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1 **Imagined paralysis alters somatosensory evoked-potentials**

2

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**Abstract**

29 Recent studies employing body illusions have shown that multisensory conflict can alter body  
30 representations and modulate low-level sensory processing. One defining feature of these body  
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  
33 processing. We investigated whether tibial nerve somatosensory-evoked potentials were modulated  
34 when participants imagined paralysis of their legs and arms. Imagined paralysis of the legs decreased  
35 P40 amplitude, but not imagined paralysis of the arms. These results show modulation of early  
36 somatosensory processing via explicit, top-down alteration to the internal representation of the body.  
37 Interestingly, P40 suppression positively correlated with bodily awareness scores whereas it  
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  
40 attend to and focus on bodily sensations.

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

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## Introduction

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

55 Illusory self-identification with a fake/virtual body is associated with physiological changes,  
56 such as decreased skin temperature (Moseley et al., 2008; Salomon, Lim, Pfeiffer, Gassert, & Blanke,  
57 2013). However De Hann et al. (2017) and Nakul et al. (2020) showed that these results were not  
58 consistent. In addition, illusory self-identification with a body increased pain threshold in healthy  
59 participants (Hansel, Lenggenhager, Kanel, Curatolo, & Blanke, 2011) and evoked mild analgesia in  
60 patients with spinal cord injury (Pozeg et al., 2017). Other studies have provided evidence that the  
61 full-body illusion modulated somatosensory information processing. Aspell, Palluel, & Blanke (2012)  
62 have shown an increase in the amplitude of early (i.e. 40 ms post-stimulus onset) tibial nerve  
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 numbness 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

71 body representation is enough to modulate sensory processing in the brain, as previously shown  
72 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,  
76 1987). This task requires that participants mentally align and transform the internal representation of  
77 their body composition (body representation) to match a target composition. Imagined leg paralysis  
78 impaired the participant's ability to mentally transform their body. This suggests that the  
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  
82 representation in performing simulated actions (Kakigi et al., 1997). Our paradigm allows to  
83 investigate the extent to which we can explicitly access and alter the body representation, and  
84 consequently somatosensory cortex activity.

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  
87 influence physiological signals relevant to the body representation. We hypothesize that imagined  
88 paralysis of the legs would influence the processing of tibial nerve signals in the somatosensory  
89 cortex. This is in contrast to imagined paralysis of the arms, which has no link with the tibial nerve.  
90 We used electroencephalography (EEG) recordings during tibial nerve electrical stimulation to assess  
91 SEP modulation during imagined paralysis. Our hypothesis is two-tailed in that there is evidence to  
92 suggest either an attenuation or amplification of SEPs and an altered body representation. On the one  
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

98 amplification of SEPs (Aspell et al., 2012; Dieguez et al., 2009), in line with the deafferentation  
99 literature showing that a reduction in dominant sensory inputs allows for the expression of latent  
100 inputs (Tinazzi, Rosso, Zanette, Fiaschi, & Aglioti, 2003; Urasaki, Genmoto, Wada, Yokota, &  
101 Akamatsu, 2002).

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## **Methods**

### **104 Participants**

105 Fourteen right-handed healthy volunteers took part (six females, eight males, age range: 22–  
106 30 years). All participants gave written informed consent and were given monetary compensation for  
107 their participation. The study was approved by the local research ethics committee at École  
108 Polytechnique Fédérale de Lausanne. Data from four participants had to be discarded because they did  
109 not show identifiable SEP (SEP amplitudes have a large inter-individual variability: Aspell et al.,  
110 2012; Van de Wassenberg, Kruizinga, Van der Hoeven, Leenders, & Maurits, 2008), thus ten  
111 participants data was included in the analysis (five females, five males, age range: 22–30 years).

