

# Imagined paralysis alters somatosensory evoked-potentials

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#### <u>Abstract</u>

Recent studies employing body illusions have shown that multisensory conflict can alter body 29 representations and modulate low-level sensory processing. One defining feature of these body 30 31 illusions is that they are sensory driven and thus passive on behalf of the participant. Thus, it remained 32 to establish whether explicit alteration of own-body representations modulates low-level sensory processing. We investigated whether tibial nerve somatosensory-evoked potentials were modulated 33 34 when participants imagined paralysis of their legs and arms. Imagined paralysis of the legs decreased P40 amplitude, but not imagined paralysis of the arms. These results show modulation of early 35 somatosensory processing via explicit, top-down alteration to the internal representation of the body. 36 Interestingly, P40 suppression positively correlated with bodily awareness scores whereas it 37 38 negatively correlated with body dissociation scores. This suggests that the ability to actively alter 39 own-body representation and its corresponding sensory processing depends upon dispositions to attend to and focus on bodily sensations. 40

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42 Key words: Imagined paralysis, body representation, imagery, somatosensory-evoked potentials,

#### **Introduction**

In the past decade, several studies have demonstrated the ability to modulate the perception of the 45 46 body by multisensory conflicts in healthy participants (for a review see Blanke, 2012). For example, during the rubber hand illusion participants observe a rubber or virtual hand being stroked in front of 47 48 them, while simultaneously experiencing their occluded real hand being stroked (Botvinick & Cohen, 1998; Hara et al., 2015; Tsakiris & Haggard, 2005). The integration of the simultaneous seen and felt 49 stroking results in the participant feeling like the rubber hand is their hand, which is also accompanied 50 51 by a drift in the perceived location of their real hand towards the rubber hand. This illusion has 52 evolved to incorporate a whole virtual body, creating a full-body illusion, characterized by illusory self-identification with, and self-relocation towards, a virtual body (Lenggenhager, Tadi, Metzinger, 53 54 & Blanke, 2007).

55 Illusory self-identification with a fake/virtual body is associated with physiological changes, such as decreased skin temperature (Moseley et al., 2008; Salomon, Lim, Pfeiffer, Gassert, & Blanke, 56 2013). However De Hann et al. (2017) and Nakul et al. (2020) showed that these results were not 57 consistent. In addition, illusory self-identification with a body increased pain threshold in healthy 58 59 participants (Hansel, Lenggenhager, Kanel, Curatolo, & Blanke, 2011) and evoked mild analgesia in patients with spinal cord injury (Pozeg et al., 2017). Other studies have provided evidence that the 60 full-body illusion modulated somatosensory information processing. Aspell, Palluel, & Blanke (2012) 61 have shown an increase in the amplitude of early (i.e. 40 ms post-stimulus onset) tibial nerve 62 63 somatosensory evoked-potentials (SEPs) during the full-body illusion. Similarly, Dieguez and 64 colleagues (2009) found that median nerve SEPs were larger during experimentally-induced illusion 65 of numbress in the index finger. These results suggest a link between experimentally-induced changes 66 in body representation and the way in which the brain processes sensory information, which also has 67 direct physiological consequences in the case of skin temperature. One common aspect of these 68 illusions is that they alter body representations through multisensory conflicts, which is passive on 69 behalf of the participant. That is, participants are not engaged in a cognitive process in order to alter 70 own-body representations. In the present study we investigated whether *mental imagery* of altered body representation is enough to modulate sensory processing in the brain, as previously shown
 during *experimentally-induced* alterations of body representation.

