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Effects of plantar hypothermia on quasi-static balance: Two different hypothermic procedures

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ABSTRACT

Inducing hypothermia to examine its effects on balance is performed with various approaches. However, data interpretations of underlying postural mechanisms often do not consider the applied hypothermic protocol. In this context, the effects of diminished plantar mechanoreceptor activity on quasi-static balance performance were investigated, examining the applicability of a continuously cooling thermal platform in comparison with conventional ice pads. Increased instability for the thermal platform compared to cooling with ice pads was hypothesized, since we expected increased temperatures for the ice pad group directly after balance tests. Similar scores on a Visual Analogue Scale (VAS) were predicted regarding subjective pain. Results showed that both cooling procedures successfully induced plantar hypothermia. However, the thermal platform was more effective with respect to reaching and maintaining the desired temperature throughout the trials, especially when comparing temperatures before and after balance tests. Therefore, balance tests indeed demonstrated increased COP parameters exclusively after permanent cooling via the thermal platform as early as after the first 10 min of cooling. Reduced plantar input may result in this postural instability, but without the need of other sensory systems to compensate. The VAS generally demonstrated higher pain scores for the ice pads, rejecting our hypothesis. This is an important finding, since pain is known to influence balance. Therefore, permanent and controllable cooling via the thermal platform should be taken into consideration when conducting related research.

1. Introduction

Intact postural control requires information from various afferent systems [1–4] resulting in multiple sensory integration. Numerous studies focus on the participation of somatosensory information in balance and gait [1,3–5]. To isolate the influence of cutaneous receptor activity, studies have simulated diminished cutaneous activity in healthy subjects using hypothermic procedures, such as ice water immersion [3,6–9] or ice/ice pads [4,5,10]. One study used ice pads (IP) placed underneath the foot sole until the baseline temperature was reduced by 5–6 °C [10]. Plantar sensitivity was significantly decreased after cooling, possibly influencing movement regulation [10]. Another study [3] investigated plantar sensitivity and balance after foot immersion into ice water (0–2 °C). Sensitivity was significantly impaired after cooling. Balance control also exhibited significantly greater speed and root mean square error of center of pressure (COP) velocity, but only for the first trial [3].

Despite frequent use of hypothermic methods, there are still some essential limitations. Foot immersion in ice water was not always restricted to plantar aspects, presumably affecting not only plantar mechanoreceptors, but also muscle spindles and joint receptors located in the ankle [9] or toes [3]. Furthermore, these methods exhibit difficulties in adjusting and maintaining specific temperatures during the entire cooling process, especially if data are subsequently collected using e.g. force plates. Consequently, the hypothermically diminished receptor activity may not remain constant for all trials. Due to these restrictions and the lack of hypothermic application standards, biomechanical parameters may be affected differently, resulting in inconsistent study findings. Therefore, we implemented a customized thermal platform (TP). Hypothermia may also lead to cold-evoked pain (mediated by e.g. Aδ-fibres [11]), which affects postural control [12,13]. Pain cannot be avoided in most hypothermic procedures, although its quantification is beneficial. Therefore, a Visual Analogue Scale (VAS) was implemented to compare both cooling procedures.

This study investigated a) the effects of hypothermically diminished plantar mechanoreceptor activity on quasi-static balance; and b) the applicability of a permanently cooling TP versus non-permanently cooling IP. Decreased skin temperature leads to reduced cutaneous

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sensitivity [10]. Consequently, most studies report motor control impairment due to increased COP parameters [7,9]. We therefore expected increased COP parameters for TP compared to cooling with IP (non-permanent cooling). Furthermore, similar foot temperatures for both groups were hypothesized directly before balance tests, and increased temperatures were expected for IP after tests. Similar scores for both hypothermic procedures were expected for VAS.

2. Methods

2.1. Subjects

36 healthy subjects were randomized and evenly divided into: group thermal platform (GTP: mean ± SD: 175.6 ± 9.9 cm, 69.7 ± 11.6 kg, 22.4 ± 1.3yrs) and group ice pads (GIP: mean ± SD: 176.6 ± 7.2 cm, 70.5 ± 9.2 kg, 22.7 ± 1.6yrs). All procedures were conducted according to the recommendations of the Declaration of Helsinki and were approved by the Ethics committee of the corresponding faculty.

2.2. Setup

Two different cooling setups were used: customary ice pads (IP) and a customized thermal platform (TP, see Supplementary material). The TP, described in Germano et al., [14], offers enough area (40 × 40 cm) for balance performance with simultaneous cooling of the plantar foot. A force plate (IMM Holding GmbH, Germany, 1 kHz) assessed quasi-static balance for both setups. An infrared thermal camera FLIR E40bx (FLIR Systems Inc., USA) measured skin temperatures.

2.3. Protocol

2.3.1. Measurement procedure

Measurements were performed at four temperature stages with subjects seated: after an acclimation period of 10 min at 25 °C (baseline, BL), after 10 min (C1) and additional 5 min (C2) of plantar cooling at 0 °C, and subsequently after 5 min of natural re-warming (RW) (Fig. 1). Both groups performed four sets of three trials of quasi-static balance (barefoot single-leg-stance, eyes open). Subjects kept the knee of the balancing leg straightened, flexed the contra-lateral knee 90°,and kept their upper limbs hanging down. When subjects were stable and in the instructed position, data collection started and trials of 25 s were collected. Plantar temperatures (T) were quantified before and after each balance set. A VAS was applied directly before each quasi-static balance set.