### **112 Task and Procedures**

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

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

### 144 **Electroencephalography: Acquisition and Pre-processing**

145 Continuous EEG was recorded with a sampling frequency of 2048 Hz from 64 active scalp  
146 electrodes (BioSemi, Netherlands) arranged in accordance with the 10-20 system and referenced to  
147 the common mode sense-driven right leg ground (CMS-DRL). Electrooculogram was recorded to  
148 control for artefacts related to eye movements, using a bipolar montage with electrodes positioned on

149 the left and right side of the eyes (for horizontal eye movements), as well as above and below the right  
150 eye (for vertical movements). Participants were instructed to avoid to move their eyes.

151 EEG pre-processing and analysis were performed with the software Cartool version 3.8  
152 (<https://sites.google.com/site/cartoolcommunity/>). EEG epochs were calculated from 100 ms before to  
153 600 ms after the onset of right tibial nerve stimulation. A baseline correction was applied from 100 to  
154 20 ms before stimulus onset. An artefact rejection threshold of  $\pm 50 \mu\text{V}$  was applied to both EEG and  
155 electrooculography signals. All accepted epochs were visually inspected and transient contaminating  
156 noise such as eye movements and muscle artefacts were rejected. On average 80 epochs (20%) per  
157 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  
160 and CPz (Cruse, Klem, Lesser, & Leuders, 1982), we defined ten target electrodes (Pz, CPz, CP1,  
161 CP2, Cz, C1, C2, FCz, FC1, FC2) located in a region of interest around Cz and CPz. Individual SEPs  
162 were calculated for each target electrode and each condition after normalization to their mean global  
163 field power (GFP). GFP is the spatial standard deviation of the scalp's electrical field at a given  
164 moment in time (Mercier, Schwartz, Michel, & Blanke, 2009) and normalization by the GFP reduces  
165 inter-subjects variability. Individual SEPs were then combined across participants to create grand-  
166 average SEPs for each target electrode.

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



174 analysis of variance (ANOVA) with two factors: experimental condition (Baseline, Imagined Arm  
175 Paralysis, Imagined Leg Paralysis) and SEP component (P40, N50, P60).

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

195 After each imagined paralysis condition, participants completed two questionnaires concerned  
196 with the perception of their legs and arms during imagery (adapted from Hartmann et al., 2011).  
197 Participants rated on a 7-point Likert scale (*1 = not true, 7 = true*) the extent to which they agreed  
198 with seven statements (Table 1). As in Hartman et al. (2011) we averaged the seven statements  
199 concerned with the perception of the legs for each participant and for each state of paralysis. The

200 seven statements concerned with the perception of the arms were also averaged for each participant  
201 and for each state of paralysis. The averaged scores were compared for both conditions by means of  
202 non-parametric Friedman ANOVA and Wilcoxon. We compared ratings for leg-related statement  
203 during imagined paralysis of the legs and imagined paralysis of the arms. This was also done for arm-  
204 related statements. Bonferroni correction was applied in order to account for multiple comparisons.

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

## 217 Results

### 218 **EEG Results**

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

222 The ANOVA revealed a significant main effect of SEP component for each target electrode,  
223 whereby the N50 amplitude was significantly lower than the P40 and P60 amplitudes (all  $F(2,18) >$   
224  $4.2$  and  $p < 0.032$ ,  $\eta_p^2 = 0.32$ ). None of the target electrodes showed a significant main effect of the  
225 paralysis condition ( $p > 0.05$ ). Interestingly, electrode CPz showed a significant interaction between

226 the paralysis condition and the SEP component ( $F(4,36) = 3.49, p = 0.016, \eta_p^2 = 0.28$ ) (Fig. 1). Tukey  
227 post-hoc tests revealed that the P40 amplitude (mean  $\pm$  SEM,  $0.51 \mu\text{V} \pm 0.16 \mu\text{V}$ ) was lower during  
228 Imagined Leg Paralysis when compared to the Baseline condition ( $0.90 \mu\text{V} \pm 0.16 \mu\text{V}, p = 0.033$ ). Yet  
229 the amplitude did not differ from the Imagined Arm Paralysis condition ( $0.83 \mu\text{V} \pm 0.28 \mu\text{V}, p = 0.25$ )  
230 (Fig. 2). The analysis also revealed a trend for a similar interaction at electrodes Cz ( $F(4,36) = 2.39, p$   
231  $= 0.069, \eta_p^2 = 0.210$ ) and C2 ( $F(4,36) = 2.47, p = 0.062, \eta_p^2 = 0.216$ ).

