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

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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).

102

103

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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546 doi:10.1007/s12529-012-9241-6

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551

552 **Table 1**

553

<i>Question</i>	<i>Arm Paralysis</i>	<i>Leg Paralysis</i>
	M (SD)	M (SD)
<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)

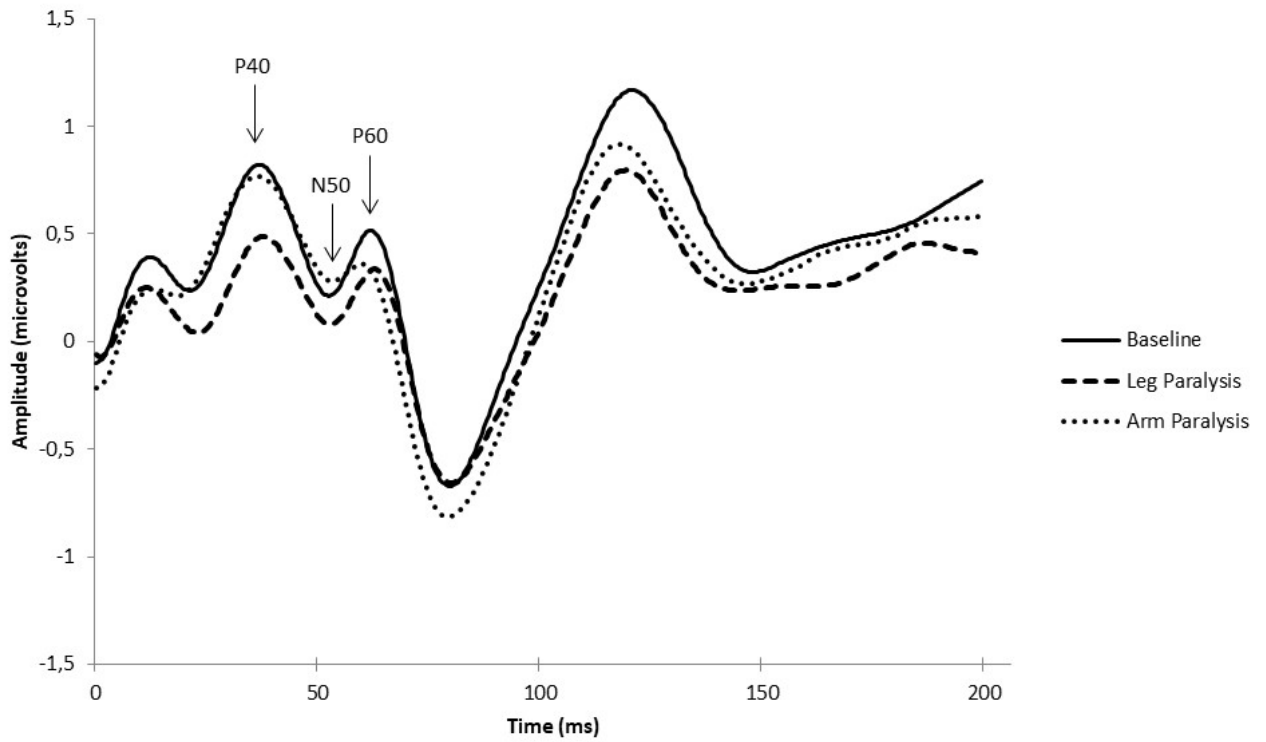
554

555

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**



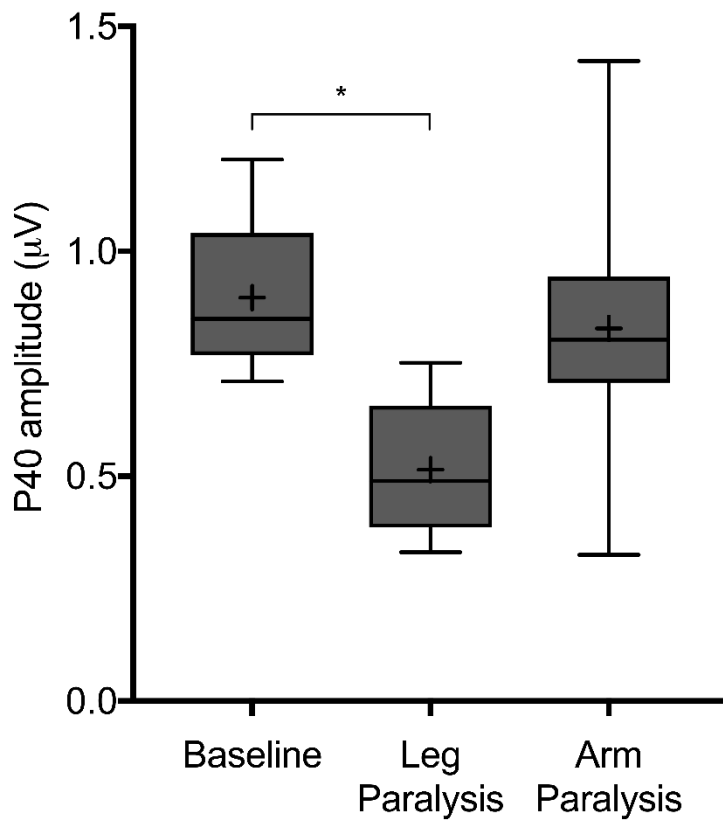
561

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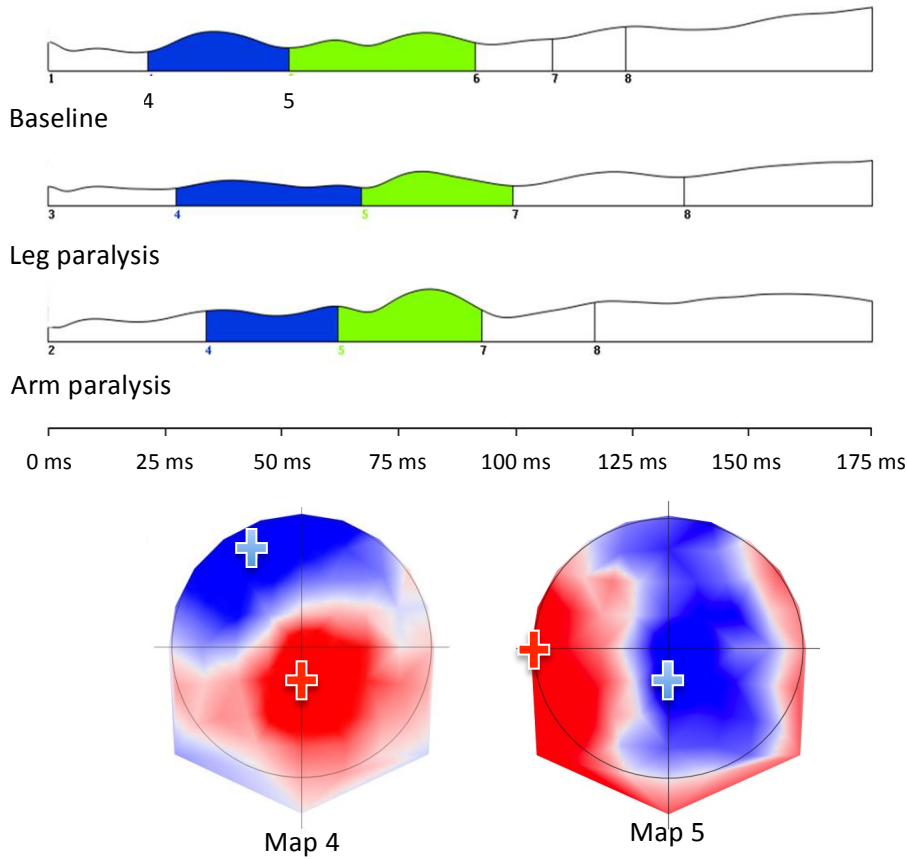
568 **Figure 2.** Mean amplitude (µV) of CPz for the P40 component across experimental
569 conditions. Asterisk (*) denotes significant differences ($p < 0.05$).

