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**Somatosensory cortical facilitation during step preparation
restored by an improved body representation in obese patients**

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Disclosure

None of the authors have potential conflicts of interest to be disclosed.

Highlights

- Enhanced processing of foot tactile input improves step initiation in the obese
- A top-down signal from the posterior parietal cortex reweights foot cutaneous inputs
- The APA are improved by an intervention program targeting body representation

Key words: Anticipatory postural adjustments, obesity, plantar sole afferents, step initiation, body representation, EEG

Abstract

Background. The anticipatory postural adjustments (APA) associated with step initiation are impaired in obese patients (e.g. longer duration, greater lateral center of pressure excursion). This could arise from the known altered internal representation of the body in obese individuals as this representation is crucial for enhancing the processing of foot cutaneous inputs prior to step initiation and for setting the APA.

Research question. The purpose of the study was to examine if the processing of foot cutaneous inputs and the preparation of the APA when planning a step are impaired in obese patients due to their damaged body internal representation (BIR). We also investigated whether these sensorimotor processes will be restored after a 15-day intervention program composed of motor and cognitive activities engaging the BIR without aiming weight loss.

Methods. We compared, prior to (D1) and after (D15) the program, the amplitude of the cortical response evoked by foot cutaneous stimulation (SEP) occurring either during quiet standing or during the planning of a step in 18 obese patients (mean body mass index, BMI: 35). The APA were analyzed by measuring the amplitude and latency of the lateral force exerted on the ground.

Results and significance. The SEP amplitude was not significantly different between the standing and stepping tasks at D1, but increased in the stepping task at D15. This enhanced sensory processing was associated with an increased activation of the posterior parietal cortex, suggesting a stronger involvement of the body representation during the planning of the stepping movement after the program. These cortical changes could have contributed to the changes in the temporal dimension of the APA observed at D15. These results suggest that programs targeting different dimensions of the BIR could be beneficial in improving the dynamic balance in obesity.

1. Introduction

Gait is initiated by anticipatory postural adjustments (APA) which are largely under feedforward control [1]. Such mode of control for gait initiation relies on the use and the quality of an internal representation of the body position in space [2] which is built up and updated by multiple sensory modalities. For example, somatosensory inputs provide crucial information on body position for setting the APA, notably the forces exerted on the ground that shift the body weight forward and laterally towards the supporting side to unload the stepping leg [3]. Importantly, several studies have pointed out notable impairments in the APA of obese patients [4] and in their balance stability in general [5]. These impairments are interpreted to be a consequence of a reduced tactile sensitivity stemming from the over-compression of the plantar mechanoreceptors in obese individuals [6]. A recent somatosensory-evoked potential (SEP) study performed with non-obese standing participants wearing a weight-vest (i.e., ~27% increased body weight) showed the impact of extra weight on plantar sensory transmission [7]. The first response recorded over the somatosensory cortex to electric stimulation of the foot sole was reduced when the participants wore the loaded vest. It should be noted that body oscillations also increased in this situation.

While the assumption that APA setting and balance control in obese individuals are impaired by a decreased tactile sensitivity appears undisputed, the question remains as to whether such impairments are also linked to an altered body internal representation (BIR) in this population. It is indeed well known that perceptual distortion of the body representation is the core feature of obesity and eating disorders [8]. An impaired body representation in obese patients could have in turn detrimental effects on the processing of foot cutaneous inputs and on the preparation of the APA associated to step initiation. The importance of the BIR in such sensorimotor processes is suggested by results showing that the enhanced processing of foot cutaneous inputs prior to step initiation coincides with an increase in the activity of the

extrastriate body area (EBA) [9]; a key region for implementing and updating multisensory representations of the body in humans [10, 11]. The BIR would be critical for the top-down signal that increases the response to tactile foot stimulation relevant for step initiation [12]. Based on the presumed altered BIR in obese individuals, using SEP techniques we first tested our prediction that the neural mechanisms reflecting enhanced processing of cutaneous inputs reported in non-obese individuals during the planning of a step forward [11] will be absent in obese individuals.

The goal of the present study was to further test the impact of the body representation on the sensorimotor processes associated with step preparation. This was achieved by comparing the response of obese patients to foot cutaneous stimulations before and after a 15-day intervention program composed of motor and cognitive activities involving body representation (e.g., proprioceptive training, dance and acting classes, mindfulness-based stress reduction (MBSR)). For instance, dance or dance-like training is known to improve the accuracy of body representation [13, 14] and also to change the APA setting [15]. It enables dancers to control to a greater extent the APA associated with leg raising with feedforward processes when compared to non-dancers who make greater use of sensory-based feedback processes [15]. On the other hand, focusing essentially on self-awareness and body sensation, the MBSR is known to impact body representations as suggested by the increased in grey matter concentration in temporoparietal area (TPJ) of MBSR participants [16]. We hypothesized that after the 15-day intervention program, obese participants will show greater activities over cortical areas involved in body representation during the planning of stepping movements. This increased activity should be associated with an enhancement of the processing of foot cutaneous inputs and changes in the APA. Finally, to gauge whether our program had an impact on the BIR, we compared the participants' responses provided before and after the intervention program to 2 standardized body image questionnaires [17]. Indeed, body image perception may constitute a

perceptual outcome of sensorimotor processes according to the embodied theories [18] which propose that the conceptual representations are grounded in sensory and motor systems.