232

233 *Please insert figures 1 and 2 about here*

234

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  
237 (Fig. 3). We analysed Map 4 (~25–60 ms) and Map 5 (~60–90 ms) overlapping with the main SEP  
238 components (30–75ms). The maximum GFP for Map 4 was significantly reduced for Imagined Leg  
239 Paralysis (mean  $\pm$  SEM,  $0.55 \mu\text{V} \pm 0.09 \mu\text{V}$ ) when compared to the Baseline condition ( $0.73 \mu\text{V} \pm$   
240  $0.10 \mu\text{V}; t(9) = 2.38, p = 0.041, d = 0.71$ ). No statistically significant differences were found between  
241 the Baseline and Imagined Arm Paralysis conditions ( $t(9) = 0.92, p = 0.382, d = 0.25$ ; Figure 4).  
242 Interestingly, the P40 component falls within Map 4 and the maximum positivity in Map 4 is at  
243 electrode CPz. There was no significant difference between the arm and leg paralysis conditions for  
244 Map 5.

245 *Please insert figures 3 and 4 about here*

246

## 247 **Questionnaires**

248 *Limb perception:* Participants reported perceptual changes in the limbs congruent with the  
249 imagined paralysis condition (Table 1). A non-parametric Friedman ANOVA was conducted and  
250 rendered a Chi-square value of 25.2, which was significant ( $p < 0.001$ ). Participants rated the legs  
251 statement significantly higher after imagined leg paralysis than imagined arm paralysis ( $z = 2.8; p =$   
252  $0.005, d = 0.83$ ). 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 Chi-  
254 square value of 25.2, which was significant ( $p < 0.001$ ). We used Bonferroni correction for multiple  
255 comparisons;  $\alpha_{\text{corr}} = 0.05/4 = 0.013$ , and the effect reported above was still statistically significant.  
256 There was no significant difference between the rating of arm statements during imagined arm  
257 paralysis and leg statements during imagined leg paralysis ( $z = 1.22$ ,  $p = 0.221$ ,  $d=0.59$ ). The intensity  
258 of perceptual changes between arms and legs during their corresponding paralysis conditions were not  
259 significantly different. In conclusion, subjective perception of the limbs was differentially influenced  
260 by the two paralysis conditions (Figure 5).

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

271 *Please insert figures 5 and 6 about here*

272

## 273 Discussion

274 We examined whether imagined paralysis modulates somatosensory information processing.  
275 We found modulation of tibial nerve SEPs compared to a Baseline condition, specifically during  
276 imagined paralysis of the legs, but not of the arms. This effect is characterised by a reduction in the  
277 maximum peak amplitude of the P40 at electrode CPz, suggesting that imagined paralysis modulates  
278 sensory processing of the leg in primary somatosensory cortex (S1). In addition to single trace

279 analysis, we showed that imagined paralysis influenced topographical brain, whereby the GFP  
280 decreased during imagined paralysis of the legs, but not of the arms, when compared to a Baseline  
281 condition. GFP modulation corresponds to a topographical map overlapping with the P40 SEP  
282 component, thus corroborating findings from single trace analysis.

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

290         Modified somatosensory processing has previously been shown during experimentally-  
291 induced body illusions (Aspell et al., 2012; Dieguez et al., 2009). The SEP amplification found in  
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  
295 likely the consequence of multisensory reweighting of signals in the brain. In contrast with these  
296 findings, our results showed P40 suppression during imagined paralysis. One of the major differences  
297 between altered body representation achieved in these studies and in the current study is that Aspell et  
298 al. (2012) and Dieguez et al. (2009) altered body representations via spatiotemporal multisensory  
299 conflicts. Although participants consciously perceived altered body representations in these studies, it  
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