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573 **Figure 3**



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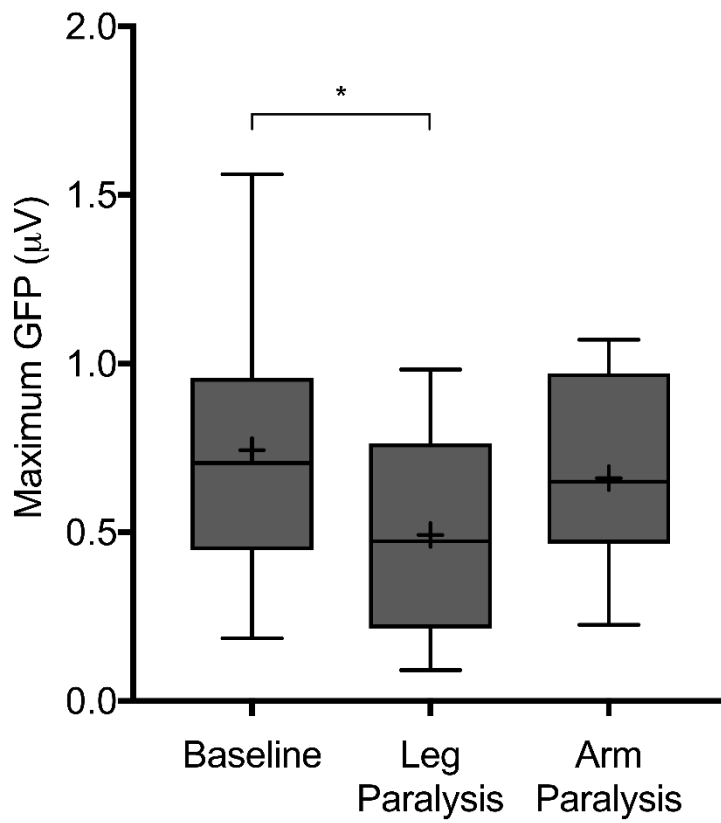
575

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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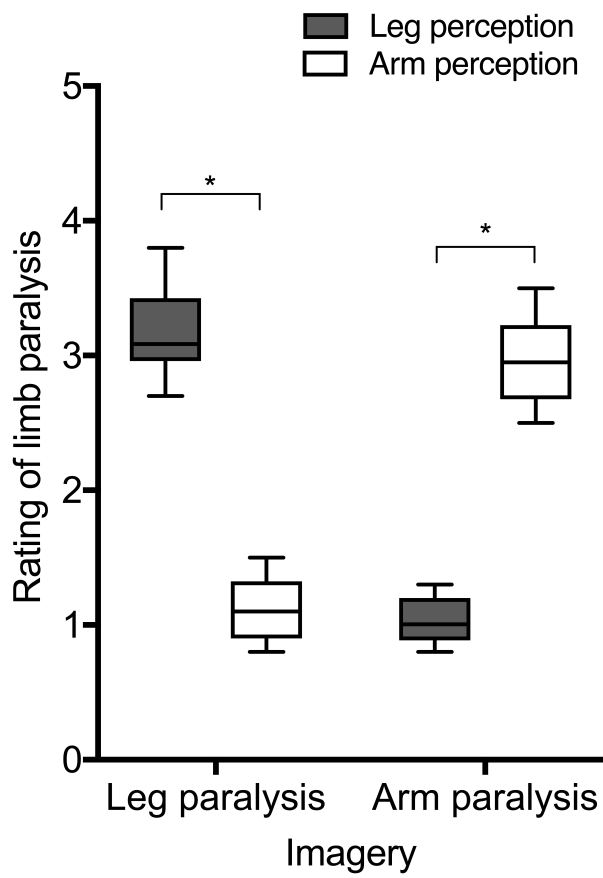
583 Figure 4