2. Methods

2.1. Participants

Eighteen obese persons (mean age: 49 ± 8 years, 13 women) took part in this study. We recruited obese persons with a body mass index (BMI) ranging from 30 to 45 (mean BMI: 35 ± 3 , mean body mass: 95 ± 12 kg, mean height: 165 ± 8 cm). Exclusion criteria were diabetes and/or fibromyalgia pathologies and left dominant leg (determined by the Edinburgh test (handedness) adapted to the lower limb). Obese patients were on day hospitalization (from 8 a.m. to 4 p.m., <http://www.cliniquesaintchristophe.com/equilibre>). They participated in a 15-day program based on proprioceptive training (10 h), dance and dance-like training (12 h), hiking and physical activity (10 h) and mindfulness-Based Stress Reduction and relaxing session (8 h) (see for details Table 1). Note that weight loss was not an objective of the program and was only marginal (averaged body mass loss: 2.6 ± 1.8 %). We also tested a control group of 5 participants (mean age: 50 ± 13 years, 3 women; mean BMI: 35 ± 3) who did not follow the training program. The experiment was conducted with the understanding and written consent of each participant, and the local research ethics committee at Saint-Christophe Clinic approved all procedures. The protocol and procedure were in accordance with the 1964 Declaration of Helsinki.

2.2. Task and Stimulating system

The experiment was performed before (D1) and after (D15) the intervention program and was part of a clinical package. For the control group, participants were tested at D1 and 2-weeks later (D15). Participants standing on a force platform performed a “Standing” and a

“Stepping” tasks. Before each trial of each task, participants were asked to self-select a comfortable side-by-side foot position and to stand still with the eyes closed and the arms alongside the body. In the Stepping task, participants were instructed to produce with their right leg, a small step forward at a comfortable speed, and to land on the same force platform surface on which they were standing. They were asked to synchronize the onset of their step with the third auditory signal (i.e., the last of three 1-s interspaced 100-ms tones, Fig 1). For reasons of homogeneity, the same tones were played in the Standing task. Each standing or stepping trial recording lasted 5s.

In both tasks, four electrical stimulations were delivered to the plantar sole (i.e., tibial nerve innervating the cutaneous receptors) of the left foot (see for details Fig.1 legend). Each (10 ms square pulses) stimulation was separated by 500ms. For the Stepping task, the stimulation occurred twice during the preparation phase of the APA (St1 and St2, respectively 600 ms and 100 ms before the GO signal) and twice during the execution phase of the APA (St3 and St4) (Fig.1). The same 4 stimulations were delivered relative to the third tone in the Standing task (hereafter all referred to as St0). As the present paper focused on the sensorimotor processes related to APA preparation, only St1 and St2 were included in the analyses, St3 and St4 permitting the same number of stimulations in both tasks. Forty stimulations were delivered for each condition. Ten trials were necessary in the Standing task to obtain 40 stimulations (4 stimulations per trial). In the Stepping task, because there was only one St1 and St2 stimulations per trial, 40 trials were necessary to have 40 stimulations for the St1 and St2 epochs. The tasks were presented in a random order.

2.3. Behavioral recordings and analyses

Participants stood on a 46 × 51 cm force plate (AMTI OR6-6, Watertown, MA, USA). Ground reaction forces (mediolateral, ML and anteroposterior, AP) and torques were recorded

at a sampling rate of 1000 Hz. The ML shear force was used to identify the APA initiation (Fig.1). To determine if the APA were modified at D15, we analyzed the lateral force exerted onto the ground (i.e. thrust, from onset to peak, Fig. 1). To assess the effect of the training program on balance control, we computed for both the Standing and Stepping tasks, the integral of the horizontal forces (i.e. impulse) in both AP and ML directions over a 1.5s-period starting at the first tone, i.e. when participants had to stand still (for the stepping task, this time-window was virtually free of step-related muscular activity). In order to analyse the forward step execution, the motion of the right foot was recorded with a Flock of Birds (Ascension Corporation) (Fig.1).

2.4. Electrophysiological recordings and analyses

Electroencephalographic (EEG) activity was continuously recorded from 64 Ag/AgCl surface electrodes embedded in an elastic cap (BioSemi ActiveTwo system: BioSemi, Netherlands). The signal was pre-amplified at the electrode sites, post-amplified with DC amplifiers, and digitized at 1024 Hz. Off-line filtering with a 50 Hz digital notch filter and a 0.5-45 Hz band-pass digital filter (48 dB/octave) implemented in BrainVision Analyzer 2 software (Brain Products, Germany) was applied. We measured the SEPs (P1N1, Fig.3A) over the Cz electrode which overlays the sensorimotor cortices.

The neural source of the SEPs was estimated using the averaged preprocessed data with the dynamic statistical parametric mapping (dSPM) implemented in the Brainstorm software [19]. The forward model was computed using a three-shell sphere boundary element model (BEM) on the anatomical MRI brain MNI Colin 27 template (15000 vertices), a predominant volume conductor model. We contrasted the absolute EEG activity computed in the source space between St1 and St0 during three 40-ms time-windows from the stimulation onset: 15-55

ms (preceding P1), 55-95 ms (encompassing P1N1), and 95-135 ms (after N1). For comparison, the same computations were performed at D1.

2.5. Body schema/image questionnaires

Currently, there is no test that can be used to directly assess the quality of an internal body representation. In the present study, this assessment was performed using two standardized questionnaires: the Body-Image Questionnaire (BIQ) [17] and an adaptation of the 1983 Stunkard's Figure Rating Scale (Fig.6B).

2.6. Statistical analyses

All behavioral (APA and balance stability) and EEG dependent variables showed normal distributions ($p > 0.05$, Shapiro-Wilk test). The Standing task (St0) was used as a baseline reference for assessing SEP modulation during the preparation phase of the stepping movement and was included in the factor Epoch along with St1 and St2. The amplitudes and latencies of the SEPs were submitted to 2 (Day: D1, D15) x 3 (Epoch: St0, St1, St2) repeated-measures analyses of variance (ANOVA). Significant effects were further analyzed using the Tukey's HSD post hoc test. Wilcoxon's test was used to compare the scores of the questionnaires. Since the sample size of the control group was small, partial Eta-Squared values for the effect size were given for the ANOVA. The threshold of significance was set at 5% for all analyses.