73 Imagined paralysis is a useful laboratory paradigm to alter own-body representations by 74 mental imagery. Hartmann, Falconer, & Mast (2011) instructed participants to imagine that they were 75 paralysed from the waist down while simultaneously performing a mental imagery task (Parsons, 1987). This task requires that participants mentally align and transform the internal representation of 76 77 their body composition (body representation) to match a target composition. Imagined leg paralysis impaired the participant's ability to mentally transform their body. This suggests that the 78 79 biomechanical constraints associated with paralysis are incorporated into the body representation, 80 impinging their ability to mentally transform it into another composition. The majority of research in 81 this field has used mental transformations and motor imagery, which focus on the use of the body representation in performing simulated actions (Kakigi et al., 1997). Our paradigm allows to 82 investigate the extent to which we can explicitly access and alter the body representation, and 83 consequently somatosensory cortex activity. 84

85 The aim of the current study was to build upon the behavioural results of Hartmann, Falconer, 86 & Mast (2011) by investigating whether the top-down process of imagining leg paralysis can influence physiological signals relevant to the body representation. We hypothesize that imagined 87 88 paralysis of the legs would influence the processing of tibial nerve signals in the somatosensory cortex. This is in contrast to imagined paralysis of the arms, which has no link with the tibial nerve. 89 90 We used electroencephalography (EEG) recordings during tibial nerve electrical stimulation to assess SEP modulation during imagined paralysis. Our hypothesis is two-tailed in that there is evidence to 91 suggest either an attenuation or amplification of SEPs and an altered body representation. On the one 92 93 hand, evidence from conversion paralysis, a psychogenic inability to perform voluntary movement, 94 shows a suppression of SEPs during the symptomatic period (Vuilleumier, 2005; Yazici, Demirci, 95 Demir, & Ertugrul, 2004). Furthermore, during hypnotic suggestion, imagery of the self-floating 96 outside the body suppresses SEPs (V. De Pascalis, Magurano, Bellusci, & Chen, 2001). On the other 97 hand, alterations in body representation in the full-body illusion and numbness illusion have shown an amplification of SEPs (Aspell et al., 2012; Dieguez et al., 2009), in line with the deafferentation
literature showing that a reduction in dominant sensory inputs allows for the expression of latent
inputs (Tinazzi, Rosso, Zanette, Fiaschi, & Aglioti, 2003; Urasaki, Genmoto, Wada, Yokota, &
Akamatsu, 2002).

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### Methods

#### 104 Participants

Fourteen right-handed healthy volunteers took part (six females, eight males, age range: 22– 30 years). All participants gave written informed consent and were given monetary compensation for their participation. The study was approved by the local research ethics committee at École Polytechnique Fédérale de Lausanne. Data from four participants had to be discarded because they did not show identifiable SEP (SEP amplitudes have a large inter-individual variability: Aspell et al., 2012; Van de Wassenberg, Kruizinga, Van der Hoeven, Leenders, & Maurits, 2008), thus ten participants data was included in the analysis (five females, five males, age range: 22–30 years).

#### 112 Task and Procedures

The experiment consisted of three blocks: Imagined Arm Paralysis, Imagined Leg Paralysis 113 and Baseline. Each block included 1) an immersion task to induce the corresponding paralysis state or 114 the baseline, 2) EEG recordings, and 3) two questionnaires to fill in at the end of each block. The 115 immersion tasks lasted 2-5 minutes as each participant worked at their own pace and were to provide 116 participants with an opportunity to draw upon an experience that emphasized the "uselessness" of 117 118 either their arms or legs and therefore help to put themselves into the situation of being unable to move the respective body part. All participants remarked that the immersion tasks for the leg and arm 119 paralysis were "challenging", "tricky" or said that "I didn't think it would be that difficult to do. For 120 the arm paralysis, participants were imagining arm paralysis and were required to write "my name 121 122 is..." using a pen inserted into the mouth during the immersion task. During EEG recordings they sat 123 on a normal chair and were asked to imagine that both of their arms were paralyzed. They were instructed to imagine that they could not move nor feel their arms. For the leg paralysis, participants 124 were required to navigate the experimental room in a manual wheelchair following an L-path during 125 the immersion task. This was done twice and involved turning. During EEG recordings, they were 126 127 asked to imagine that both of their legs were paralysed. They were instructed to imagine that they could not move nor feel their legs from the waist down. They remained seated on a manual 128 wheelchair throughout the recordings in order to help to maintain the imagery state. For the baseline, 129 participants were asked to walk twice following the same L-path than during the immersion task of 130 the imagined leg paralysis. During EEG recordings, they sat relaxed in a normal chair without 131 performing any task and with their arms on their legs. In all conditions participants were asked to 132 keep their eyes closed. The three EEG recordings lasted 3.5 minutes each and were counterbalanced 133 134 across participants. After each imagery block, participants answered two questionnaires pertaining to 135 the perception of their leg and arm during imagined paralysis.

