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EFFECTS OF INDUCED PLANTAR HYPOTHERMIA ON DYNAMIC BALANCE

[1,2] Andresa M. C. Germano, [1]Daniel Schmidt, [1]Tobias Heß, [1]Günther Schlee, [1]Thomas L. Milani
[1]Department of Human Locomotion, Chemnitz University of Technology, Chemnitz, Germany
[2] email: andresa.germano@s2010.tu-chemnitz.de, web: www.tu-chemnitz.de

SUMMARY
The purpose of the present study was to examine the effects of hypothermically reduced plantar sensitivity on dynamic balance after unexpected translatoric perturbations. 52 healthy subjects participated in this study. COP excursions and iEMG were analyzed in two intervals: 0-100 ms and 101-300 ms post perturbation. Contrary to the expectations, results showed significant differences only in interval 2 with both reduced iEMG and decreasing COP excursions as effect of hypothermia (0 °C). This could be explained by compensations derived from other sensory systems or by learning effects during trials. Further studies are needed to clarify this outcome.

INTRODUCTION
The human body remains in balance as a result of visual, vestibular and somatosensory systems, the latter including plantar mechanoreceptors [1]. In order to study the isolated role of plantar mechanoreceptors in balance regulation, hypothermic approaches like cooling are frequently used [2]. However, these procedures have proven to present some limitations since a) joint receptors could be affected, b) while stepping on e.g. a force platform, feet immediately reheat, and c) it is difficult to control and maintain a determined temperature during tests. Therefore, the purpose of the present study was to examine the effect of an isolated, permanent and controlled induced hypothermia of the foot sole by a thermal-plate during dynamic balance tests. After hypothermia, significant increases in both COP excursions and integrated EMG (iEMG) were hypothesized.

METHODS
52 healthy and injury-free subjects (mean±SD: 23.6±3.0 yrs, 70.7±13.0 kg, 1.7±0.10 m) participated. Prior to the tests, all participants were informed about the purpose of this study and were instructed to cancel trials when experiencing any discomfort. All procedures were conducted according to the recommendations of the Declaration of Helsinki and proved by the ethics committee. To induce unexpected perturbations, the horizontally moveable bottom platform of a Posturomed training device (Haider Bioswing GmbH, Germany) was deflected by 20 mm and released by triggering an electromagnet. After releasing, the bottom platform swung until it reached the original position and subjects had to regain balance. A force platform was fixed onto the bottom platform (IMM Holding GmbH, Germany; sampling rate 1 kHz). Finally, on top of the force platform, a self-developed customized thermal-plate (Chemnitz University of Technology) was attached to induce hypothermia. Subjects stood with their dominant leg on the thermal-plate and all conditions were performed adjusting the plate temperature to 25 °C (stage 1) and 0 °C (stage 2). The acclimatization times were five and 10 minutes for stages 1 and 2, respectively. Three randomized trials were performed in two perturbation directions: antero-posterior (AP) and medio-lateral (ML). Before the tests, subjects performed several trials to get familiar to the apparatus. Temperatures of three anatomical locations (first/fifth metatarsal head (Met1/Met5) and heel) were monitored by an infrared thermal camera (Flir E40bx, Flir Systems Inc., USA) before and after data collection at each stage. Balance ability was quantified by calculating center of pressure (COP) excursions in the antero-posterior (AP_COP) and medio-lateral (ML_COP) directions as well as total COP excursions. Also, iEMG of three lower leg muscles (M. gastrocnemius medialis (Gm), M. fibularis longus (Fib), M. tibialis anterior (Tib)) were analyzed applying wireless EMG surface electrodes (Bagnoli System, Delsis Inc., USA; sampling rate 1 kHz). Total collection time was 3000 ms, however, in this study all data were analyzed in two intervals: 0-100 ms post perturbation (interval 1) and 101-300 ms post perturbation (interval 2). Data were processed in R (The R Foundation for Statistical Computing, Austria) and statistical analysis was conducted in PASW Statistics 18.0 (SPSS Inc., USA). Normal distribution was tested by using the Shapiro-Wilk test (p=0.05). For parametrical data (COP), differences between temperature stages were examined using ANOVA repeated measures and following Bonferroni post-hoc test (p=0,05); while for non-parametrical data (iEMG) differences were obtained using Friedmann test and following Wilcoxon test (p=0.05).

RESULTS AND DISCUSSION
Prior to the measurements, average temperatures (±SD) at stage 1 were (25.0±0.4, 25.4±0.7, 25.2±0.5) °C and at stage 2 (3.4±0.7, 4.8±2.4, 3.6±1.1) °C for heel, Met1 and Met5, respectively. Directly after the measurements, plantar temperatures in stage 1 were (25.1±0.5, 25.3±0.6, 25.2±0.4) °C and in stage 2 (3.3±0.6, 3.8±1.1, 3.2±0.8) °C for heel, Met1 and Met5, respectively.