3. Results

3.1. Motor task performance and equilibrium

The time to peak force significantly decreased at D15 relative to D1 ($t_{17} = 3.29$, $p = 0.004$, Fig. 2A) while no significant difference in the peak force amplitude was observed ($t_{17} = -0.73$, $p = 0.48$). As a consequence, the amount of lateral force exerted onto the ground (i.e. the area under the force-time trace) significantly decreased in D15 ($t_{17} = -2.52$, $p = 0.02$). The latency of these lateral forces did not significantly differ between D1 and D15 ($t_{17} = -1.75$, $p = 0.1$). The timing of the onset of the forces relative to the Go signal varied between participants, ranging between -229 ms and +252 ms (average: 7.4 ± 130 ms). Because St1 was triggered 600 ms before the Go signal, this indicates that for all participants, St1 epoch was free of motor activity and occurred during the planning of the movement. The amplitude and the duration of the forward step movement did not significantly differ between D1 and D15 and were on average 26 ± 5 cm and 938 ± 203 ms, respectively (amplitude: $t_{17} = 0.39$, $p = 0.69$; duration: $t_{17} = 0.66$, $p = 0.52$).

Variables related to balance control (Fig.2B) were analyzed to verify whether the stability varied across the experimental sessions (D1, D15). The ANOVAs did not show significant effect of Day (D1 and D15) on the force integrals in both the Standing ($F_{1,17} = 0.28$; $p = 0.59$; $p = 0.91$) and Stepping tasks ($F_{1,17} = 0.01$; $p = 0.91$). Importantly, these behavioural results indicate that the control of the patients' APA was modified after the program but not the control of their static balance.

3.2. Brain activity

The ANOVA revealed a significant Epoch x Day interaction on the amplitude of the P1N1 ($F_{2,34} = 3.49$; $p = 0.04$) (Fig.3B). The decomposition of the interaction indicated that solely after the program (i.e. D15), the P1N1 amplitude was greater during the early preparation phase of the stepping movement (St1) than in both St0 ($p = 0.0017$) and St2 ($p = 0.0003$). Note that in the standing task (St0) similar P1N1 amplitudes were observed at D1 and D15 ($p > 0.05$).

The ANOVA did not show significant effect of Epoch ($F_{1,17} = 2.38$; $p = 14$) or Day ($F_{1,17} = 0.2$; $p = 0.63$) on P1 latency (overall mean 66 ± 9 ms). Similarly, the latency of N1 (overall mean 92 ± 11 ms) was not significantly impacted by the factors Epoch ($F_{1,17} = 0.8$; $p = 0.36$) and Day ($F_{1,17} = 0.18$; $p = 0.68$).

The source analyses estimated the left posterior parietal cortex (PPC) as the generator of the increased SEP at D15 (see statistical maps of Fig. 4). No such significant effect of the APA preparation on the PPC activity was found at D1. Interestingly, we also observed an increased activity of left premotor cortex (BA6, PMC) during the preparation phase at D15 which culminated 95-135 ms after St1 stimulation and which was not observed at D1. Being first observed 95-135 ms post St2 stimulation (see Fig.5), the premotor activity was delayed in D1 relative to D15.

Importantly, the control group did not show significant effect of Epoch (St0, St1; $F_{1,4} = 0.66$; $p = 0.55$, $\eta_p^2 = 0.14$) or Day (D1, D15; $F_{1,4} = 0.47$; $p = 0.53$, $\eta_p^2 = 0.11$) or Epoch x Day interaction ($F_{2,8} = 2.19$; $p = 0.17$, $\eta_p^2 = 0.35$) on the amplitude of the P1N1. In addition, none of the 3 analyzed time-windows showed significant neural sources activity (e.g., PPC, PMC) differences between St0 and St1, both at D1 and at D15. Moreover, the latency of the left PMC activity did not significantly differ between D1 and D15 ($t_4 = 0.08$; $p = 0.93$). On average, the activity of the PMC increased $115 \text{ ms} \pm 10$ after St2. This latency is similar to that observed in the experimental group, but only at D1. Overall, similarities of the SEP and brain sources variables suggest that the changes observed at D15 in the experimental group resulted from the intervention program rather than from uncontrolled time-related effects.

3.3. Body representation/image questionnaires

The BIQ score was greater at D15 than at D1 ($z = 2.11$; $p = 0.03$), suggesting a change in the obese patients' body image at the end of the program (Fig. 6A). Moreover, the patients perceived their BMI (Fig. 6B) as being smaller at D15 than at D1 ($z = 2.66$; $p = 0.007$).

4. Discussion

Through behavioural (APA) and EEG (SEP and source localisation) analyses, the present study showed an enhancement of somatosensory processes during step preparation after a two-week intervention program that aimed at improving obese patients' BIR.

Previous studies have shown that all markers of postural stability improve when obese individuals lose weight (~20% weight loss in Teasdale et al. [20]) and that the transmission of sensory inputs to the cortex is greater in individuals not carrying extra weight [7]. In the present study, weight loss after the intervention program was ~3% only and was not associated with balance improvement. Therefore, the changes in the sensorimotor processes observed here unlikely resulted from the patients' decreased body weight. In addition, because it was not observed in the Standing task at D15, the increased SEP at D15 cannot merely stem from a greater sensitivity of cutaneous receptors per se (note this is also suggested by the same perceptual threshold to cutaneous stimulations between D1 and D15). One could argue that the increase in early SEP could have resulted from uncontrolled time-related effects rather than genuine changes in sensorimotor processing due to the program. However, the absence of increased negativity at D15 relative to D1 in the control group (corroborated by high Eta-squared values), composed of obese patients who did not follow the intervention program, does not support this hypothesis. Rather, we hypothesize that the sensorimotor changes observed after the program, which enhanced relevant foot cutaneous information for step preparation [21], were linked to a modified BIR or a more efficient use of this representation by the patients.