#### 136 Tibial Nerve Stimulation

Participants received tibial nerve stimulation via two skin electrodes attached to the inside site of the right leg ankle. We used a Grass S48 stimulator to generate electrical pulses and a Matlab (version R2012B, MathWorks®) script synchronized EEG recordings and electrical stimulation. During each experimental condition the tibial nerve was stimulated 400 times at a frequency of 2 Hz with pulse duration of 0.2 ms (for a similar procedure see Aspell et al., 2012) with intensity just below motor threshold (Hume & Cant, 1978). No participant reported pain or discomfort with this level of stimulation.

# 144 Electroencephalography: Acquisition and Pre-processing

Continuous EEG was recorded with a sampling frequency of 2048 Hz from 64 active scalp electrodes (BioSemi, Netherlands) arranged in accordance with the 10-20 system and referenced to the common mode sense-driven right leg ground (CMS-DRL). Electrooculogram was recorded to control for artefacts related to eye movements, using a bipolar montage with electrodes positioned on the left and right side of the eyes (for horizontal eye movements), as well as above and below the righteye (for vertical movements). Participants were instructed to avoid to move their eyes.

EEG pre-processing and analysis were performed with the software Cartool version 3.8 (https://sites.google.com/site/cartoolcommunity/). EEG epochs were calculated from 100 ms before to 600 ms after the onset of right tibial nerve stimulation. A baseline correction was applied from 100 to 20 ms before stimulus onset. An artefact rejection threshold of  $\pm$  50  $\mu$ V was applied to both EEG and electrooculography signals. All accepted epochs were visually inspected and transient contaminating noise such as eye movements and muscle artefacts were rejected. On average 80 epochs (20%) per participant were rejected. The data was band-pass filtered (1-40 Hz) with a 50 Hz notch filter.

#### 158 EEG Analysis

159 Somatosensory-evoked potentials: Because tibial SEPs are maximal for midline electrodes Cz and CPz (Cruse, Klem, Lesser, & Leuders, 1982), we defined ten target electrodes (Pz, CPz, CP1, 160 161 CP2, Cz, C1, C2, FCz, FC1, FC2) located in a region of interest around Cz and CPz. Individual SEPs were calculated for each target electrode and each condition after normalization to their mean global 162 field power (GFP). GFP is the spatial standard deviation of the scalp's electrical field at a given 163 moment in time (Mercier, Schwartz, Michel, & Blanke, 2009) and normalization by the GFP reduces 164 165 inter-subjects variability. Individual SEPs were then combined across participants to create grandaverage SEPs for each target electrode. 166

We looked for classical early tibial SEP components in each participant. The first cortical component of tibial stimulation appears ipsilateral to the leg of stimulation at 40 ms (P40) (Cruse et al., 1982; Kakigi et al., 1995; Kakigi et al., 1997). Tibial SEP components also include the N50 (~50 ms) and P60 (~60 ms), all of which originate from area 3b in the primary somatosensory cortex (Kakigi et al., 1995). Accordingly, three time windows corresponding to each of the SEP components were considered: 30-45 ms, 45-60 ms and 60-75 ms. As the Shapiro-Wilk tests confirmed the normality of data, SEP amplitudes from each target electrode were subjected to a repeated-measures analysis of variance (ANOVA) with two factors: experimental condition (Baseline, Imagined Arm
Paralysis, Imagined Leg Paralysis) and SEP component (P40, N50, P60).