306 an obstructive object (a glove) between their hand and a painful stimulus, and found a reduction in the  
307 N140 and P200 amplitudes. Likewise, De Pascalis et al. (2008) found a similar suppression of the  
308 N140 and P200 responses to painful stimulation when participants imagined floating outside of their  
309 body. While the body representation was not the primary target of these studies, they suggest that  
310 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  
314 stimulation around the time period of the later response at 110–200 ms originate in or near to SII, as  
315 well as in the posterior parietal and frontal cortex (Allison, McCarthy, Wood, Darcey, et al., 1989;  
316 Allison, McCarthy, Wood, Williamson, & Spencer, 1989; Kakigi et al., 1995). These later changes  
317 were mostly attributed to the detection of visuo-tactile conflicts that were not present in our study  
318 (Aspell et al., 2012; Press, Heyes, Haggard, & Eimer, 2008). Heydrich et al. (2018) suggested that  
319 areas beyond S1 (such as the secondary motor cortex, see Bufalari, Aprile, Avenanti, Di Russo, &  
320 Aglioti, 2007) are associated with changes in somatosensory processing linked to altered states of  
321 bodily self-consciousness (e.g. illusory self-identification with an avatar). However the  
322 electrophysiological data of Press et al. (2008) indicate that the process of filtering what may or may  
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  
325 correlated with PBCS and body dissociation scores. Those with the disposition to attend to and focus  
326 on bodily sensations exhibited the largest SEP suppression. It is reasonable to assume that heightened  
327 bodily awareness results in increased accessibility to the internal representation of the body and an  
328 enhanced ability to impose upon this sensory representation. Conversely, those scoring high in body  
329 dissociation exhibited the least amount of suppression, or showed the reverse and exhibited an  
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

332 should aim to elaborate on these findings and establish the causal role of body awareness and body  
333 dissociation in accessing and manipulating own-body representations.

334           While the underlying mechanisms of top-down modulation in S1 remain a topic for future  
335 research, our findings still have a significant clinical implication for Mindfulness Based Therapy  
336 (MBT) and motor imagery (MI) in the presence of pain. Recent trends in clinical intervention have  
337 ventured towards MBT (Baer, 2003), an intervention that encourages patients to focus on their current  
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,  
340 & Oh, 2010), as well as in reducing stress and symptoms associated with physical and psychosomatic  
341 disorders (Grossman, Niemann, Schmidt, & Walach, 2004), including pain (Rosenzweig et al., 2010)  
342 and irritable bowel syndrome (Ljotsson et al., 2010; Zernicke et al., 2013). One commonality between  
343 MBT and paralysis imagery is that they shift attention towards a specific body part and require  
344 participants to focus on the sensory perception of that body part. In light of our findings, future  
345 research should establish whether MBT similarly influences low-level sensory processing. Such  
346 evidence would enable MBT to be tailored to patients with specific body related disorders. Modifying  
347 the body schema via motor imagery (MI) could also be a promising approach for the treatment of  
348 clinical disorders. MI refers to the mental representation of an action without engaging in its actual  
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  
352 lower limb amputees (Saruco et al., 2019). However, Gustin et al. (2008) reported exacerbation of  
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  
356 results in the generation of pain”. Thus, imagined paralysis or the “no movement” imagery may have  
357 analgesic effects in patients with chronic arm/leg pain or phantom limb pain, for example. Further  
358 research should be conducted as MI is altered in a number of pathologies characterized by an

359 impairment of action performances (Coslett, Medina, Kliot, & Burkey, 2010; Fiori et al., 2013; Ionta  
360 et al., 2016; Scandola, Aglioti, Avesani, et al., 2017; Scandola, Aglioti, Pozeg, Avesani, & Moro,  
361 2017; Schwoebel, Friedman, Duda, & Coslett, 2001).

