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Feeling touch on the own hand restores the capacity to visually discriminate it from someone else' hand: Pathological embodiment receding in brain-damaged patients

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24 Abstract

25 The sense of body ownership, i.e. the belief that a specific body part belongs to us, can 26 be selectively impaired in brain-damaged patients. Recently, a pathological form of 27 embodiment has been described in patients who, when the examiner's hand is located 28 in a body-congruent position, systematically claim that it is their own hand (E+ 29 patients). This paradoxical behavior suggests that, in these patients, the altered sense of 30 body ownership also affects their capacity of visually discriminating the body-identity 31 details of the own and the alien hand, even when both hands are clearly visible on the 32 table. Here, we investigated whether, in E+ patients with spared tactile sensibility, a 33 coherent body ownership could be restored by introducing a multisensory conflict 34 between what the patients feel on the own hand and what they see on the alien hand. 35 To this aim, we asked the patients to rate their sense of body ownership over the alien 36 hand, either after segregated tactile stimulations of the own hand (out of view) and of 37 the alien hand (visible) or after synchronous and asynchronous tactile stimulations of 38 both hands, as in the rubber hand illusion set-up. Our results show that, when the tactile 39 sensation perceived on the patient's own hand was in conflict with visual stimuli 40 observed on the examiner's hand, E+ patients noticed the conflict and spontaneously 41 described visual details of the (visible) examiner's hand (e.g. the fingers length, the 42 nails shape, the skin color...), to conclude that it was not their own hand. These data 43 represent the first evidence that, in E+ patients, an incongruent visual-tactile stimulation 44 of the own and of the alien hand reduces, at least transitorily, the delusional body 45 ownership over the alien hand, by restoring the access to the perceptual self-identity 46 system, where visual body identity details are stored.

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49 Keywords:

50 Brain-damaged Patients; Sense of Body Ownership; Body Awareness; Pathological
51 Embodiment; Multisensory Conflict.

52

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57 **1. Introduction**

58 The sense of body ownership (i.e. the feeling that our different body parts belong to us; 59 Blanke, Slater, & Serino, 2015; Gallagher, 2000) is something that we typically take 60 for granted. However, experimental manipulations in healthy people, such as the rubber 61 hand illusion (RHI) (Botvinick & Cohen, 1998), can temporarily alter the sense of body 62 ownership. During the RHI, the subjects watch a lifelike rubber hand being touched 63 while their own hand, hidden from view, is touched at the same time. This manipulation 64 creates the disturbing *feeling* that the artificial hand is part of the own body, and the 65 real hand can be somehow 'disembodied' (Della Gatta et al., 2016; Longo, Schüür, Kammers, Tsakiris, & Haggard, 2008; Moseley et al., 2008), although subjects always 66 67 know that the rubber hand is not part of their body. More dramatic body ownership 68 alterations can be observed in pathological conditions (Brugger & Lenggenhager, 69 2014). Brain damage can disrupt the sense of body ownership and make patients 70 convinced that one of their upper or lower limbs does not belong to them but to another 71 person, as in the somatoparaphrenic syndrome (Bisiach, Meregalli, & Berti, 1990; 72 Vallar & Ronchi, 2009). Recently, a complementary body awareness disorder has been 73 described where brain-damaged patients claim that the examiner's hand is their own 74 hand, whenever it is located in a body-congruent position. Because of this pathological 75 embodiment, we named them E+ patients (Fossataro, Gindri, Mezzanato, Pia, & 76 Garbarini, 2016; Garbarini et al., 2013, 2014, 2015; Garbarini & Pia, 2013; Pia, 77 Garbarini, Fossataro, Burin, & Berti, 2016; Pia, Garbarini, Fossataro, Fornia, & Berti, 78 2013). In order to observe this phenomenon, the co-examiner's hand must be placed on 79 the table next to the patient's contralesional affected hand, aligned with the patient's 80 shoulder and, therefore, perceived in egocentric perspective. In this set-up, when the 81 examiner asks the patient to identify his/her own affected hand, either by reaching with 82 his/her intact hand or by naming a colored object in front of it, the patient systematically 83 identifies the examiner's hand as his/her own. By contrast, pathological embodiment 84 does not occur when the alien hand is misaligned with the patient's shoulder, when it 85 is perceived in allocentric perspective or positioned in the intact ipsilesional body-side 86 and when, instead of a human hand, a rubber hand is used. Considering the E+ patients' 87 neurological characteristics, pathological embodiment seems to be strongly associated 88 to severe primary sensory-motor deficits as well as to other cognitive deficits, such as

89 neglect and personal neglect. However, none of these deficits alone can explain 90 pathological embodiment because double dissociations between embodiment, neglect 91 and primary sensory-motor deficits have been described (Garbarini, Pia, Fossataro, & 92 Berti, in press). It is interesting to note that, the incidence of somatoparaphrenia in E+ 93 patients is quite low. This, in turn, is consistent with the fact that this disease is rarely 94 observed after the first week post-stroke (Vallar & Ronchi, 2009), whereas the 95 pathological embodiment is reported in the sub-acute or chronic phase of the illness 96 (Fossataro et al., 2016; Garbarini et al., 2013, 2014, 2015; Garbarini & Pia, 2013; Pia 97 et al., 2016, 2013). However, when both the own and the alien hands are present and 98 the examiner explicitly asks about their ownership, E+ patients not only misidentify the 99 alien hand as their own, but also misattribute their own hand to the other person. In 100 other words, E+ patients show, only in this condition, an explicit sense of disownership. 101 The coexistence of the two delusional beliefs (i.e., disownership of the own hand and 102 ownership of an alien hand) in the same patient, suggests that these two forms of body 103 delusion might share at least some features. Accordingly, a previous study investigating 104 the relationship between asomatognosia and RHI in stroke patients suggested that a 105 number of asomatognosic patients, with impairment of the ability to perceive their real 106 hand as belonging to them, easily integrated the fake hand as their own (Zeller, Gross, 107 Bartsch, Johansen-Berg, & Classen, 2011).

108 One of the most counterintuitive observations related to E+ patients' behavior is that 109 pathological embodiment occurs not only with a static alien hand, but also when the 110 alien hand moves or when it is touched. Indeed, when E+ patients observe the 111 examiner's hand reaching for an object or being stimulated, they experience to move 112 their own hand (Fossataro et al., 2016; Garbarini et al., 2013, 2015) or to feel tactile 113 sensations on it (Fossataro et al., 2016; Garbarini et al., 2014; Pia et al., 2013). With 114 respect to the motor domain, it is interesting to note that E+ patients with contralesional 115 hemiplegia are usually aware of their motor deficits and, when they are asked to move 116 their affected hand, they perfectly know that they cannot perform any movement (i.e. 117 they are not anosognosic). Thus, we could expect that, when the alien hand moves, the 118 pathological embodiment would recede and patients would correctly recognize that the 119 moving hand is the examiner's hand and not their own. On the contrary, what we found 120 is that, when the alien hand moves, E+ patients claim they are moving their own 121 (paralyzed) hand (Fossataro et al., 2016; Garbarini et al., 2013, 2015). This suggests 122 the presence of a top-down control of the sense of body ownership on motor awareness.