176 Scalp topography: Topographical analysis of tibial SEP was conducted to investigate periods of stable brain activation within and between experimental conditions (Murray, Brunet, & Michel, 177 2008). EP topographical analysis searches for time-segments of stable map topography that represent 178 functional microstates of the brain during information processing. This method has been applied to the 179 180 analysis of tibial SEPs (Aspell et al., 2012), visual EPs (Lopez, Mercier, Halje, & Blanke, 2011), and auditory Eps (Giroud, Lemke, Reich, Matthes, & Meyer, 2017). In the first step of the analysis, EP 181 topographies (maps or microstate segments) were established using a spatial clustering algorithm 182 183 (Tibshirani & Walther, 2005). The cluster analysis is dependent upon the global explained variance (GEV), which is the goodness of fit to a template map during a specific time period and the strength 184 of the global field power (GFP) during that time period (Murray et al., 2008). This step identifies the 185 dominant map topographies on the scalp in the group-average SEP data during and across the three 186 experiment conditions. In the second step, we analysed the extent to which these dominant maps are 187 188 present and verified in participant data. This was achieved by performing a fitting procedure based on the spatial correlations between participant data and the template maps identified from the group-189 average EP data in the temporal domain (Lopez et al., 2011). Participant data corresponding to the 190 191 dominant maps established in the first step are subjected to statistical analysis (two-tailed *t*-test). In 192 keeping with our investigation into somatosensory processing, we analysed map topographies only 193 during the time windows that correspond to SEPs.

#### 194 Questionnaires

After each imagined paralysis condition, participants completed two questionnaires concerned with the perception of their legs and arms during imagery (adapted from Hartmann et al., 2011). Participants rated on a 7-point Likert scale (1 = not true, 7 = true) the extent to which they agreed with seven statements (Table 1). As in Hartman et al. (2011) we averaged the seven statements concerned with the perception of the legs for each participant and for each state of paralysis. The seven statements concerned with the perception of the arms were also averaged for each participant and for each state of paralysis. The averaged scores were compared for both conditions by means of non-parametric Friedman ANOVA and Wilcoxon. We compared ratings for leg-related statement during imagined paralysis of the legs and imagined paralysis of the arms. This was also done for armrelated statements. Bonferroni correction was applied in order to account for multiple comparisons.

At the end of the experiment participants completed two questionnaires. The Private Body 205 206 Consciousness Subscale (PBCS; Miller, Murphy, & Buss, 1981) is a 5-item questionnaire gauging the 207 extent to which participants are consciously aware of internal bodily processes. Participants rated on a 5-point scale (1 = not true of me, 5 = very true of me) the extent to which they agreed with statements 208 such as "I am sensitive to internal bodily tensions". The Scale of Body Connection (SBC; Price & 209 Thompson, 2007) gauge the extent to which participants can connect with or disconnect from bodily 210 processes (for a review see Mehling et al., 2009). Participants rated on a 5-point scale (1 = not at all, 5 211 = all the time) the extent to which they agreed with statements pertaining to two subscales measuring 212 body awareness (12 items, e.g., "Take cues from the body") and body dissociation (8 items, e.g., 213 214 "Feel separated from body"). Average scores from each of the scales were correlated with the maximum amplitude difference between the imagined leg paralysis and the Baseline condition using 215 Spearman correlations. Statistical analysis was performed using Statistica 10. 216

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#### Results

#### 218 EEG Results

Somatosensory-evoked potentials: As predicted, the results show a significant modulation of
 the SEP P40 component during imagined leg paralysis, but not during imagined arm paralysis, when
 compared to Baseline conditions.