Several key elements of the present study support this hypothesis. The various modules of the program taken by the patients are known to engage cognitive and sensorimotor dimensions of the BIR [15, 14, 16; for review, see Fabre et al. [22]. Indeed, activities emphasizing body awareness such as dance, Tai Chi Chuan or MBSR improve balance sensorimotor control and BIR. For example Marmeleira et al. [14] has shown that sedentary participants over 55 years of age trained in creative dance (i.e., 54 h over 12 weeks) show improvements in the sense of joint position and in the perception of segment orientation relative to space, suggesting enhanced proprioceptive sensory processes. Similarly McGibbon et al. [23] reported in participants older than 50 years that a 10-h training in Tai Chi Chuan leads to an improvement of balance control through vestibular mechanism. On the other hand, mindfulness practice, in addition to improving balance [24], has been associated with neural structural changes as observed by [16] in the temporo-parietal junction (TPJ) after a 8 week-program (total of 26 h). As reviewed by [25], this cortical region is known to host a spatial representation of the self [10], and to be involved in the perception of body parts ([26] in the mental imagery of one's body [27] Ionta et al. 2011)). The structural change observed over the TPJ region by Hölzel et al. (2011) [16] is then consistent with an improvement of the BIR after the mindfulness program.

The increased activity of the inferior parietal lobules (BA 39/40, i.e. TPJ) prior to, and during the P1N1 at D15, but not at D1 suggests a stronger involvement of the BIR during the planning of the stepping movement after the program. This representation would play an important role in the setting of the APA as suggested by studies showing that the APA of individuals involved in dance and dance-like training are highly accurate and do not necessitate online adjustments [15]. APA setting is known to be achieved by adjusting their temporal dimension [28] and was reflected here in a decreased duration of the shear forces exerted on the ground.

The premotor activities (i.e. BA6) preceding step initiation were observed earlier at D15 than at D1, while the APA onset time and the step length were not modified by the program. The dorsolateral PMC is known for contributing to the motor command of self-paced stepping movements and for generating feedforward signals for triggering the APA [1, 22]. The PMC is also considered as being crucial in situations where the mapping between sensory inputs and motor actions is important [29]. In this light, changes in the premotor activities noted here at D15 and not present in the control group at D1 or D15, are consistent with an enhanced preparation of the focal leg movement after the program. This preparation could have benefited from BIR-related information stored in the PPC which has dense connections with the premotor cortex [26]. Then by improving the BIR is also a means to improve the motor preparation as previously shown for dancers [15] resulting here in modification of premotor activations at D15.

A limitation of the present study is that it does not provide information as to whether the behavioral and neurophysiological changes observed during step preparation last over time after the intervention program. Another limitation is that it is still not possible to differentiate between the various contributions to these changes of the different modules of the program and of the different sensory modalities involved. Even if some training elements are performed with eyes closed (e.g., MBSR and relaxing session), it is possible that visual information during training still contributes to the changes of BIR observed since it is constructed with multisensory information [10, 11]. Also even with eyes closed, as in this experiment, it is possible for the participants to use a visual representation of the body during the preparation of a movement with the lower limb. Indeed Mouchnino et al. [9] have shown that an increase in activation of the extrastriate body area (EBA) is a part of the step preparation mechanism with eyes closed. EBA is known to host visual representation of the body, like Limanowski [11] showed that this brain area integrates visual and proprioceptive information into a body

representation. Downing et al. [30] also showed that EBA is specialized in visual processing of the human body.

In conclusion, our results show that a two-week program improves the BIR of obese patients, which in turn, leads to an enhanced processing of foot cutaneous inputs prior to step initiation. Despite the limitations of the protocol, the results of the present study suggest that the implementation of intervention programs which incorporate tasks targeting different dimensions of the BIR, could be part of a strategy to improve the dynamic postural control in obese individuals.