When E+ patients are not in the embodiment condition, they are aware of their motor impairment, whereas when body awareness is affected by the experimental manipulation, then they seem to feel that their left (paralyzed) hand moves. Interestingly, other aspects of motor cognition are affected by the sense of body ownership such as the sense of agency because E+ patients ascribed the alien hand's movements to themselves (Fossataro et al., 2016; Garbarini et al., 2013, 2015).

129 With respect to the sensory domain, it is important to note that E+ cases with spared 130 tactile sensibility on both hands have been described (Fossataro et al., 2016; Garbarini 131 et al., 2014; Pia et al., 2013). In these cases, we could expect that, when the patients 132 observe the alien hand being stimulated without receiving tactile stimuli on their own 133 hand, the pathological embodiment would recede and the patients would correctly 134 recognize that the stimulated hand was the examiner's hand and not their own. On the 135 contrary, what we found is that, when E+ patients observe the alien hand being touched, 136 they report to feel tactile sensation on their own hand (Garbarini et al., 2014; Pia et al., 137 2013). It is important to note that the tactile sensation on the alien hand is reported 138 either when they had intact tactile sensibility on the own hand [a few cases with spared 139 tactile sensibility have been described (Fossataro et al., 2016; Garbarini et al., 2014; 140 Pia et al., 2013)] or when the own hand is affected by tactile anesthesia but they do not 141 acknowledge the sensory deficit [anosognosia for hemianaesthesia; see (Pia, 142 Spinazzola, et al., 2014; Pia, Cavallo, & Garbarini, 2014)]. On the other hand, when 143 patients are aware that they cannot feel any tactile stimulation on the own hand 144 (hemianaesthesia without anosognosia), they did not report to experience any tactile 145 stimuli on the alien hand. These observations suggest that the belief the patients have, 146 not only about their body, but also about their sensory abilities (whether true or false) 147 is transferred to the alien hand, once it is embodied (Pia et al., 2013). This means that 148 this delusion of body ownership meets the criteria of a recently proposed definition of 149 the embodiment concept, claiming that others' body parts can be considered as fully 150 embodied, "if and only if", as in these patients, "some properties of them are processed 151 in the same way as the properties of one's own body" (De Vignemont, 2011).

152 In the present paper, we asked whether, and to what extent, this altered sense of body 153 ownership, exerting top-down modulation on sensory perception, can be contrasted by 154 a bottom-up multisensory conflict between what the patients feel on the own hand and 155 what the patients see on the alien hand, restoring a coherent sense of self (Gentile,

156 Guterstam, Brozzoli, & Ehrsson, 2013). To this aim, three rare cases of E+ patients with spared tactile sensibility on the contralesional body parts were selected. Together 157 158 with two control groups (E- patients with similar neurological/neuropsychological 159 characteristics and age-matched healthy subjects), they took part in two experiments. 160 In both experiments, the examiner's hand (i.e. alien hand) was always visible on the 161 table while the patient's hand was hidden from view (as in the RHI set-up). Patients 162 were asked to rate their sense of body ownership over the alien hand, either after 163 segregated tactile stimulations of the own hand (out of view) and of the alien hand 164 (visible on the table) (Experiment 1) or after synchronous and asynchronous tactile 165 stimulations of both hands, as in the RHI set-up (Experiment 2). See details in section 166 2.2 and in Figure 1A and 1B. In Experiment 1, we hypostasized that to feel a touch on 167 the (hidden) own hand, while the alien (visible) hand is not touched, should create a 168 multisensory conflict that may reduce (or even cancel) the pathological embodiment 169 over the alien hand. In Experiment 2, we hypostasized that, in the asynchronous 170 condition, where both hands are stimulated but with a temporal difference, the strength 171 of the pathological embodiment might be reduced.

172 **2. Materials and methods**

173 **2.1 Patients' recruitment and participants**

Six brain-damaged patients of cerebrovascular origin, with contralesional upper limb 174 175 sensory-motor deficits, were recruited at the "San Camillo" Hospital (Turin, Italy). 176 Exclusion criteria were: 1) previous neurological or psychiatric history; 2) severe 177 general cognitive impairment [i.e. patients under the MOCA cut off were excluded 178 (Bosco et al., 2017)]; 3) visual field deficits (i.e. patients with hemianopia were 179 excluded); 4) tactile deficits [i.e. we included patients without hemianaesthesia (AH=0) 180 or patients with tactile extinction (i.e. omission of the left contralesional stimulus during bilateral stimulation) who showed spared tactile sensibility when unilateral tactile 181 182 stimuli were delivered to the left hand (AH=1) (Pia, Spinazzola, et al., 2014; Pia, 183 Cavallo, et al., 2014)]. All patients were assessed using common neuropsychological 184 tests: see demographic details and neurological/neuropsychological assessment results 185 in Table 1.

--- Table 1 about here ---

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189 In order to include patients in the experimental or in the control group, we tested them 190 with an ad hoc protocol devised to assess the presence/absence of pathological 191 embodiment, proposed in previous studies (Fossataro et al., 2016; Garbarini et al., 2013, 2014, 2015; Garbarini & Pia, 2013; Pia et al., 2013). According to this evaluation, 192 193 patients were classified as E+ or E- patients. Three out of six patients were assigned to 194 the E+ patients group (mean age \pm standard deviation= 75.66 \pm 3.05) and the others three 195 to the E- patients group (mean age \pm standard deviation= 75.33 \pm 9.02). Note that, in this 196 first evaluation, we also used additional trials in which a rubber hand was used instead 197 of the examiner's hand. According to previous studies (Pia et al., 2013), when the 198 rubber hand was used, the pathological embodiment did not occur. Thus, in the 199 experimental procedures (see section 2.2), we always used the co-examiner's hand.

Ten aged-matched healthy subjects (6 females, mean age \pm standard deviation: 69.7 \pm 13.34) were enrolled in the study as healthy control group. All participants were naive to the experimental procedure and to the aim of the research and provide written informed consent to participate in the study. In accordance with the Declaration of Helsinki (BMJ 1991; 302: 1194), all the experimental procedures were approved by the Ethical Committee of the ASL TO 1 of Turin (protocol number 46485/13).