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

370

#### 371 **Author contributions**

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

378

#### 379 **Disclosure Statement**

380 The authors report no conflict of interest



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552 **Table 1**

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<i>Question</i>	<i>Arm Paralysis</i>	<i>Leg Paralysis</i>
	M (SD)	M (SD)
<hr/> <i>Legs</i>		
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)
 <i>Arms</i>		
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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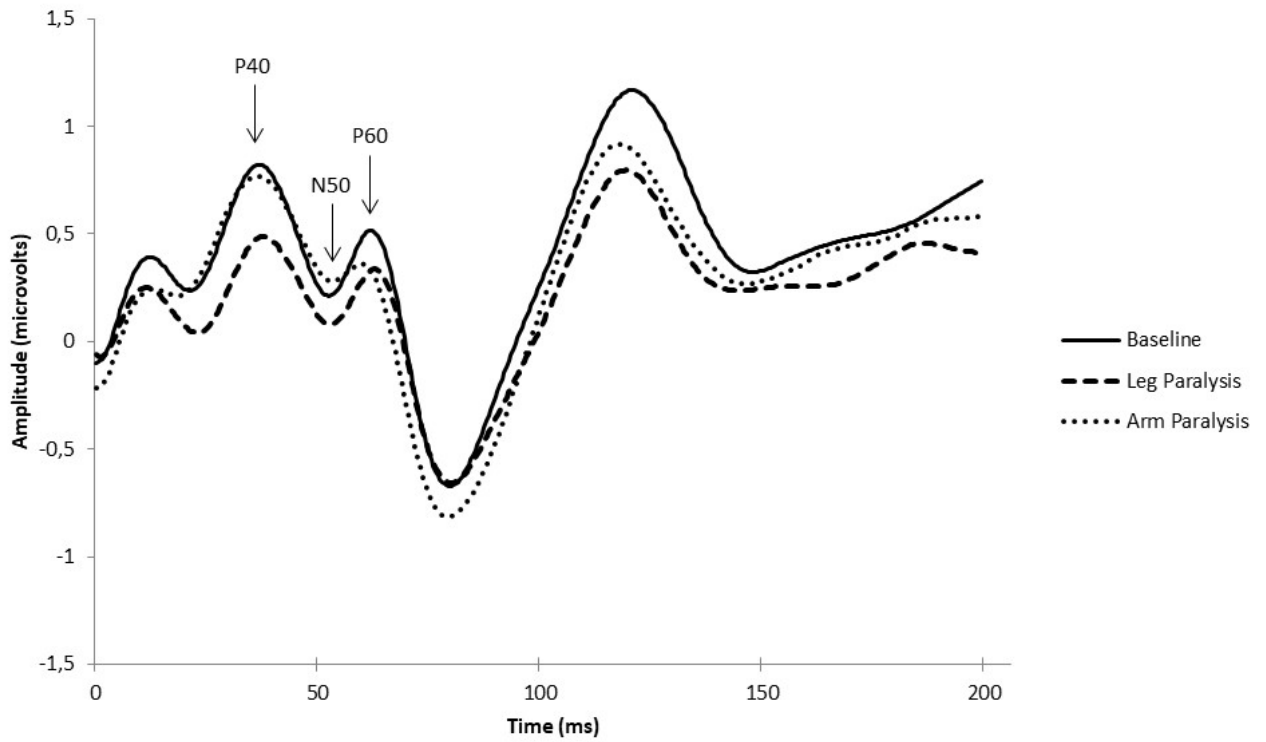
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556 **Table 1.** Mean and standard deviations in relation to seven statements concerned with the  
557 perception of either the legs or arms during paralysis imagery. Statements are rated on a 7-  
558 point Likert scale (*1 = not true, 7 = true*).