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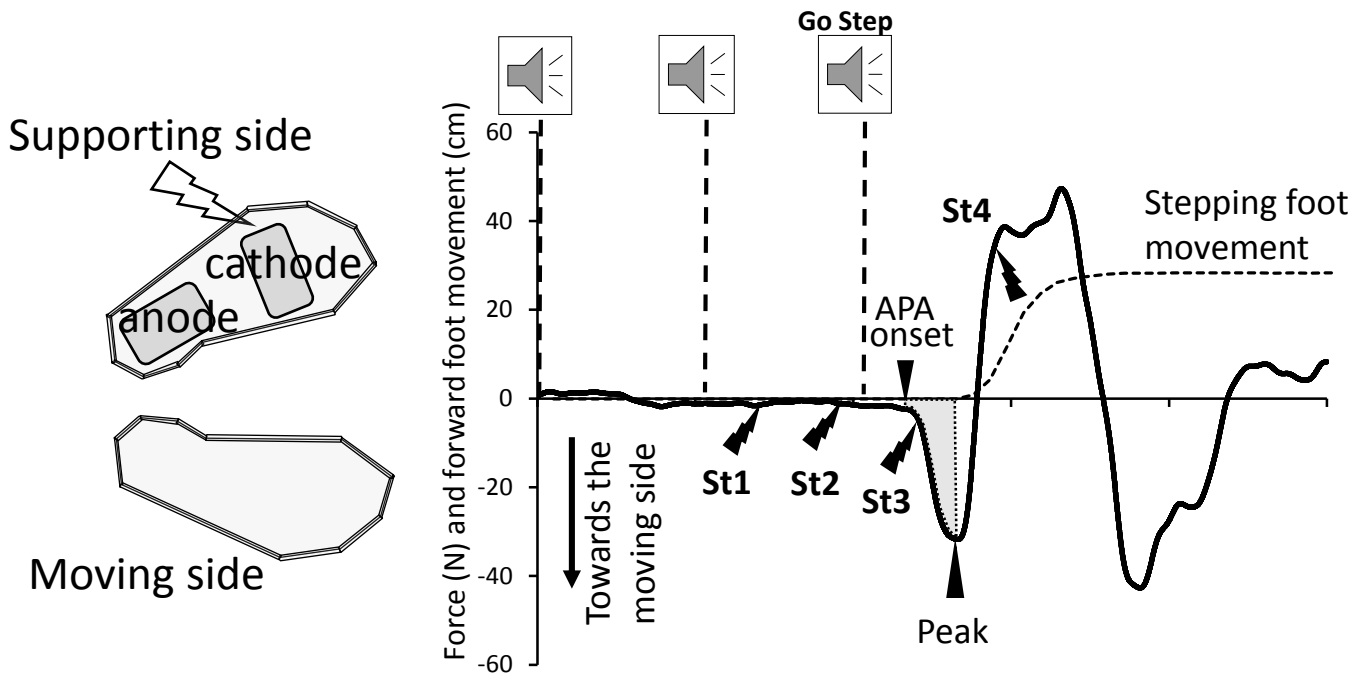
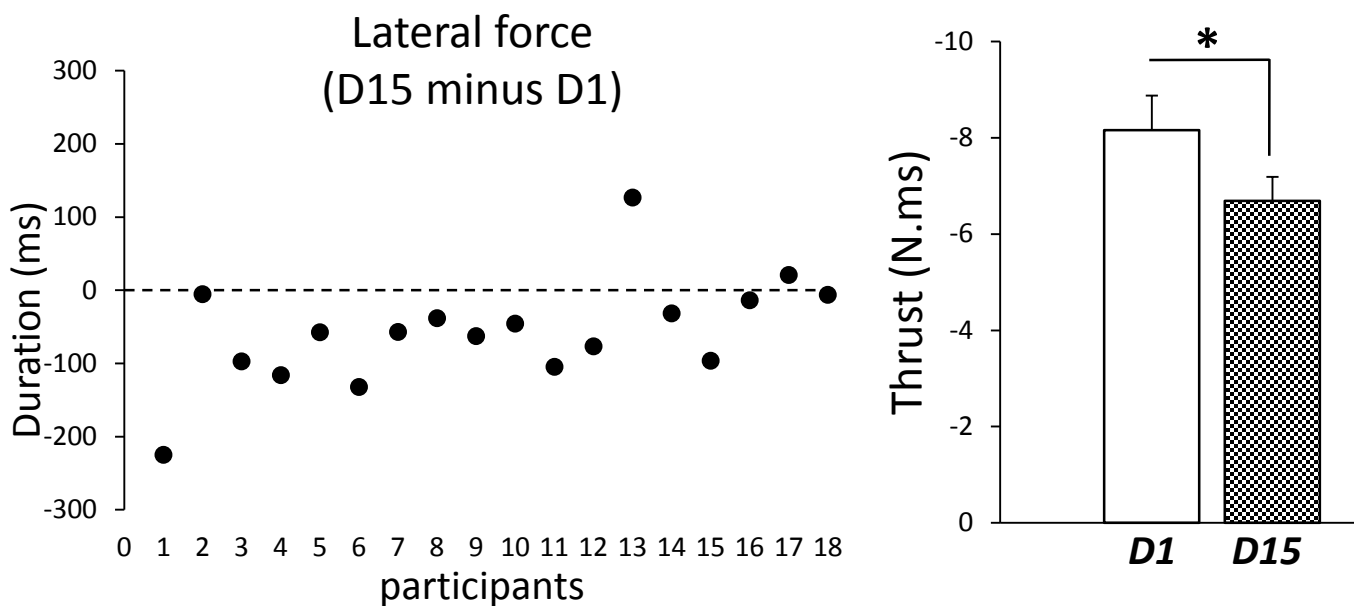


Figure 1: *Left panel:* Position of stimulation electrodes under the left foot. The stimulus was delivered by an isolated bipolar constant current stimulator (DS5 Digitimer, Welwyn Garden City, UK); using 5×9 cm Platinum Foam electrodes located under the metatarsal region (cathode) and underneath the heel (anode). The stimulation consisted of a single rectangular 10-ms pulse. The stimulation intensity was set at 25% higher than the lowest intensity producing a constant perception of the stimulation while standing still. For each participant, the minimal intensity required for the stimulation to be constantly perceived was similar for both D1 and D15. Therefore, the stimulation intensity was kept identical for both sessions (mean amplitude: 8.2 ± 1.7 mA). For all participants, this intensity was below the motor threshold (i.e., no visible evoked response in the EMG traces). *Right panel:* Behavioral recordings during the Stepping task for one representative participant: mediolateral shear forces (filtered with a 4th order Butterworth low-pass filter with 10 Hz cut-off frequency) (solid line) and right foot forward displacement (dotted line) (positive and negative values represent forces directed to the left and to the right of the participant, respectively). The shaded area on the graph indicates the analyzed portion of the ground reaction forces. Speakers represent the onset of the 3-sound signals with 1-s interval. Lightning symbols on the right panel indicate the timing of the electric stimulations during motor preparation and execution.