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207 2.2 Experimental procedure

208 We employed a black wooden box (60x40x5 cm) divided in two equal parts (30x30x20 209 cm) by a panel. One of the two parts was open to the view in order to allow viewing 210 the other's hand (stimulated or not, according to the experimental condition), while the 211 other half has to take out of sight the real subject's hand. Two square holes (12x12 cm) 212 on either horizontal sides of the box allowed placing both the participant's arm and the 213 experimenter's arm (i.e. alien hand). A black towel covered the subject's shoulders and 214 the proximal end of both the subject's real hand and the alien hand, so that the alien 215 hand was perceived as an extension of the participant's own left hand and arm. The box 216 was placed in front of the subject's chest (about 15 cm far) and set in order to have the 217 other's hand, placed in the half of the box open to the view, aligned with the

218 participant's left shoulder. Before starting, participants were familiarized with the 219 setting, and instructed to all procedures and rating scales. The participants' left arm was 220 placed within the part of the box hidden to the view, the palm was facing down and the 221 fingers were stretched out. In the other half of the box, open to the view, the co-222 experimenter's left hand (i.e. alien hand) was placed (at a distance of approximately 25 223 cm from the own hand), exactly where the subject's hand has to be. During each 224 experimental condition, participants were asked to look carefully at the alien hand in 225 the half of the box open to the view. See Figure 1.

--- Figure 1 about here ---

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229 2.2.1. Experiment 1

230 Participants underwent two different conditions, in which they were asked to carefully 231 watch the alien hand, placed in a congruent position with respect to their body, while 232 their own hand (the contralesional affected hand in patients) was always out of view. 233 In the first condition, tactile stimuli were delivered to the alien hand (Alien condition) 234 while in the second condition stimuli were delivered to the own hand (Own condition). 235 Each stimulation lasted about 180 s. See Figure 1A. All participants underwent both 236 conditions and the order of conditions was randomized between subjects. In both 237 conditions, at the end of the stimulation procedure, participants were asked to rate their 238 agreement with respect to both Ownership and Sensation statement (see section 2.3).

239

240 2.2.2. Experiment 2

Participants underwent the classical RHI conditions in which they were asked to carefully watch the alien hand, placed in a congruent position with respect to their body, while their own hand (the contralesional affected hand in patients) was always out of view. The participants' own hand could be c) synchronously stroked with the alien hand, (Synchronous condition) or d) asynchronously stroked with alien hand (Asynchronous condition). Each stimulation lasted about 180 s. All participants underwent all conditions, which were counterbalanced between subjects. See Figure 1B. Note that, differently from the classical RHI paradigm we did not use a rubber hand but a real human hand (the co-examiner's one). As mentioned above, the rubber hand is not able to induce the pathological embodiment and here we were interested in evaluating the embodiment persistence/receding, depending on the conditions. Note also that the proprioceptive drift measure, usually employed during the RHI, was not employed here because of the proprioceptive deficit shown by E+ patients. Due to this deficit, they were not able to perform the task at the baseline, pre-stimulation condition.

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256 **2.3** Self report measures

257 In both experiments, at the end of each stimulation condition, participants were asked 258 to rate on a 0-10 Likert scale their agreement/disagreement with respect to two ad hoc 259 statements, concerning both the tactile sensation and the sense of ownership over the 260 alien hand (as in Bucchioni et al., 2016). Sensation statement: "I felt the tactile 261 sensation coming from the hand I was looking at". Ownership statement: "I felt as mine 262 the hand I was looking at". The Likert scale was ranking from 0 (i.e. I don't agree at 263 all) to 10 (i.e. I totally agree). Note that, in the clinical evaluation, in order to assess 264 the presence/absence of pathological embodiment, patients were asked to answer to 265 yes/no questions (Fossataro et al., 2016; Garbarini et al., 2013, 2014, 2015; Garbarini 266 & Pia, 2013; Pia et al., 2013). However, during the experimental phases, in order to 267 quantify the expected embodiment receding and to compare the patients' and the 268 controls' responses, participants were asked to rate their sense of body ownership on a 269 Likert scale.

270

271 2.4 Data analysis

In both Experiment 1 and Experiment 2, similar analyses were performed. With respect to the healthy controls data, we first assessed for the normal distribution of the residual by means of the Shapiro-Wilk Test. Since the residuals were not normally distributed (p<0.05), the Wilcoxon signed-rank test for pairwise comparisons (two tailed) was used for both Sensation and Ownership statement separately, in order to compare the subjective ratings of the two experimental conditions (Experiment 1: Alien vs Own; Experiment 2: Synchronous vs Asynchronous). For each test performed, we reported 279 mean, standard deviation, Z, p and r value [calculated manually by dividing the Z value 280 by the squared-root of the total sample size (Rosenthal, 1994)]. With respect to E-281 patients and E+ patients, given the small number of cases (i.e. three patients for each 282 group), we performed a between groups analysis by means of a Crawford test (one 283 tailed), specifically devised to test differential deficits exhibited by clinical sample on 284 two different test. "It does this by applying William's test for non-independent 285 correlations (Williams, 1959): the correlation between group membership (clinical 286 versus control) and Test A is compared with the correlation of group membership and 287 Test B. Computing a correlation between group membership and a variable is 288 equivalent to running a t-test or one-way ANOVA comparing the control and patient 289 samples on the variables" (Crawford, Blackmore, Lamb, & Simpson, 2000). Thus, 290 correlations between group membership (E+, E- patients or control) and scores on both 291 test A (i.e. Alien condition in Experiment 1; Synchronous condition in Experiment 2) 292 and test B (i.e. Own condition in Experiment 1; Asynchronous condition in Experiment 293 2) were computed and entered in the analysis.

294 Finally, in order to compare the presence/absence of the embodiment phenomenon between each E+ patient and both healthy subjects and E- groups, the subjective ratings 295 296 were entered in a Crawford's test (one tailed) specifically devised to test whether an 297 individual's score is significantly different from a control or normative sample. "It 298 provides a point and interval estimate of the abnormality of the case's score, i.e. it 299 estimates the percentage of the population that would obtain a lower score (together 300 with a 95% confidence interval on this percentage)" (Crawford, Garthwaite, & Porter, 301 2010).

302

303 **3. Results**

304 3.1 Experiment 1

In healthy controls group, Wilcoxon test, at both Ownership and Sensation statement, does not showed a significant difference between Own and Alien condition [mean \pm standard deviation; Ownership statement: Alien= 0.6 ± 1.57 ; Own= 2.3 ± 3.88 ; Z=1.278019; p= 0.20; *r*=0.40; Sensation statement: Alien= 0.8 ± 1.3 ; Own= 1.3 ± 3.19 ; Z=0.13484; p= 0.89; *r*= 0.04). This means that healthy subjects gave similarly low 310 ratings in both conditions, suggesting that segregated stimulations of the own and the 311 alien hand do not modulate the sense of body ownership. See Figure 2.