559

560 **Figure 1**



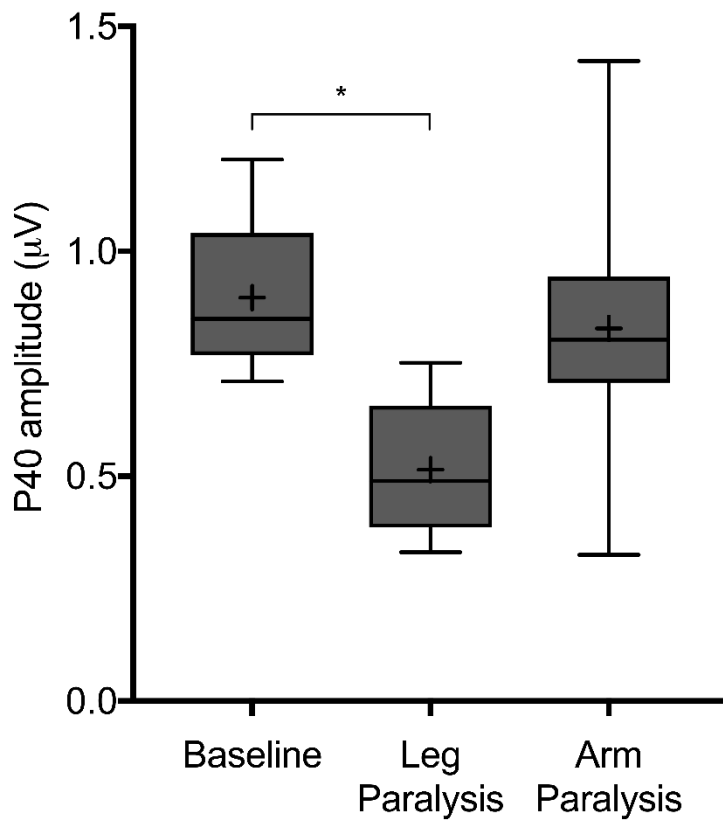
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562 **Figure 1.** Single traces for electrode CPz depicting SEP components for all three  
563 experimental conditions

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566 **Figure 2**



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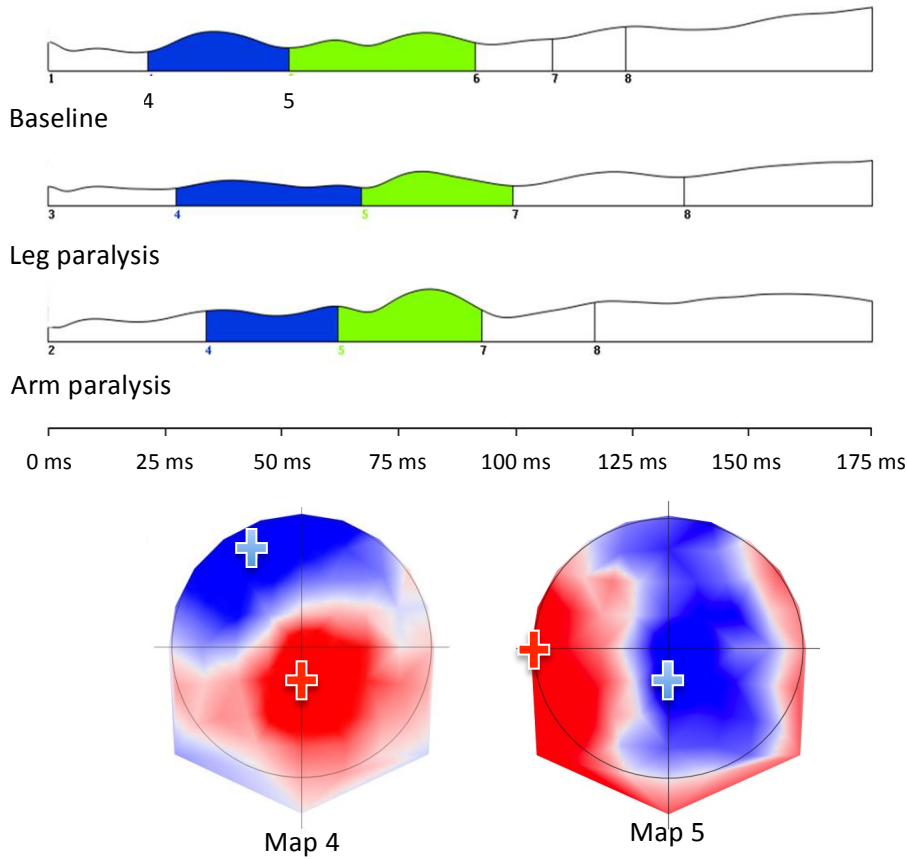
568 **Figure 2.** Mean amplitude (µV) of CPz for the P40 component across experimental  
569 conditions. Asterisk (\*) denotes significant differences ( $p < 0.05$ ).