A Anticipatory postural adjustments



B Balance maintenance

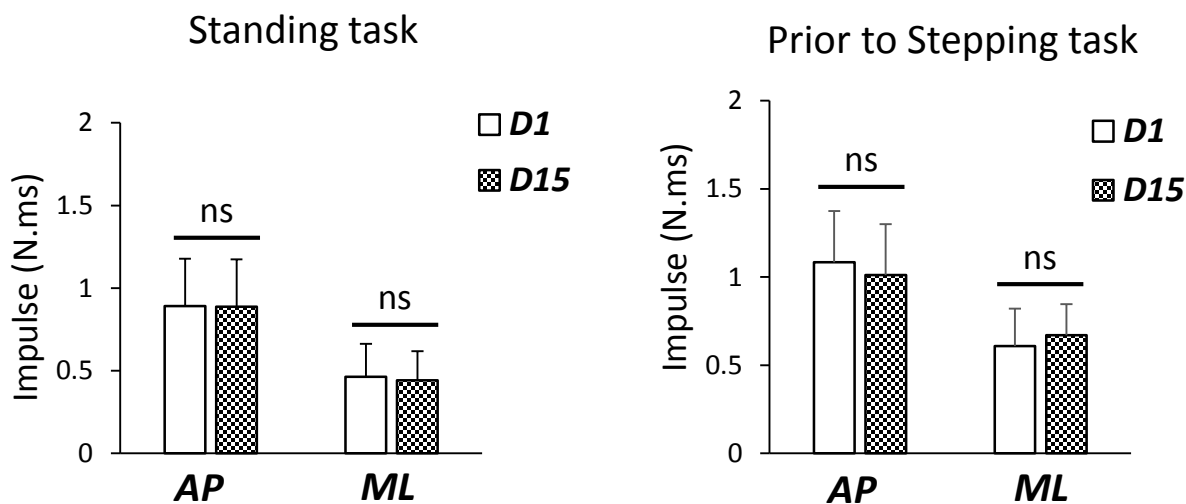


Figure 2: **A.** Left panel: Difference for each participant between the mean time to peak force recorded at D15 and at D1 (D15-D1). Negative values indicate that time to peak force was shorter at D15. Right panel: Mean amplitude for all participants of the averaged thrust computed between the APA onset and the lateral peak force in the Stepping task in D1 and D15 (error bars represent standard error across participants) (* $p < 0.05$). **B.** Mean impulse in AP and ML directions computed during the Standing task and prior to the APA in the Stepping task (left and right panels, respectively) when the participants were still motionless (error bars represent standard deviation across participants)

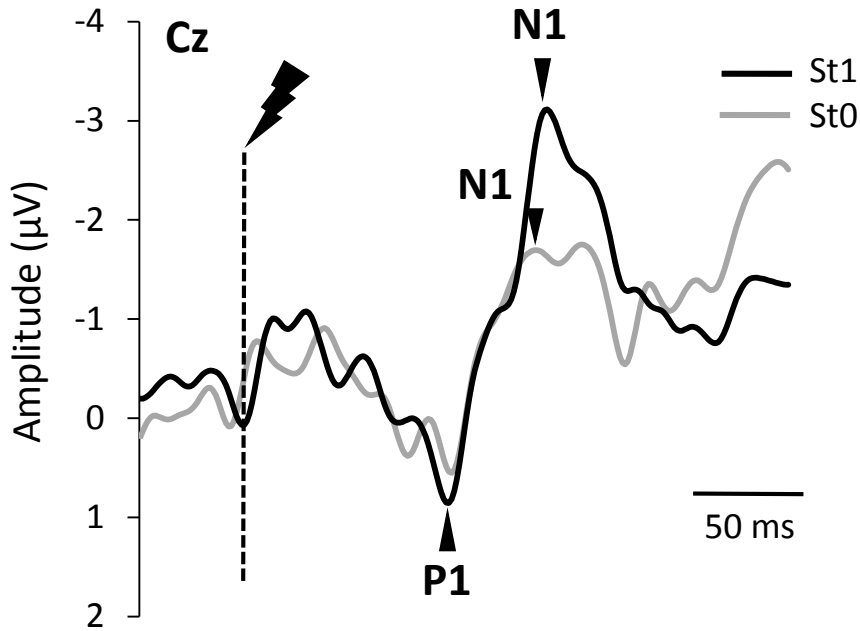
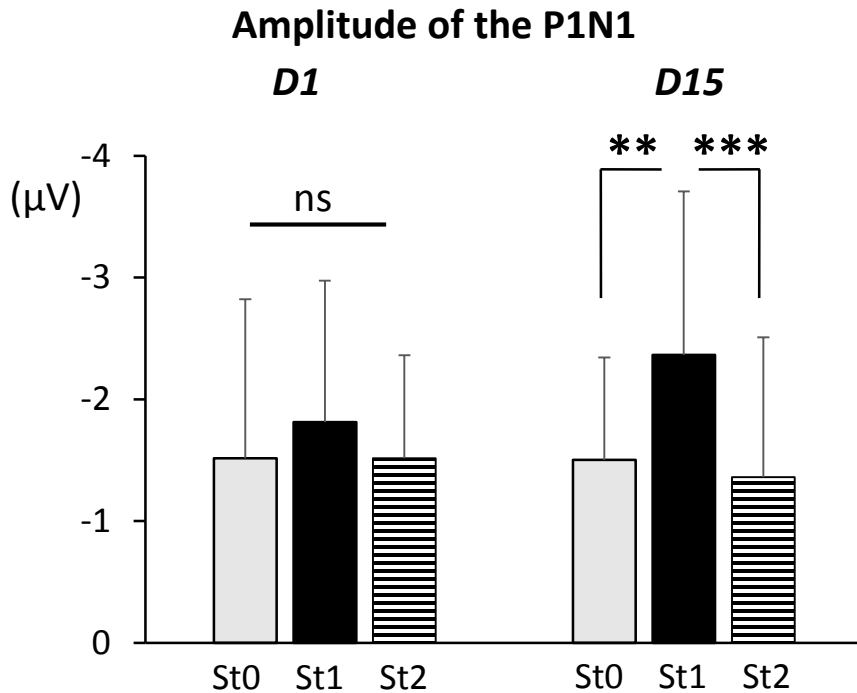
A**B**

Figure 3: A. Average of the somatosensory-evoked potential recorded over Cz electrode for 1 representative participant recorded at D15 and synchronized to St0 and St1 stimulations (grey and black lines, respectively). **B.** Mean amplitude for all participants of the averaged P1N1 evoked by the electric foot stimulation during standing (St0) and step preparation (St1, St2) at D1 and D15 (error bars represent standard error across participants). (** $p < 0.01$, *** $p < 0.001$).