Table 1: Mean (±SD): iEMG [mV*ms] and COPs [mm] for antero-posterior and medio-lateral perturbation directions.

	antero-posterior (AP)				medio-lateral (ML)			
	Interval 1		Interval 2		Interval 1		Interval 2	
Stages	**25 °C**	**0 °C**	**25 °C**	**0 °C**	**25 °C**	**0 °C**	**25 °C**	**0 °C**
COP_Total	113.2±15.0	115.1±18.3	95.4±16.1‡	90.9±16.8‡	114.2±16.5	113.6±15.8	89.9±12.8*****	86.5±13.0*****
COP_AP	69.0±9.1	69.6±9.7	58.6±12.1#	52.3±10.2#	70.9±13.5	70.4±12.5	61.5±9.9	58.9±10.6
COP_ML	75.6±12.1	76.4±12.9	62.9±11.4	63.2±13.0	74.8±8.3	74.6±8.9	52.8±7.3	51.0±6.1
Tib	1006.5 ±711.4	972.1 ±639.0	11829.9 ±4253.2**§**	11338.8 ±4868.2**§**	1071.5 ±782.8	1200.4 ±782.8	19121.3 ±6694.5**ϕ**	17865.9 ±5883.9**ϕ**
Fib	2180.2 ±1044.6	2197.8 ±1216.0	5418.4 ±2573.9	5010.9 ±2506.4	2960.5 ±1950.6	3021.4 ±1870.4	4591.9 ±1466.3	4491.5 ±1522.6
Gm	2498.7 ±1208.0	2507.2 ±1148.7	3679.0 ±1584.8	3935.3 ±1819.7	2368.2 ±1138.4	2322.1 ±1169.1	10309.9 ±4017.7†	9352.2 ±3299.2†

Significant differences: ‡ p=0.012; *# p=0.000;* **§** *p=0.045;* ***** *p=0.028;* **ϕ** *p=0.011;* **†** *p=0.003.*

Data of plantar foot temperatures indicate that hypothermia was both successfully induced and maintained during all conditions. Since it has been demonstrated that a variation of 5-6°C of the initial foot sole temperature influences the functionality of plantar mechanoreceptors [2], it can be stated that plantar receptors were affected by hypothermia. Discrepancies between the temperature of the thermal-plate in stage 2 (0 °C) and plantar foot temperatures likely occurs due to protection mechanisms, e.g. cold induced vasodilatation [3]. In interval 1, no significant differences for all COP parameters and iEMGs were found between temperature stages, in both perturbation conditions (AP, ML). In contrast, during interval 2, significant decreases of Total- and AP COP excursions as well as iEMG of Tib were seen after hypothermia in the AP perturbation condition. In interval 2, significant differences were also found for the ML perturbation: Total COP excursion and iEMG of Tib and Gm showed a significant decrease after hypothermia (Table 1). Initially, it was hypothesized that a reduction of skin temperature would reduce the functionality of plantar mechanoreceptors and, consequently, would induce increases in both COPs and iEMGs. However, results reveal significant differences only in interval 2 and in an opposite direction as was predicted. Therefore, our hypothesis could not be confirmed. The absence of significant differences during interval 1 can be explained by previous studies showing lower leg EMG onset latencies at around 100 ms after similar unexpected perturbations [4]. Also, during similar anterior platform perturbations, active COP displacement occurred at 132.9±12.5 ms (mean±SD) [4]. Analyzed data measured by an accelerometer (not conclusively analyzed yet) suggest that the first reversal point of the bottom platform occurred at around 100 ms post trigger. Therefore, corrective lower leg muscle activity and following active COP displacements to regain balance after unexpected perturbations likely were not present during interval 1. Significant lower iEMG and shorter COP displacements found in interval 2 after hypothermic reduction of plantar sensory inputs could be explained by the multisensory organization of the human balance system. Thereby, an impairment of plantar sensor activity may be compensated by other sensory systems [5]. Furthermore, learning effects during balance tests, which might have dominated these hypothermic effects, seem plausible. Postural sway represents the sum movement of the COP [6] and little sway represents less energy costs in terms of retaining postural balance [7]. Therefore, learning effects are conducted to optimize motor performance [7]. At first, dynamic balance ability, as it was tested in the present study by unexpected perturbations, requires an elevated optimization of motor performance in comparison to quasi-static tests. Secondly, performance difficulty was increased by one leg stances, especially when the ML perturbation direction was executed. Thus, the requirement for motor optimizing learning effects is highly present and it may be the main argument of explanation for the balance improvement even after hypothermia. According to the present data, however, it was not clear whether plantar sensory inputs could be compensated or not since learning effects seem to play a dominant role. Further analysis of the present data should include time-specific parameters such as EMG onset and offset latencies. In the future, studies are needed to investigate the role of plantar sensory input on balance, while minimizing the possible influence of learning effects during tests. Finally, a positive aspect of this study was the permanent and controlled plantar hypothermia, which was successfully induced.

CONCLUSIONS

This study showed that permanent plantar foot hypothermia could be successfully induced during the trials by using a thermal-plate. Results showed an improvement of dynamic balance ability after hypothermia, rejecting the initial hypothesis. This might be explained by the presence of compensatory sensory inputs or by learning effects. Therefore, the specific role of plantar receptors remains unknown and further investigation should include approaches to minimize the influence of learning effects.

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