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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**

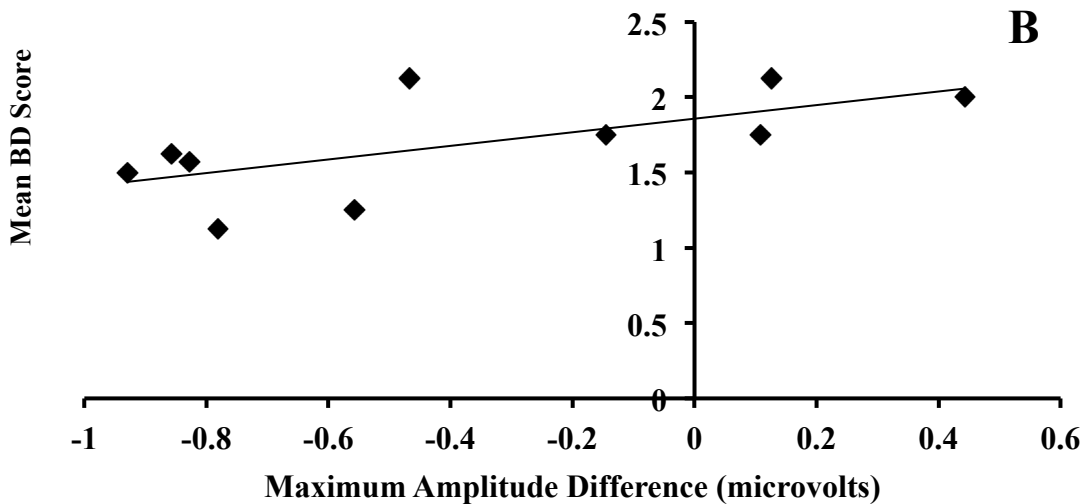
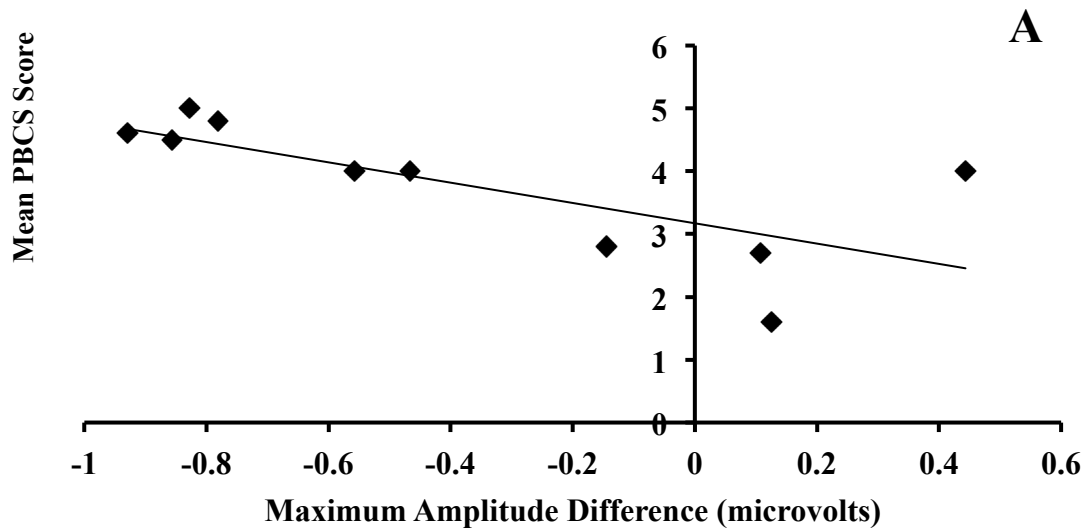


593

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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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 ($\rho = 0.65, p = 0.028$).