312 Between E- patients and healthy subjects group, Crawford test for differential deficits 313 in pathological sample (Crawford et al., 2000) showed that, at both Ownership and 314 Sensation statement, there are no differences in groups performances. At the Ownership 315 statement, the correlation between group membership and score on the Alien condition 316 (-0.106) was comparable to the correlation between group membership and the score 317 on the Own condition (-0.06), [t(10) = -0.085; p = 0.46]. At the Sensation statement, the 318 correlation between group membership and score on the Alien condition (-0.213) was 319 comparable to the correlation between group membership and the score on the Own 320 condition (0.20), [t(10) = -0.856; p = 0.21]. Crucially, between E+ patients and E-321 patients group, Crawford test for differential deficits in pathological sample (Crawford 322 et al., 2000) showed that, at both Ownership and Sensation statement, there was a 323 significant difference in groups performances. At the Ownership statement, the 324 correlation between group membership and score on the Alien condition (0.991) was 325 significantly greater than the correlation between group membership and the score on the Own condition (-0.192), [t(3)=3.229; p=0.02]. At the Sensation statement, the 326 327 correlation between group membership and score on the Alien condition (0.996) was 328 significantly greater than the correlation between group membership and the score on 329 the Own condition (-0.48), [t(3)=3.386; p=0.02]. Finally, between E+ patients and 330 healthy subjects group, Crawford test for differential deficits in pathological sample 331 (Crawford et al., 2000) showed that, at both Ownership and Sensation statement, there 332 was a significant difference in groups performances. At the Ownership statement, the 333 correlation between group membership and score on the Alien condition (0.802) was 334 significantly greater than the correlation between group membership and the score on the Own condition (-0.149), [t(10)=2.77; p=0.01]. At the Sensation statement, the 335 336 correlation between group membership and score on the Alien condition (0.769) was 337 significantly greater than the correlation between group membership and the score on 338 the Own condition (-0.085), [t(10)=2.104; p=0.03]. Thus, this suggests that only E+ 339 patients group, due to the pathological embodiment, gave significantly greater scores 340 in the Alien condition (mean \pm standard deviation, Ownership= 9 ± 1 ; Sensation= 341 8.3 ± 0.57), than to the Own condition (mean \pm standard deviation, Ownership=

 1.06 ± 1.67 ; Sensation= 0.06 ± 0.05) showing an embodiment persistence in the Alien condition and crucially, an embodiment receding in the Own condition. See Figure 2.

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--- Figure 2 about here ---

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347 For both Ownership and Sensation statement, Crawford's tests (one tailed) for singlesubject analysis (Crawford et al., 2010), showed that in the Alien condition there is a 348 349 significant difference between each E+ patient's ratings and the ratings of both healthy 350 subjects group (mean \pm standard deviation, Ownership= 0.6 \pm 1.57; Sensation= 351 1.3 \pm 3.19) and E- patients group (mean \pm standard deviation, Ownership= 0.26 \pm 0.25; Sensation= 0.1 ± 0.1). This suggests that, in this condition, only E+ patients gave high 352 353 ratings (E+1: Ownership= 8; Sensation=8; E+2: Ownership= 10; Sensation= 9; E+3: 354 Ownership= 9; Sensation= 8) due to the pathological embodiment persistence (p < 0.005355 for each comparison; see Figure 2). Crucially, no difference between each E+ patients 356 and both E- patients group and healthy subjects group was found in the Own condition 357 (p>0.05 for each comparison; see Figure 2), showing that, in this condition, all three 358 E+ patients, due to the pathological embodiment receding, gave low ratings (E+1: 359 Ownership= 0; Sensation=0; E+2: Ownership= 3; Sensation= 0; E+3: Ownership= 0; 360 Sensation= 0) comparable to those given by the control groups (mean \pm standard deviation, E- patients: Ownership= 1.8 ± 2.77 ; Sensation= 2.9 ± 4.42 ; healthy subjects: 361 362 Ownership= 2.3 ± 3.88 ; Sensation= 0.8 ± 1.61). Single-subject analysis results are 363 reported in Table 2.

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367 **3.2 Experiment 2**

In healthy controls group, Wilcoxon test, at both Ownership and Sensation statement, showed a significant difference between the Synchronous and the Asynchronous condition [mean \pm standard deviation; Ownership statement: Synchronous= 5.22 \pm 3.93; Asynchronous= 1 \pm 1.88; Z= 2.66557; p= 0.007; *r*= 0.84; Sensation statement:

--- Table 2 about here ---

- 372 Synchronous= 4.62 ± 3.55 ; Asynchronous= 0.62 ± 1.55 ; Z= 2.66557; p= 0.007; r= 0.84).
- 373 In healthy subjects, this result mirrors the classical RHI effect with higher ratings for
- the Synchronous condition compared to the Asynchronous condition. See Figure 3.

375 Between E- patients and healthy subjects group, Crawford test for differential deficits 376 in pathological sample (Crawford et al., 2000) showed that, at both Ownership and 377 Sensation statement, there were no differences in groups performances. At the 378 Ownership statement, the correlation between group membership and score on the 379 Synchronous condition (0.051) was comparable to the correlation between group 380 membership and the score on the Asynchronous condition (-0.192), [t(10)=0.825; p=381 0.21]. At the Sensation statement, the correlation between group membership and score 382 on the Synchronous condition (0.379) was comparable to the correlation between group 383 membership and the score on the Asynchronous condition (0.438), [t(10) = -0.223; p =384 0.41]. Crucially, between E+ patients and E- patients group, Crawford test for 385 differential deficits in pathological sample (Crawford et al., 2000) showed that, at both 386 Ownership and Sensation statement, there were no differences in groups performances. 387 At the Ownership statement, the correlation between group membership and score on 388 the Synchronous condition (0.613) was comparable to the correlation between group 389 membership and the score on the Asynchronous condition (0.746), [t(3) = -0.317; p =390 0.38]. At the Sensation statement, the correlation between group membership and score 391 on the Synchronous condition (0.204) was comparable to the correlation between group 392 membership and the score on the Asynchronous condition (-0.027), [t(3)=0.482; p=393 0.33]. Finally, between E+ patients and healthy subjects group, Crawford test for 394 differential deficits in pathological sample (Crawford et al., 2000) showed that, at both 395 Ownership and Sensation statement, there were no differences in groups performances. 396 At the Ownership statement, the correlation between group membership and score on 397 the Synchronous condition (0.398) was comparable to the correlation between group 398 membership and the score on the Asynchronous condition (0.579), [t(10) = -0.677; p =399 0.25]. At the Sensation statement, the correlation between group membership and score 400 on the Synchronous condition (0.482) was comparable to the correlation between group 401 membership and the score on the Asynchronous condition (0.386), [t(10)=0.376; p=402 0.35]. Thus, in E+ patients group, these results suggest an embodiment persistence in 403 the Synchronous condition (mean \pm standard deviation= 8.33 ± 1.15) and crucially, an 404 embodiment receding in the Asynchronous condition (mean \pm standard deviation= 405 3.33 \pm 4.93). See Figure 3.