The ANOVA revealed a significant main effect of SEP component for each target electrode, whereby the N50 amplitude was significantly lower than the P40 and P60 amplitudes (all F(2,18) >4.2 and p < 0.032,  $\eta_p^2 = 0.32$ ). None of the target electrodes showed a significant main effect of the paralysis condition (p > 0.05). Interestingly, electrode CPz showed a significant interaction between the paralysis condition and the SEP component (F(4,36) = 3.49, p = 0.016,  $\eta_p^2 = 0.28$ ) (Fig. 1). Tukey post-hoc tests revealed that the P40 amplitude (mean ± SEM, 0.51 µV ± 0.16 µV) was lower during Imagined Leg Paralysis when compared to the Baseline condition (0.90 µV ± 0.16 µV, p = 0.033). Yet the amplitude did not differ from the Imagined Arm Paralysis condition (0.83 µV ± 0.28 µV, p = 0.25) (Fig. 2). The analysis also revealed a trend for a similar interaction at electrodes Cz (F(4,36) = 2.39, p= 0.069,  $\eta_p^2 = 0.210$ ) and C2 (F(4,36) = 2.47, p = 0.062,  $\eta_p^2 = 0.216$ ).

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235 Scalp topography: Analysis of group-average EPs revealed eight sequential maps of stable 236 brain activation (up to 175 ms after stimulus onset) following tibial stimulation in all three conditions (Fig. 3). We analysed Map 4 (~25-60 ms) and Map 5 (~60-90 ms) overlapping with the main SEP 237 238 components (30-75ms). The maximum GFP for Map 4 was significantly reduced for Imagined Leg Paralysis (mean  $\pm$  SEM, 0.55  $\mu$ V  $\pm$  0.09  $\mu$ V) when compared to the Baseline condition (0.73  $\mu$ V  $\pm$ 239  $0.10 \text{ }\mu\text{V}$ ; t(9) = 2.38, p = 0.041, d = 0.71). No statistically significant differences were found between 240 the Baseline and Imagined Arm Paralysis conditions (t(9) = 0.92, p = 0.382, d = 0.25; Figure 4). 241 Interestingly, the P40 component falls within Map 4 and the maximum positivity in Map 4 is at 242 electrode CPz. There was no significant difference between the arm and leg paralysis conditions for 243 244 Map 5.

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#### 247 Questionnaires

*Limb perception*: Participants reported perceptual changes in the limbs congruent with the imagined paralysis condition (Table 1). A non-parametric Friedman ANOVA was conducted and rendered a Chi-square value of 25.2, which was significant (p < 0.001). Participants rated the legs statement significantly higher after imagined leg paralysis than imagined arm paralysis (z = 2.8; p =0.005, d = 0.83). The reverse was true for arm-related statements during imagined arm paralysis (z = 253 2.8; p = 0.005, d = 0.64). A non-parametric Friedman ANOVA was conducted and rendered a Chisquare value of 25.2, which was significant (p < 0.001). We used Bonferroni correction for multiple 254 comparisons;  $\alpha \text{corr} = 0.05/4 = 0.013$ , and the effect reported above was still statistically significant. 255 There was no significant difference between the rating of arm statements during imagined arm 256 257 paralysis and leg statements during imagined leg paralysis (z = 1.22, p = 0.221, d=0.59). The intensity of perceptual changes between arms and legs during their corresponding paralysis conditions were not 258 significantly different. In conclusion, subjective perception of the limbs was differentially influenced 259 by the two paralysis conditions (Figure 5). 260

Bodily consciousness: Spearman correlations revealed a significant negative correlation 261 between maximum peak amplitude difference of the P40 between the Baseline and imagined leg 262 paralysis conditions and PBCS scores ( $\rho = -0.78$ , p = 0.008). That is, those scoring high in their 263 awareness of body sensations, exhibit the greatest amount of amplitude suppression of the P40 264 component during imagined leg paralysis (Figure 5). Conversely, those scoring high on the body 265 dissociation (BD) subscale of the SBC showed the least amount P40 amplitude suppression during 266 267 imagined leg paralysis ( $\rho = 0.65$ , p = 0.028). That is, participants who have a higher disposition to disconnect themselves from sensory and emotional states show less modulation of somatosensory 268 processing. By contrast, the body awareness subscale of the SBC did not correlate significantly with 269 270 SEP data ( $\rho = -0.28, p = 0.441$ ).