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573 **Figure 3**



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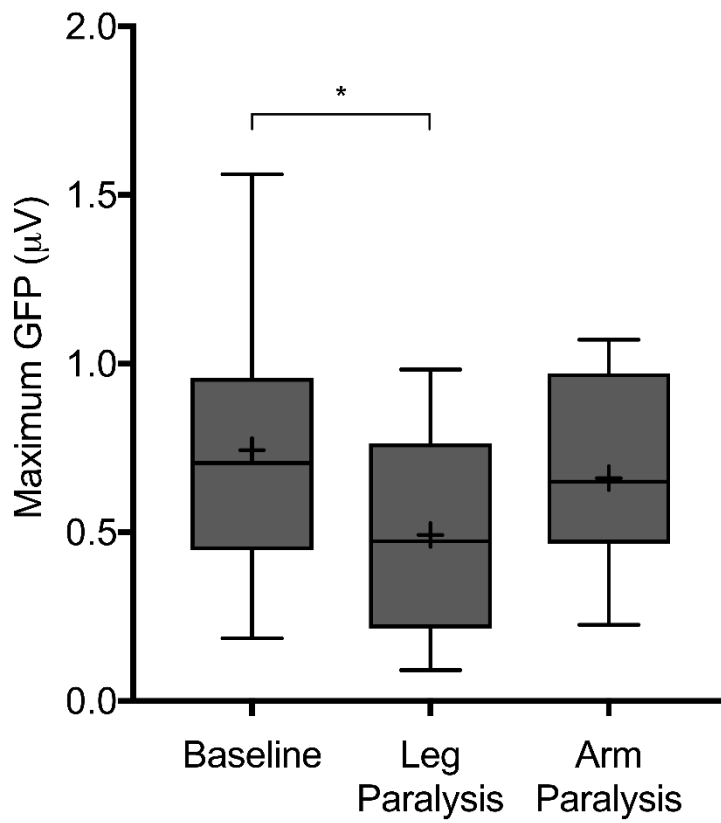
576 **Figure 3.** Segments of stable brain topography (GFP) across all three experimental  
577 conditions. Maps 4 (blue) and 5 (green) denote the topography that corresponds to the SEP  
578 window. Topographical polarity for Map 4 (on the left) and Map 5 (on the right) is displayed  
579 in. The blue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

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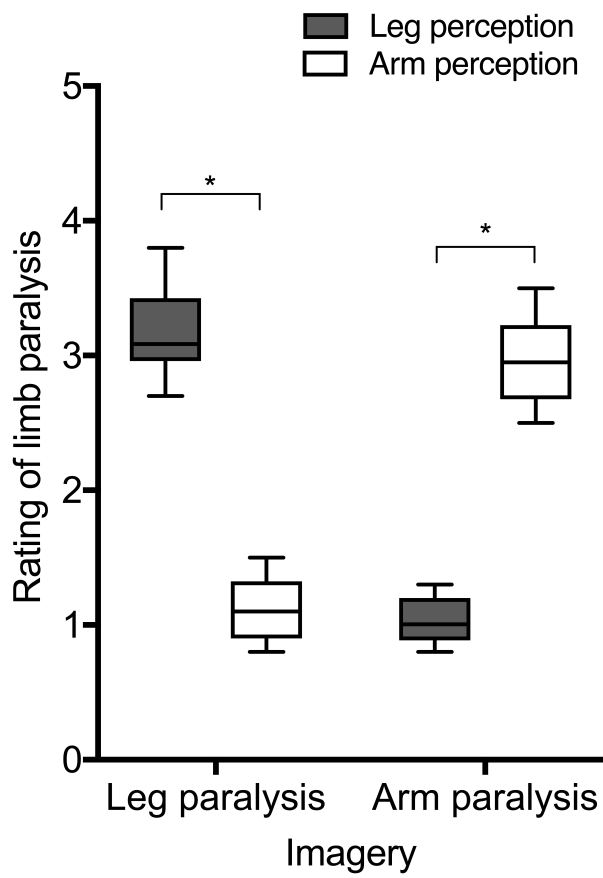
583 **Figure 4**