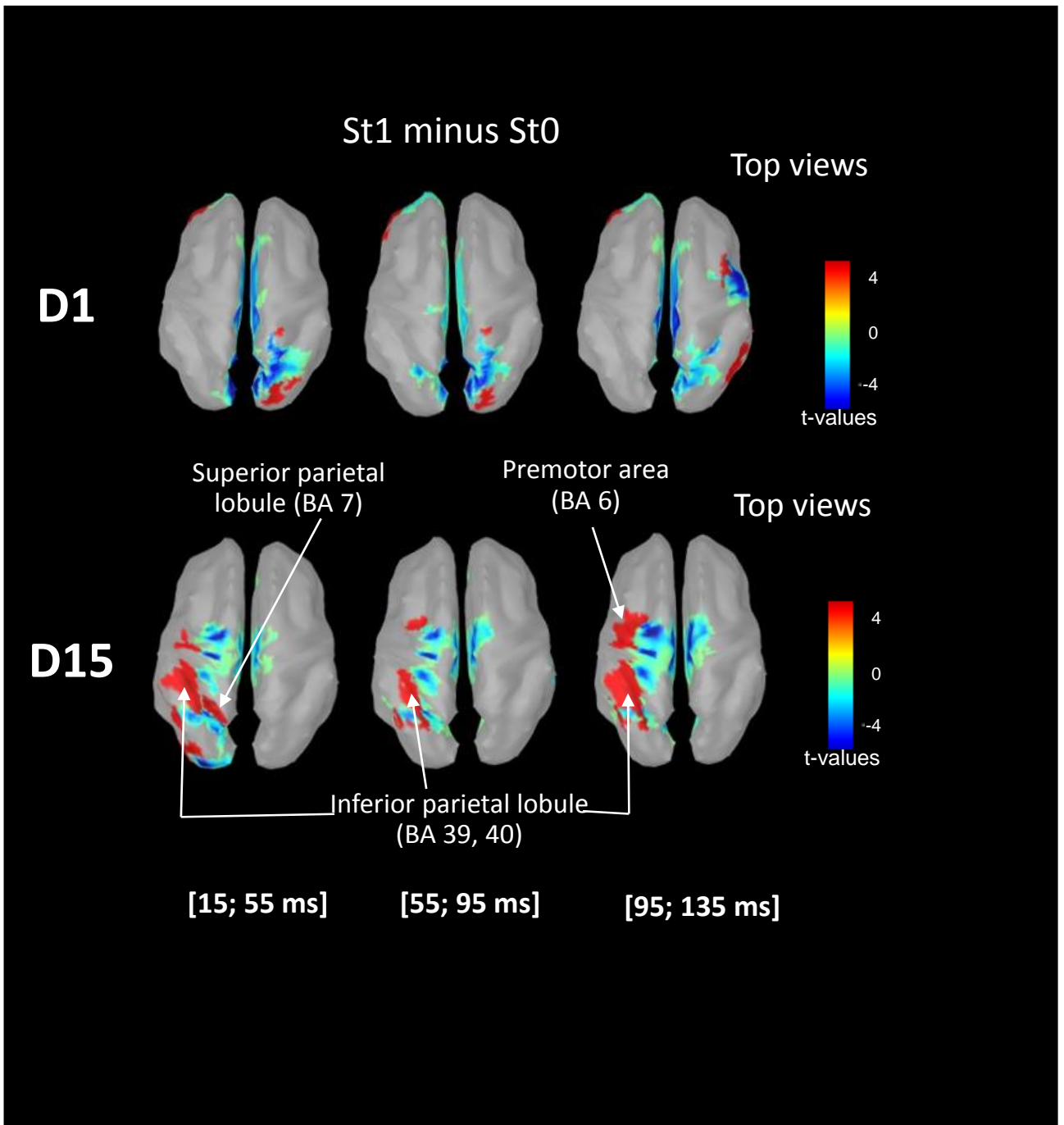


Figure 4: Statistical source estimation maps (top views) for the Stepping (St1) vs Standing (St0) tasks contrast averaged over three time windows for both D1 and D15: preceding the P1 component [15;55 ms], encompassing the P1N1 [55;95 ms], and following the N1 component [95;135 ms]. The superior (BA 7) and inferior (BA 39/40) PPC showed greatest activities before, during and after the SEP when participants prepared a step at D15 (as indicated by the shade of red)