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--- Figure 3 about here ---

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409 For both Ownership and Sensation statement single-subject analysis (see Table 3), performed by means of Crawford's tests (one tailed), showed that, in Synchronous 410 411 condition, no difference was found between each E+ patients and both E- patients and 412 healthy subjects, either for the Ownership or for Sensation statement (p > 0.05 for each 413 comparison; see Figure 3). In the Asynchronous condition, for both the Sensation and 414 Ownership statement, different results were found depending on each patient. Patient 415 E+1, both at Sensation and Ownership statement, gave high ratings (Ownership: 9; 416 Sensation: 9), significantly different compared to the low ratings given by both E-417 patients (mean \pm standard deviation, Ownership= 0.26 \pm 0.38; Sensation= 3.56 \pm 5.57) 418 and healthy subjects (mean \pm standard deviation, Ownership= 1 ± 1.88 ; Sensation= 419 0.62 ± 1.55) (p< 0.05 for each comparison; see Figure 3). On the contrary, patient E+2, 420 both at Sensation and Ownership statement, gave low ratings (Ownership= 1; 421 Sensation= 1), comparable to those given by both E- patients and healthy subjects (p> 422 0.05 for each comparison; see Figure 3). Finally, patient E+3, at the Ownership 423 statement, gave high ratings (Ownership: 10) significantly different compared to the 424 low ratings given by both E- patients and healthy subjects (p < 0.05 for each 425 comparison; see Figure 3). By contrast, patient E+3, at the Sensation statement, gave 426 low ratings (sensation: 0), comparable to those given by both E- patients and healthy 427 subjects (p > 0.05 for each comparison; see Figure 3). Single-subject analysis results are 428 reported in Table 3.

- 429 --- Table 3 about here ---
- 430

431 **4. Discussion**

When patients with pathological embodiment (E+ patients) look at the examiner'shand, located in a body-congruent position, systematically claim that that hand is their

434 own. In the present study, we asked whether, in E+ patients with spared tactile 435 sensibility, a coherent body awareness can be restored, when a multisensory conflict 436 between what the patients feel on the own hand and what they see on the alien hand is 437 introduced (Gentile et al., 2013). Indeed, we found that, when tactile sensations did not 438 coincide with the visual feedback, that is when the tactile stimuli were delivered on the 439 hidden own hand and not on the visible examiner's hand, the pathological embodiment 440 receded.

441 In Experiment 1, our results showed, both in healthy subjects and in E- patients, that 442 separated tactile stimulations of the own and the alien hand did not modulate the 443 participants' sense of body ownership. Although some studies suggest that a 444 modulation of the body ownership can be obtained in normal subjects by the sole vision 445 of the fake hands being touched (Ferri, Chiarelli, Merla, Gallese, & Costantini, 2013; 446 Holmes, Snijders, & Spence, 2006), our control groups were not affected by this 447 stimulation. On the contrary, in E+ patients, the already altered sense of body ownership 448 was modulated by the experimental conditions. When E+ patients observed the alien 449 hand being touched without receiving any tactile stimuli on their own hand (Alien 450 condition), the pathological embodiment was maintained whereas, when E+ patients 451 perceived tactile stimuli on their own hand without observing any tactile stimuli on the 452 alien hand (Own condition), the pathological embodiment receded. It is interesting to 453 note that the behavior shown in the Alien condition resembles mirror-touch synesthesia, 454 where people can experience tactile sensations in a given body part simply by looking 455 at another person being touched on the same part. This might be due to an atypical 456 functioning of the mirror-touch system (Blakemore, Bristow, Bird, Frith, & Ward, 457 2005). It has been also proposed that, in synesthetic people, the abnormal sensory 458 feelings are accompanied by an alteration of the self-other discrimination system (for a 459 review Banissy & Ward, 2013). This alteration does not lead to an actual misattribution 460 of the other people body parts to the own body, as in E+ patients. However, a greater 461 illusory experience, compared to healthy controls, has been described in synesthetic 462 subjects during different experimental manipulations of body ownership (Aimola 463 Davies & White, 2013; Maister, Banissy, & Tsakiris, 2013). In E+ patients, body 464 ownership might exert a top-down modulation on visuo-tactile bimodal neurons in 465 somatosensory cortex, known to be activated by vision through a mirror-like 466 mechanisms, when subjects observe other bodies being touched (Bonini, 2016; Ishida,

467 Nakajima, Inase, & Murata, 2009; Keysers & Gazzola, 2009). Normal body ownership, 468 in order to discriminate between self and other's body, either up-regulates the 469 somatosensory cortical activity, in order to bind conscious experience to the own body, 470 or down-regulates the cortical activity, in order to avoid conscious experience for the 471 events occurring on the others' bodies. On the contrary, in E+ patients, pathological 472 body ownership, no longer able to discriminate between oneself and another body, can 473 only up-regulate the somatosensory cortical activity, binding conscious tactile 474 experience to both oneself and the other's body (Garbarini et al., in press). Indeed, the 475 sense of ownership reported by E+ patients over the alien hand is not something that 476 they just believe, but is more than just a mere judgment. It is something that they report 477 to feel as own body (De Vignemont, 2011).