2.3.2. Inducing plantar hypothermia

TP was set to 0 °C and IP were stored in a fridge-freezer (0 °C) and changed every three minutes during the measurements to ensure homogenous temperatures. GIP performed single-leg-stances on the force plate immediately after plantar cooling. GTP performed single-leg-stances on top of the cooled TP (force plate mounted underneath).

Plantar sensitivity measurements and balance tests are time consuming, endangering participant concentration. We therefore decided not to include sensitivity tests in our protocol. To investigate plantar sensitivity for the same temperature stages comparing IP and TP, we performed a pilot study: Plantar sensitivity (Met I) of nine healthy subjects (mean ± SD 28.1 ± 4.3years) was analyzed at 200 Hz. For each subject, three sensitivity trials were collected for each temperature stage. After cooling, mean plantar sensitivity (considering three trials) was reduced at C1 (GTP: 5.5 ± 3.8 μm; GIP: 1.44 ± 3.82 μm) and C2 (GTP: 5.6 ± 4.0 μm; GIP: 2.0 ± 4.0 μm) compared to BL (GTP: 0.8 ± 0.5 μm; GIP: 0.8 ± 0.4 μm). However, the reduction was only significant when cooling via TP (BL vs. C1 $p = 0.008$; BL vs. C2 $p = 0.015$). Comparing GIP to GTP, plantar sensitivity deteriorated more for TP than for IP after the intervention. When considering only the first trials of the sensitivity tests directly after cooling, GIP also showed a significant reduction of plantar sensitivity after cooling: for BL vs. C1 (0.66 ± 0.44 μm vs. 2.21 ± 1.18 μm; $p = 0.007$) and for BL vs. C2 (0.66 ± 0.44 μm vs. 3.05 ± 2.17 μm; $p = 0.008$). Furthermore, comparing the first and the 3rd sensitivity trials for C1 and C2, cooling via TP only changed sensitivity slightly (C1: 3%, C2: 8%), while cooling via IP changed considerably (C1: 53%, C2: 55%). Cooling via IP was able to reduce plantar sensitivity, but, considering the mean of all three trials, could not maintain the same amount of sensitivity reduction compared to TP.

2.3.3. VAS for pain

Subjects completed a VAS to indicate subjective pain perception (line length: 10 cm, "0 = no pain", "10 = extreme pain") before each of the four balance sets. To enable comparability between hypothermic setups, plantar hypothermia was induced using TP and IP simultaneously, one for each foot. To minimize the duration of cooling, subjects performed single-leg-stances. Since only one leg of each subject was used, cooled either by TP or IP, subjects were randomly assigned to group TP or IP (GTP, GIP).

2.4. Data analysis

Heel temperatures were analyzed using ThermaCAM™ Researcher Pro 2.8 SR-1 (FLIR Systems Inc., USA). Force data were analyzed using R (The R Foundation for Statistical Computing, Austria) to calculate COP total excursions, COP velocity, and COP root mean square (RMS). Force plate data were low pass filtered (cutoff frequency 0.1, Butterworth 4th order). The first 5 s of each trial were disregarded and only the last 20 s were analyzed. COP total excursion represents the sum of COP displacement during each 20 s trial. COP velocity was calculated using the average COP velocity during the 20 s. RMS of COP represents the variation of COP excursions during each trial, indicating more instability for greater RMS values. For all parameters, the mean of the three trials was used to define the value for each subject at each temperature stage. VAS data were analyzed calculating mean ± SD (cm) of the distances between 0 and the vertical line.

2.5. Statistical analysis

Plantar temperature differences were analyzed using a Mann-Whitney-U test (between groups) and a Wilcoxon test (within groups). Effects of the experimental conditions on COP parameters were examined using repeated measures analysis of variance (ANOVA) following post hoc tests (Bonferroni) (within groups) and independent-samples *t*-tests (between groups). Due to the number of temperature stages, the level of significance was adjusted to $\alpha = 0.05/4 = 0.0125$.

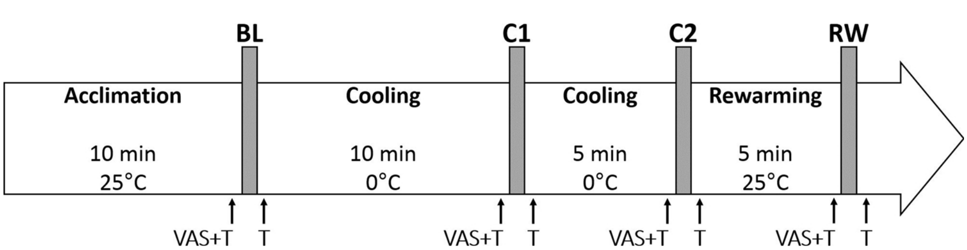

Fig. 1. Testing sequence for both groups: BL (baseline), C1 (cooling 1), C2 (cooling 2), and RW (rewarming). Arrows indicate visual analog scale (VAS) and plantar foot temperature (T) measurements, either before or after quasi-static balance sets (grey rectangles).