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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**

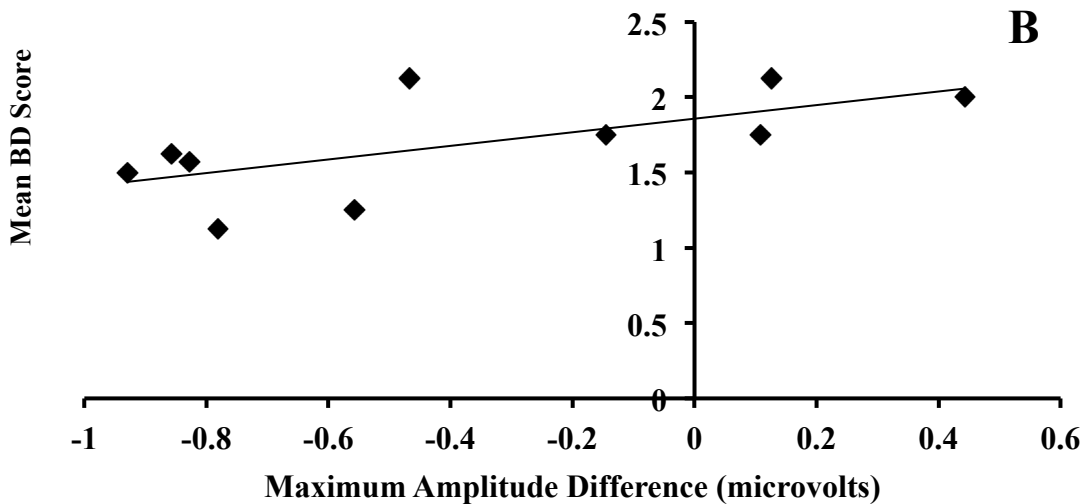
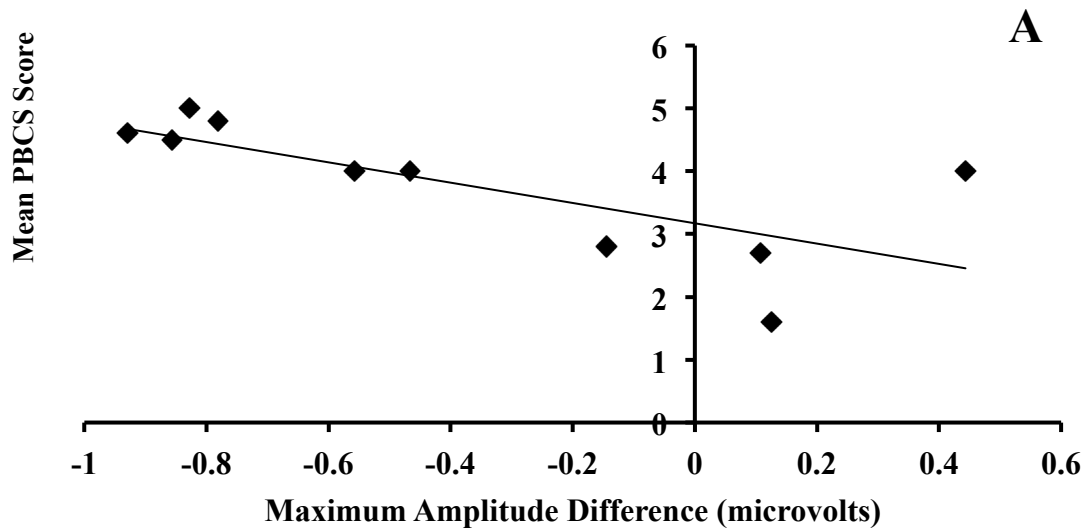


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594 **Figure 5.** Box-and-whiskers plots of the perception of either the legs or arms during paralysis  
595 imagery. Asterisk (\*) denotes significant differences ( $p < 0.05$ ).

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597



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