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#### **Discussion**

We examined whether imagined paralysis modulates somatosensory information processing. We found modulation of tibial nerve SEPs compared to a Baseline condition, specifically during imagined paralysis of the legs, but not of the arms. This effect is characterised by a reduction in the maximum peak amplitude of the P40 at electrode CPz, suggesting that imagined paralysis modulates sensory processing of the leg in primary somatosensory cortex (S1). In addition to single trace analysis, we showed that imagined paralysis influenced topographical brain, whereby the GFP decreased during imagined paralysis of the legs, but not of the arms, when compared to a Baseline condition. GFP modulation corresponds to a topographical map overlapping with the P40 SEP component, thus corroborating findings from single trace analysis.

We have previously shown that imagined paralysis can influence mental imagery of the body (Hartmann et al., 2011). During imagined paralysis, the biomechanical constraints of paralysis are attributed to the limbs represented in the body representation, impinging upon the ability to mentally transform them. Subjective reports indicate that imagined paralysis evoked weakness, heaviness, and immobility of the limbs (Hartmann et al., 2011). Here, we expand upon our understanding of paralysis imagery by showing that it is a cognitive process which is able to modulate low-level somatosensory information processing.

290 Modified somatosensory processing has previously been shown during experimentallyinduced body illusions (Aspell et al., 2012; Dieguez et al., 2009). The SEP amplification found in 291 292 these studies is consistent with SEP amplitude increases in response to transient physical anaesthesia 293 of a body part (Tinazzi et al., 2003; Urasaki et al., 2002). The increase in SEP amplitude 294 accompanying altered body representation found by Aspell et al. (2012) and Dieguez et al. (2009) is likely the consequence of multisensory reweighting of signals in the brain. In contrast with these 295 296 findings, our results showed P40 suppression during imagined paralysis. One of the major differences between altered body representation achieved in these studies and in the current study is that Aspell et 297 al. (2012) and Dieguez et al. (2009) altered body representations via spatiotemporal multisensory 298 conflicts. Although participants consciously perceived altered body representations in these studies, it 299 300 was somewhat sensory driven and did not require active cognitive effort on their behalf. Paralysis 301 imagery, on the other hand, requires participants to *consciously* and *mentally* act to alter own-body 302 representations. Thus, attenuation of SEPs in the present study may reflect explicit efforts to alter the 303 body representation and inhibit sensory perceptions of the legs that might not be considered as crucial 304 by the central nervous system. Our results are consistent with several studies using hypnotic 305 suggestion. For example, De Pascalis, Cacace, & Massicolle (2008) instructed participants to imagine

an obstructive object (a glove) between their hand and a painful stimulus, and found a reduction in the
N140 and P200 amplitudes. Likewise, De Pascalis et al. (2008) found a similar suppression of the
N140 and P200 responses to painful stimulation when participants imagined floating outside of their
body. While the body representation was not the primary target of these studies, they suggest that
own-body imagery can modulate somatosensory processing.

311 Later activation changes have also been observed in the literature. Long-latency (>40 ms) 312 components are thought to be generated by several areas, including area 3b, areas 1 and 2, secondary 313 somatosensory cortex (SII), and primary motor cortex (area 4). SEP components to tibial nerve stimulation around the time period of the later response at 110–200 ms originate in or near to SII, as 314 315 well as in the posterior parietal and frontal cortex (Allison, McCarthy, Wood, Darcey, et al., 1989; Allison, McCarthy, Wood, Williamson, & Spencer, 1989; Kakigi et al., 1995). These later changes 316 were mostly attributed to the detection of visuo-tactile conflicts that were not present in our study 317 (Aspell et al., 2012; Press, Heyes, Haggard, & Eimer, 2008). Heydrich et al. (2018) suggested that 318 areas beyond S1 (such as the secondary motor cortex, see Bufalari, Aprile, Avenanti, Di Russo, & 319 320 Aglioti, 2007) are associated with changes in somatosensory processing linked to altered states of bodily self-consciousness (e.g. illusory self-identification with an avatar). However the 321 electrophysiological data of Press et al. (2008) indicate that the process of filtering what may or may 322 323 not become part of one's body is not the same as volitional alteration of body representation.