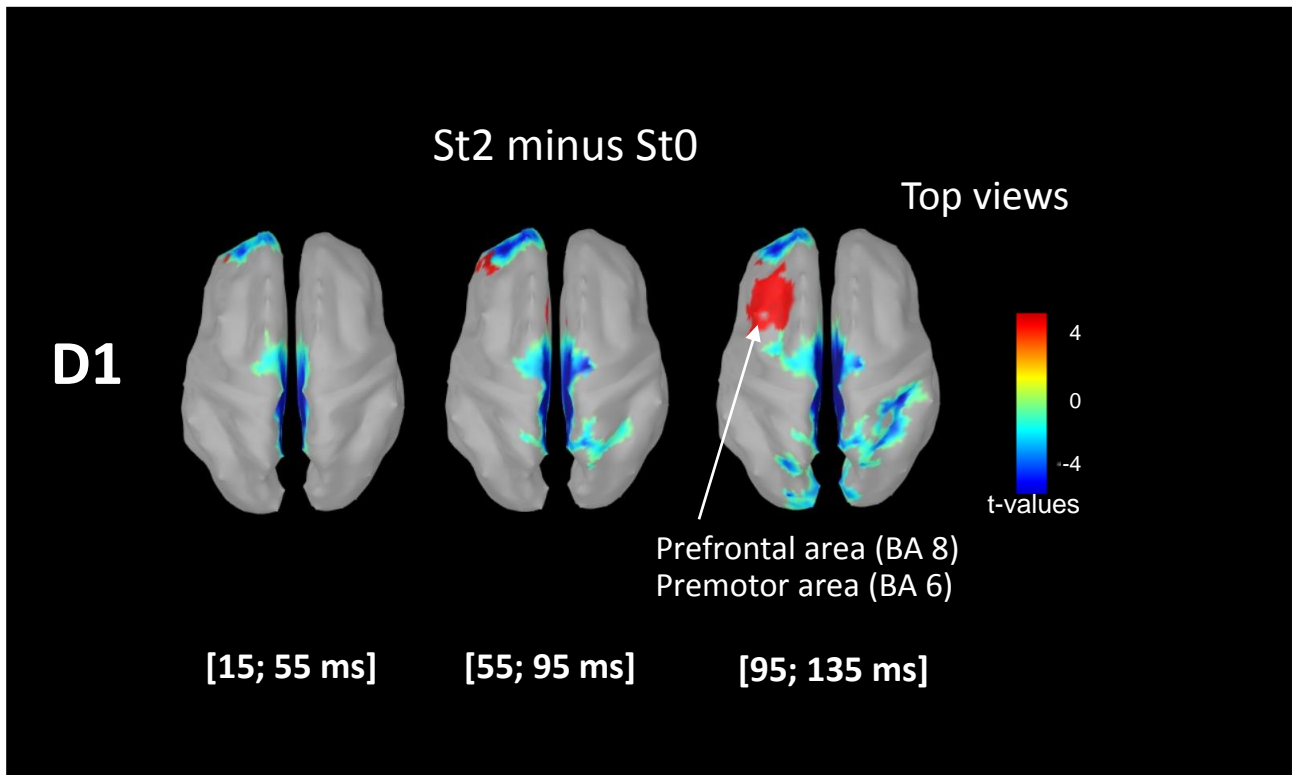


Figure 5: Statistical source estimation maps (top views) for the Stepping (St2) vs Standing (St0) tasks contrast averaged over three time windows at D1: preceding the P1 component [15;55 ms], encompassing the P1N1 [55;95 ms], and following the N1 component [95;135 ms]. Large activity of the prefrontal (BA 8) and premotor (BA 6) areas were observed in the late phase of the APA preparation (as indicated by the shade of red).

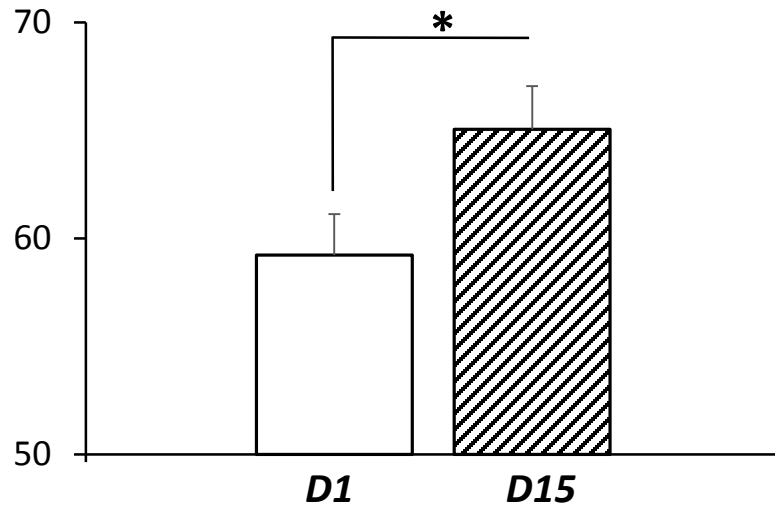
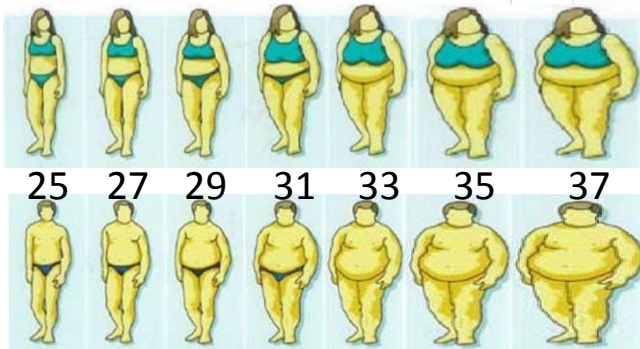
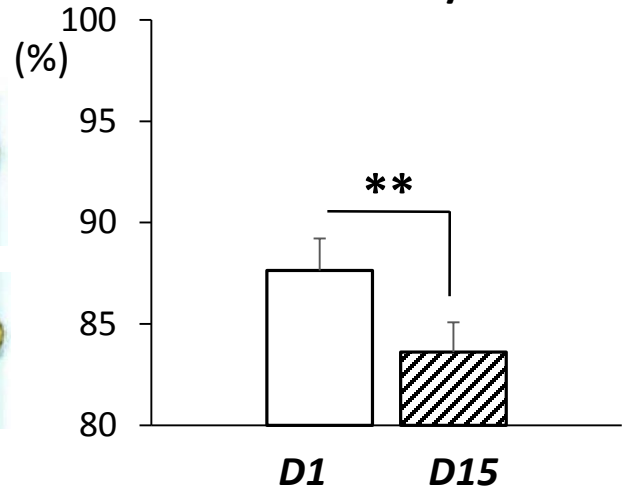
A**BIQ score****B****Perceived BMI/real BMI**

Figure 6: **A.** Mean averaged scores across all participants to the 19-item (bipolar) questionnaire [23] at D1 and D15. The aim of this questionnaire is to assess obese individuals' perception, satisfaction, and attitudes towards their bodily appearance. For each item, participants rated themselves on five-point scales, the sum of which providing a favourable body image index (scores of 19 and 95 corresponding to the least and most favourable scores, respectively). Error bars represent standard error across participants. **B.** Adaptation of the Stunkard's Figure Rating Scale where participants had to select the figurine (among 7 figurines, BMI ranging from 25 to 37, see left panel) with the silhouette that they deemed to be closest to their usual appearance. The histogram shows the mean average of perceived BMI in percentage of the real BMI for all participants at D1 and D15 (error bars represents standard error across participants). (*, $p < 0.05$; **, $p < 0.01$).