478 The above described results of the Alien condition confirm similar findings in our 479 previous studies (Fossataro et al., 2016; Garbarini et al., 2014; Pia et al., 2013). In the 480 present research, novel findings show that, when E+ patients perceived tactile stimuli 481 on their own hand without observing any tactile stimuli on the alien hand, the 482 pathological embodiment receded (lower ratings at the Ownership statement) as well 483 as the corresponding tactile sensation (lower ratings at the Sensation statement). How 484 can we explain this embodiment receding? Body ownership is an inherently multimodal 485 concept, since all senses together contribute to build a coherent body representation 486 (Blanke, 2012; Blanke et al., 2015). However, when somatosensory inputs are lost, as 487 after brain damage, a residual capacity to discriminate between self and others' body 488 can rely only on visual inputs. Indeed, we have observed E- cases with severe motor, 489 tactile and proprioceptive deficits, who immediately discriminate between the own and 490 the alien hand referring to different visual details [the color of the skin, the shape, the 491 age, the dimension of the hand]. These visual-identity details resemble the concept of 492 "body image" which represents the perceived form of our body, in terms of its size, 493 shape, and distinctive characteristics (Gallagher, 1986), or the more recently proposed 494 concept of "somatoperception", which refers to the essentially perceptual process of 495 constructing perceptual representations of the body and somatic stimuli from perceptual 496 input (Longo, Azãnón, & Haggard, 2010). These visual-identity details are stored in 497 what we call a "perceptual self-identity system" (Garbarini et al., in press), that allows, 498 when spared as in E- patients, to discriminate between self and others' body. On the 499 contrary, E+ patients, where the lesion must have damaged the possibility to directly

access the perceptual self-identity system, are not able to utilize visual details to discriminate between the own and the alien hand and base their ownership judgment on a pre-existing knowledge of body structure (pre-existing body representation), that does not include updated details of the body self. Thus, in E+ patients, each stimulus matching the constraints of this pre-existing body representation (e.g. a human hand, aligned with the patients' shoulder and perceived in egocentric perspective) is felt as part of the patient's own body [i.e. it is embodied, (De Vignemont, 2011)].

507 However, when E+ patients have a spared somatosensory system, this can be activated 508 by the tactile stimulation received on the own hand, and this may be sufficient to 509 immediately access the perceptual identity system and therefore become aware of the 510 visual self/other identity details previously ignored. Indeed, during the Own condition, 511 while perceiving tactile stimuli on their own hand and observing the alien not-512 stimulated hand, all three E+ patients noticed the visuo-tactile conflict, spontaneously 513 naming several details of the examiners' hand (e.g. the fingers length, the nails shape, 514 the skin color...) and concluding that the alien hand was not their own hand.

515 Interestingly, in normal subjects, the experimentally induced modulation of ownership 516 during the RHI has been shown to enhance the perceived physical similarity between 517 self and other body [i.e. normal subjects experiencing the RHI perceived their hand and 518 the rubber hand as significantly more similar in terms of their physical appearance 519 (Longo, Schüür, Kammers, Tsakiris, & Haggard, 2009)]. Coherently, during the RHI, 520 an increase of the functional connectivity between posterior visual-related areas, 521 involved in body part recognition (i.e. lateral occipitotemporal cortex -LOC and 522 extrastriate body area - EBA), and anterior brain areas involved in multisensory 523 integration (i.e. premotor cortex, PMC), was found to be stronger in the "re-calibration 524 phase" before illusion onset (Limanowski & Blankenburg, 2015). According to a recent 525 model of "prediction error minimization" during the RHI (Apps & Tsakiris, 2014), this 526 increased fronto-occipital functional connectivity, conveyed to parietal regions, 527 presumably resolves the conflict associated to sensory input during the illusion, such as 528 the discrepancy in visual appearance between real and rubber hand. Interestingly, a 529 recent time-frequency EEG study of the RHI (Kanayama, Morandi, Hiraki, & Pavani, 530 2016), showed that, during synchronous visuo-tactile stimulation, an altered causal 531 relationship from the medial frontal to the parietal regions transitorily unlocks the 532 mechanisms that preserve body integrity, allowing RHI to emerge. Interestingly, the

533 lesion pattern of the three E+ patients here (see Table 4) is compatible with previous 534 studies on E+ patients (Fossataro et al., 2016; Garbarini et al., 2015), showing a main 535 involvement of the white matter tracts connecting frontal to posterior areas of the brain 536 (i.e. the superior longitudinal fasciculus is one of the most frequent finding associated 537 to pathological embodiment). Thus, a damaged connectivity between frontal and 538 posterior visual-related areas, such as EBA and LOC, can potentially explain the E+ 539 patients' deficit in accessing the body visual details stored in the perceptual self-identity 540 system.

- 541
- 542

--- Table 4 about here ---

543

544 We can speculate that, in the three E+ cases described here, during the stimulation of 545 the own hand, the online activity of the spared somatosensory system can force the 546 connection with the visual areas where the information related to the body self-details 547 are stored, thus producing the (transitory) embodiment receding. Within the framework 548 provided by predictive coding, it has been suggested that RHI emerges through 549 attenuation of somatosensory precision. For instance, touch-evoked potentials, elicited 550 by brush-strokes, were selectively attenuated during the RHI (Zeller, Litvak, Friston, 551 & Classen, 2014). Coherently, the intrinsic connectivity in the primary somatosensory 552 area (S1) was significantly attenuated during the illusion perception due to a top-down 553 modulation exerted by PMC (Zeller, Friston, & Classen, 2016). If, during the RHI, in 554 order for the embodiment to occur, the somatosensory system has to be down-regulated, 555 it makes sense that, in E+ patients, in order for the embodiment to recede, the (spared) 556 somatosensory system has to be up-regulated. Thus, the stimulation in the Own 557 condition, may produce a reverse RHI effect, enhancing the somatosensory precision 558 and unveiling the conflict between the patient's and the examiner's hand.

In Experiment 2, for both Ownership and Sensation statement, all three groups gave
higher ratings in the Synchronous than the Asynchronous condition. In healthy subjects
and in E- patients, this result mirrors the classical RHI effect (Botvinick & Cohen, 1998;
Burin et al., 2015; Della Gatta et al., 2016; Ehrsson, Spence, & Passingham, 2004;
Moseley et al., 2008; Tsakiris, 2010; Tsakiris & Haggard, 2005). In E+ patients, sensory
manipulations similar to the ones used to induce RHI in normal subjects, maintain

565 embodiment of the alien hand in Synchronous condition. In the Asynchronous condition, known to prevent the embodiment of the rubber hand during the RHI, the 566 567 group analysis showed a receding of pathological embodiment similar to that found in 568 Experiment 1. However, in single-subject analysis, we found different results 569 depending on the patient. In particular, an embodiment receding was present, according 570 to the Sensation statement, in two out of three patients (E+2 and E+3) and, according 571 to the Ownership statement, only in one patient (E+2). In other words, the stimulation 572 in the Asynchronous condition obtains less reliable results that the manipulation of 573 Experiment 1. This may not be so surprising if we consider the important difference 574 between the conditions of the two experiments. Indeed, in the first experiment, when tactile stimulations were segregated, the contradiction between what the patients felt on 575 576 the own hand and what the patients saw on the alien hand was sufficient to counteract 577 the embodiment attitude. In the second experiment, although the Asynchronous 578 condition introduced a temporal delay between two tactile stimulations (on the own and 579 on the alien hand), both hands were touched (although in slightly different moments). 580 When the touch was delivered on the own hidden hand, this resembled the Own 581 condition of Experiment 1, possibly pressing towards a receding from the embodiment. 582 However, immediately after that, another touch was delivered on the visible alien hand, 583 triggering the typical embodiment condition. Therefore, in the Asynchronous 584 condition, two conflicting stimulations may have caused the variability of patients' 585 responses, depending on which of the two stimulations prevails.