324 Another interesting result of the present study was that the magnitude of SEP suppression correlated with PBCS and body dissociation scores. Those with the disposition to attend to and focus 325 on bodily sensations exhibited the largest SEP suppression. It is reasonable to assume that heightened 326 bodily awareness results in increased accessibility to the internal representation of the body and an 327 328 enhanced ability to impose upon this sensory representation. Conversely, those scoring high in body dissociation exhibited the least amount of suppression, or showed the reverse and exhibited an 329 330 increase in SEP amplitudes. It could be the case that those exhibiting high body dissociation are using 331 a less sensory-bound body representation to achieve imagined paralysis. However, further research should aim to elaborate on these findings and establish the causal role of body awareness and bodydissociation in accessing and manipulating own-body representations.

334 While the underlying mechanisms of top-down modulation in S1 remain a topic for future research, our findings still have a significant clinical implication for Mindfulness Based Therapy 335 (MBT) and motor imagery (MI) in the presence of pain. Recent trends in clinical intervention have 336 ventured towards MBT (Baer, 2003), an intervention that encourages patients to focus on their current 337 338 internal bodily sensations, emotions and thoughts with an attitude of non-judgmental acceptance. 339 MBT has been successful in the treatment of acute anxiety and depression (Hofmann, Sawyer, Witt, & Oh, 2010), as well as in reducing stress and symptoms associated with physical and psychosomatic 340 disorders (Grossman, Niemann, Schmidt, & Walach, 2004), including pain (Rosenzweig et al., 2010) 341 and irritable bowel syndrome (Ljotsson et al., 2010; Zernicke et al., 2013). One commonality between 342 MBT and paralysis imagery is that they shift attention towards a specific body part and require 343 participants to focus on the sensory perception of that body part. In light of our findings, future 344 research should establish whether MBT similarly influences low-level sensory processing. Such 345 346 evidence would enable MBT to be tailored to patients with specific body related disorders. Modifying the body schema via motor imagery (MI) could also be a promising approach for the treatment of 347 clinical disorders. MI refers to the mental representation of an action without engaging in its actual 348 349 execution (Moran, Guillot, Macintyre, & Collet, 2012). It involves the absence of overt motor output 350 rather than of overt movement itself (MacIntyre, Madan, Moran, Collet, & Guillot, 2018). The 351 repetitive use of MI has been shown to promote motor recovery and to alleviate phantom-limb pain in lower limb amputees (Saruco et al., 2019). However, Gustin et al. (2008) reported exacerbation of 352 353 pain in response to MI in spinal cord injury patients with neuropathic pain. These authors suggested 354 that "the generation of pain may be an example of a "mental" or "cognitive" allodynia where 355 activation of sensory pathways on a background of central neuronal hyperexcitability or sensitization results in the generation of pain". Thus, imagined paralysis or the "no movement" imagery may have 356 357 analgesic effects in patients with chronic arm/leg pain or phantom limb pain, for example. Further research should be conducted as MI is altered in a number of pathologies characterized by an 358

impairment of action performances (Coslett, Medina, Kliot, & Burkey, 2010; Fiori et al., 2013; Ionta
et al., 2016; Scandola, Aglioti, Avesani, et al., 2017; Scandola, Aglioti, Pozeg, Avesani, & Moro,
2017; Schwoebel, Friedman, Duda, & Coslett, 2001).

