstein, D.M. Reineke, The effects of bold whirpool on power, speed, agility, and range of motion, Journal of Sports Science and Medicine 7 (2008) 387–394.

[22] H. Piedrahita, J. Oksa, H. Rintamäki, C. Malm, Effect of local leg cooling on upper limb trajectories and muscle function and whole body dynamic balance, European Journal of Applied Physiology 105 (2009) 429–438.

[24] M. Roerdink, M.D. de Haart, A. Daffertshofer, S.F. Donker, A.C. Geurts, P.J. Beek, Dynamical structure of center-of-pressure trajectories in patients recovering from stroke, Experimental Brain Research 174 (2006) 256–269.

[25] S.B. Rutkove, Effects of temperature on neuromuscular electrophysiology, Muscle and Nerve 24 (2001) 867–882.

[26] F. Stal, P.A. Fransson, M. Magnusson, M. Karlberg, Effects of hypothermic anesthesia of the feet on vibration-induced body sway and adaptation, Journal of Vestibular Research 13 (2003) 39–52.

[27] J.F. Stins, M.E. Michielsen, M. Roerdink, P.J. Beek, Sway regularity reflects attentional involvement in postural control: effects of expertise, vision and cognition, Gait and Posture 30 (2009) 106–109.

[28] A.J. Strang, J. Haworth, M. Hieronymus, M. Walsh, L.J. Smart, Structural changes in postural way lend insight into effects of balance training, vision, and support surface on postural control in a healthy population, European Journal of Applied Physiology 111 (2011) 1485–1495.

[29] U. Ückert, W. Joch, Effects of warm-up and precooling on endurance performance in the heat, British Journal of Sports Medicine 41 (2007) 380–384.

[30] T. Westerlund, J. Oksa, J. Smolander, M. Mikkelsson, Thermal responses during and after whole-body cryotherapy (−110 °C), Journal of Thermal Biology 28 (2003) 601–608.