586 It is important to note that the embodiment phenomena observed in E+ patients in the 587 Synchronous condition and in the RHI in normal subjects have important similarities 588 and crucial differences. On one hand, pathological embodiment relies on similar 589 constraints as those present in the RHI. It has been demonstrated that the RHI does not 590 arise when the fake hand is placed in allocentric perspective or in a non-compatible 591 posture, or when it is replaced by a neutral object (Costantini & Haggard, 2007; Ehrsson 592 et al., 2004; Tsakiris & Haggard, 2005). Similar constraints characterize the 593 pathological embodiment observed in E+ patients, which occurs only when the alien 594 hand is aligned with the patients' shoulder and perceived in egocentric perspective congruently with the patient's body. This means that to meet postural constrains is a 595 596 necessary pre-requisite to induce the embodiment. On the other hand, there are several 597 differences between the altered body ownership during the RHI and the abnormal body

598 ownership in E+ patients. First of all, the RHI is obtained with a prosthetic, human-599 like, plastic hand while in E+ patients, only a real human hand is able to induce the 600 pathological embodiment, suggesting that a pre-existing distinction between biological 601 and artificial categories (Kriegeskorte et al., 2008; Mazzoni, Brunel, Cavallari, 602 Logothetis, & Panzeri, 2011) is spared in our patients. Thus, while the RHI studies point 603 out the human-like appearance as a necessary constraint for inducing the embodiment, 604 the E+ patients' studies suggest that also a biological constraint plays an important role 605 in the construction of body ownership. Accordingly, it has been described a 606 somatoparaphrenic patient who, during the self-touch stimulations, achieved ownership 607 over the own (previously disembodied) arm and over different foreign arms (including 608 both human and rubber hand), but the stroking time that was needed to achieve the 609 sense of ownership was longer for the rubber hand compared to the human hand (van 610 Stralen, van Zandvoort, & Dijkerman, 2011). Second, in E+ patients, pathological 611 embodiment is a consequence of brain lesions and it is spontaneous and not induced by 612 an experimental procedure that manipulates different sources of stimulation. In other 613 words, differently from the RHI, no concurrent tactile stimuli are necessary, but the 614 simple vision of the alien hand induces pathological embodiment in E+ patients. Third, 615 while in the RHI subjects always know that the rubber hand is not their real hand, in 616 the E+ condition, patients actually believe that the alien hand belongs to themselves. In 617 other words, the embodiment phenomenon is qualitatively different from the illusion 618 experienced during the RHI and represents a completely altered subjective feeling of 619 body self. For this reason, we usually employed "yes or no" answers to detect the 620 presence/absence of the delusion instead of subjective ratings on a Likert scale, as 621 during the RHI procedure. However, when a Likert scale was used, as in the present 622 study, we noticed that, while healthy subjects gave ratings distributed through all the 623 Likert scale, E+ patients' ratings had a bimodal distribution, with responses centered at 624 the two extremities of the scale (as if they were giving yes or no answer).

625

626 **5. Conclusion**

Previous studies demonstrated that experimental procedures inducing a multisensory conflict between touch and vision have been satisfactorily applied in clinical rehabilitation contexts. Indeed, cross modal illusions, such as the mirror box illusion and the RHI, seem to be useful in restoring, at least in part, disorders of body 631 representation related to pain, sensory, and motor impairments in neuropsychological and neurological diseases (Bolognini, Russo, & Vallar, 2015). The present findings 632 633 represent the first evidence that, in E+ patients with spared tactile sensibility, a 634 multisensory conflict between what the patients feel on the own hand and what they 635 observe on the alien hand reduces, at least transitorily, the delusional body ownership 636 over the alien hand, by restoring the access to a perceptual self-identity system, where 637 visual body identity details are stored. This, in turn, suggests that a spared bottom-up 638 mechanism, such as the processing of tactile stimuli, may modulate a top-down process, 639 such as the sense of body ownership, by restoring an effective connection with visual 640 areas containing information related to the visual details of the body self.

641

Patients' neuropsychological assessment	E+1	E+2	E+3	E-1	E-2	E-3
Sex	F	F	F	М	М	М
Age	73	75	79	66	84	76
General cognitive impairment	24.5	19.7	17	24	22	21
Visual Field Defect	0-0	0-0	0-0	0-0	0-0	0-0
Hemiplegia (HP)	1	3	0	2	3	0
Hemianaesthesia (HA)	1	0	1	1	0	0
Anosognosia for HP	/	0	/	0	/	/
Proprioception	+	+	+	+	-	-
Extrapersonal Neglect	-	+	+	+	-	-
Personal Neglect	-	+	+	+	-	-

Somatoparaphrenia	-	-	-	-	-	-
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644 Table 1. Patients' demographic and clinical data

Presence (E+) or absence (E-) of embodiment of the experimenter's arm. Sex: M = 645 646 Male, F = Female. General cognitive impairment: MOCA cut off $\geq 17/30$ (Bosco et al., 647 2017). For visual field defect (the two values refer to the upper and lower visual 648 quadrants, respectively), hemiplegia, hemianesthesia and anosognosia for hemiplegia scores were ranged from normal (0) to severe defects (3) (Pia, Spinazzola, et al., 2014; 649 650 Pia et al., 2016; Piedimonte et al., 2015; Piedimonte, Garbarini, Pia, Mezzanato, & 651 Berti, 2016; Spinazzola, Pia, Folegatti, Marchetti, & Berti, 2008); in HA we gave score 652 equal to 1 to patients with tactile extinction; in AHP /= not assesable. Proprioception (-653 = no deficit; + = presence of deficit) assessed by means of the joint position matching 654 task, whereby a patient is asked to recreate (i.e. match) a reference joint angle (i.e. position) in the absence of vision (i.e. using proprioceptive information) (Goble, 2010). 655 656 Extrapersonal neglect (- = no deficit; + = presence of deficit;): BIT, conventional subtests cut-off \geq 129/146; BIT behavioral subtest cut-off \geq 67/81; DILLER cut-off 657 omissions $l-r \ge 5$. Personal neglect (- = no deficit; + = presence of deficit;): FLUFF cut 658 659 off omissions $L \leq 2$. The presence/absence of somatoparaphrenia was evaluated 660 according to Fotopoulou and coworker (Fotopoulou et al., 2011).