A limitation of the current study is the relatively low sample size, which can result in an 362 overestimation of the observed effect. A replication of our findings in a higher-powered sample is 363 therefore desirable to test the robustness of this effect. To conclude, we have confirmed that the body 364 365 representation is malleable via conscious, top-down processes. Previous research has also shown that body representation can be influenced by passive manipulations to multisensory signals, resulting in 366 altered low-level sensory processing. The current study expands upon these results by showing that 367 low-level sensory processing can be modulated by explicit, top-down alterations to the body 368 representation. Paralysis imagery can penetrate early levels of somatosensory processing. 369

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#### **Author contributions**

E. Palluel and C.J. Falconer developed the study concept. All authors contributed to the study design.
Testing and data collection were performed by E. Palluel and C.J. Falconer. E. Palluel, C.J. Falconer,
C. Lopez, S. Marchesotti, M. Hartman performed the data analysis and interpretation under the
supervision of O. Blanke and F.W. Mast. E. Palluel and C.J. Falconer drafted the manuscript, and C.
Lopez and M. Hartman provided critical revisions. All authors approved the final version of the
manuscript for submission.

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#### 379 Disclosure Statement

380 The authors report no conflict of interest

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## 552 Table 1

# 553

Question	Arm Paralysis	Leg Paralysis
	M (SD)	M (SD)
Legs		
During the experiment, my legs felt useless	1.22 (0.44)	3.33 (1.23)
My legs felt heavy during the experiment	1.00 (0.00)	3.66 (1.23)
During the experiment I had the impression that I couldn't use my legs as well as I am used to.	1.00 (0.00)	3.44 (1.13)
During the experiment my legs felt weak	1.00 (0.00)	3.66 (1.41)
During the experiment my legs felt strange, as if they did not belong to my body	1.00 (0.00)	1.22 (0.44)
During the experiment my legs felt paralyzed	1.00 (0.00)	3.33 (0.88)
During the experiment I had the impression that I could not have moved my legs if I had wanted to	1.00 (0.00)	3.44 (0.88)
Arms		
During the experiment, my arms felt useless	3.22 (1.20)	1.44 (0.53)
My arms felt heavy during the experiment	3.66 (1.23)	1.22 (0.44)
During the experiment I had the impression that I couldn't use my arms as well as I am used to.	3.22 (1.20)	1.00 (0.00)
During the experiment my arms felt weak	3.33 (1.32)	1.00 (0.00)
During the experiment my arms felt strange, as if they did not belong to my body	1.33 (0.50)	1.00 (0.00)
During the experiment my arms felt paralyzed	3.22 (1.39)	1.00 (0.00)
During the experiment I had the impression that I could not have moved my arms if I had wanted to	2.77 (0.83)	1.00 (0.00)

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**Table 1.** Mean and standard deviations in relation to seven statements concerned with the perception of either the legs or arms during paralysis imagery. Statements are rated on a 7point Likert scale (l = not true, 7 = true).

560 Figure 1



Figure 1. Single traces for electrode CPz depicting SEP components for all threeexperimental conditions



**Figure 2.** Mean amplitude ( $\mu$ V) of CPz for the P40 component across experimental conditions. Asterisk (\*) denotes significant differences (p < 0.05).

573 Figure 3



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**Figure 3.** Segments of stable brain topography (GFP) across all three experimental conditions. Maps 4 (blue) and 5 (green) denote the topography that corresponds to the SEP window. Topographical polarity for Map 4 (on the left) and Map 5 (on the right) is displayed in. The blue cross denotes the area of maximum negativity and the red cross denotes the area of maximum positivity.

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Figure 4. Maximum GFP was significantly lower during the Imagined Leg Paralysis condition for Map 4 as compared to Baseline. Asterisk (\*) denotes significant differences (p < 0.05). 

592 Figure 5



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**Figure 5**. Box-and-whiskers plots of the perception of either the legs or arms during paralysis

595 imagery. Asterisk (\*) denotes significant differences (p < 0.05).

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**Figure 6.** Plots show the maximum peak amplitude difference between the Imagined Leg Paralysis and the Baseline conditions relative to the mean score of the PBCS (A) and BD subscale (B). Analysis revealed a significant negative correlation between the amplitude difference with PBSC scores ( $\rho = -0.78$ , p = 0.008) and a significant positive correlation between the amplitude difference and BD scores ( $\rho = 0.65$ , p = 0.028).

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