661

1		ALIEN CONDITION							OWN CC	ONDITION		
EX	Ow	nership stater	nent	Sen	sation staten	nent	Owr	nership stater	ment	Ser	isation staten	nent
	E+1	E+2	E+3	E+1	E+2	E+3	E+1	E+2	E+3	E+1	E+2	E+3
vs Controls	t= 4.25 *p= 0.001 Z-CC= 4.485	t= 5.05 *p= 0.0003 Z-CC= 5.697	t= 4.83 *p= 0.001 Z-CC= 5.091	t= 1.85 *p= 0.05 Z-CC= 1.958	t= 2.14 *p= 0.03 Z-CC= 2.257	t= 1.85 *p= 0.05 Z-CC= 1.958	t= -0.553 p= 0.29 Z-CC= -0.583	t= 0.10 p= 0.45 Z-CC= 0.112	t= -0.60 p= 0.28 Z-CC= -0.633	t= 0.43 p= 0.33 Z-CC= -0.462	t= 0.438 p= 0.33 Z-CC= -0.462	t= 0.438 p= 0.33 Z-CC= -0.462
rs E- patients	t= 26.812 *p= 0.001 Z-CC= 30.96	t= 33.74 *p= 0.0004 Z-CC= 38.96	t= 30.276 *p= 0.0005 Z-CC= 34.96	t= 68.416 *p= 0.0001 Z-CC= 79.00	t= 77.076 *p= 0.0001 Z-CC= 89.00	t= 68.416 *p= 0.0001 Z-CC= 79.00	t= -0.5 p= 0.33 Z-CC= -0.578	t= 0.37 p= 0.37 Z-CC= 0.43	t= -0.56 p= 0.31 Z-CC= -0.65	t= 0.372 p= 0.37 Z-CC= -0.430	t= 0.372 p= 0.37 Z-CC= -0.430	t= 0.372 p= 0.37 Z-CC= -0.430

662

663 Table 2. Experiment 1: Single subject analysis.

664 Significance test on difference between case's score and control sample, both healthy
665 subjects and E- patients group. Z-CC: effect size for difference between case and
666 controls (plus 95% CI), *p<0.05.

XP 2	SYNCHRONOUS CONDITION							А	SYNCHRONO		DN	
ш Ш	Ow	nership stater	nent	Sen	sation statem	nent	Owi	nership stater	nent	Ser	sation staten	nent
	E+1	E+2	E+3	E+1	E+2	E+3	E+1	E+2	E+3	E+1	E+2	E+3
vs Controls	t= 0.737 p= 0.241 Z-CC= 0.777	t= 0.951 p= 0.184 Z-CC= 1.002	t= 0.737 p= 0.241 Z-CC= 0.777	t= 1.176 p= 0.13 Z-CC= 1.234	t= 1.176 p= 0.13 Z-CC= 1.234	t= 0.639 p= 0.269 Z-CC= 0.670	t= 4.057 *p= 0.001 Z-CC= 4.255	t= 0.297 p= 0.387 Z-CC= -0.313	t= 4.564 *p= 0.001 Z-CC= 4.787	t= 5.155 *p= 0.0003 Z-CC= 5.406	t= 0.234 p= 0.41 Z-CC= -0.245	t= -0.381 p= 0.35 Z-CC= -0.4
vs E- patients	t= 0.716 p= 0.274 Z-CC= 0.827	t= 0.930 p= 0.225 Z-CC= 1.074	t= 0.716 p= 0.274 Z-CC= 0.827	t= 0.462 p= 0.344 Z-CC= 0.534	t= 0.462 p= 0.344 Z-CC= 0.534	t= -0.228 p= 0.420 Z-CC= -0.263	t= 20.457 *p= 0.001 Z-CC= 23.62	t= 1.732 p= 0.11 Z-CC= 2.00	t= -22.798 *p= 0.001 Z-CC= 26.32	t= 0.846 p= 0.243 Z-CC= 0.977	t= -0.398 p= 0.364 Z-CC= -0.46	t= -0.554 p= 0.317 Z-CC= -0.639

669 **Table 3. Experiment 2: Single subject analysis.**

670 Significance test on difference between case's score and control sample, both healthy

subjects and E- patients group. Z-CC: effect size for difference between case and
controls (plus 95% CI), *p<0.05.

673

Patients	Etiology	Lesion Side	Involved brain structures
*E+1	Н	RH	Basal ganglia, sub-cortical fronto-parietal periventricular white matter and middle temporal gyrus
E+2	Ι	RH	Basal ganglia (including caudate nucleus, putamen and globus pallidus) and sub-cortical fronto-parietal periventricular white matter (including uncinate fasciculus; internal capsule; external capsule, superior fronto-occipital fasciculus; superior longitudinal fasciculus; superior corona radiata)
*E+3	Ι	RH	Thalamus and sub-cortical fronto-parietal periventricular white matter
*E-1	Ι	RH	Superior temporal gyrus; insula; putamen; supramarginal gyrus; periventricular temporo- parietal white matter
E-2	Ι	RH	Superior temporal gyrus, supramarginal gyrus, rolandic operculum, insula, internal and external capsule and temporo-parietal periventricular white matter.
E-3	Ι	RH	Inferior and middle temporal gyrus, temporo- parietal periventricular white matter

674

675 **Table 4. Patients' involved brain structures.**

676 Etiology: H = hemorrhage; I = ischemia. Lesion Side: RH = Right Hemisphere; LH =

677 Left Hemisphere. Lesions were mapped onto the MNI stereotactic space with standard

678 MRI volume (voxels of 1 mm³) through a computerized technique. Image

- 679 manipulations were obtained with the software MRIcron (Rorden & Brett, 2000). * For
- 680 these patients, MRI or CT were not available and we reported the brain lesions
- 681 according to the medical report.
- 682
- 683

684 **FIGURE**



Figure 1. Experimental Conditions. Graphic representation of the experimental
conditions in Experiment 1 (panel A) and in Experiment 2 (panel B).



Figure 2. Experiment 1 results. Graphs show the mean subjective ratings with standard errors in the Own condition and the Alien condition, for both Ownership (left panel) and Sensation statement (right panel), in E+ patients (red), E- patients (green) and Healthy subjects (blue). Single subject's ratings are represented by means of different black icons (E+1: circle; E+2: square; E+3: triangle). ** p < 0.005.



Figure 3. Experiment 2 results. Graphs show the mean subjective ratings with standard errors in the Synchronous and the Asynchronous condition, for both Ownership (left panel) and Sensation statement (right panel), in E+ patients (red), Epatients (green) and Healthy subjects (blue). Single subject's ratings are represented by means of different black icons (E+1: circle; E+2: square; E+3: triangle). ** p < 0.005.

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