Corporeal Illusions in Chronic Spinal Cord Injuries

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Abstract

While several studies have investigated corporeal illusions in patients who have suffered from a stroke or undergone an amputation, only anecdotal or single case reports have explored this phenomenon after spinal cord injury. Here we examine various different types of bodily misperceptions in a comparatively large group of 49 people with spinal cord injury in the post-acute and chronic phases after the traumatic lesion onset. An extensive battery of questionnaires concerning a variety of body related feelings was administered and the results were correlated to the main clinical variables. Six different typologies of Corporeal Illusion emerged: Sensations of Body Loss; Body-Part Misperceptions; Somatoparaphrenia-like sensations; Disownership-like sensations; Illusory motion and Misoplegia. All of these (with the exception of Misoplegia) are modulated by clinical variables such as pain (visceral, neuropathic and musculoskeletal), completeness of the lesion, level of the lesion and the length of time since lesion onset. In contrast, no significant correlations between bodily illusions and personality variables were found. These results support data indicating that at least some cognitive functions (in particular the body, action and space representations) are embodied and that somatosensory input and motor output may be necessary to build and maintain a typical self-body representation.

Keywords: Spinal Cord Injuries; Corporeal Illusions; Embodied Cognition Theory; Pain; Body representation

1. Introduction

Implicit and explicit awareness of one's own body is fundamentally important, not only for the sense of self but also for people to be able to carry out actions in the external space around them and to interact with other people and objects. The representations underlying body awareness are the result of the continuous integration of information coming from somatosensory, motor, interoceptive, vestibular, visual and acoustic sources. This integration process provides immediate feedback on the current state of the body. This information is also integrated with higher-order cognitive functions (e.g. spatial perception and memory) to obtain a detailed map of the body and its relationships with the environment. Thus, body representations are the complex result of multiple components (Berlucchi & Aglioti, 2010). However, while the specific role of each of these components has been studied, the subject is still a matter of debate. A relevant contribution to the topic of bodily representations comes from the field of neuropsychology. Disorders in body representation after brain damage have been described since the beginning of the 20th century (Head & Holmes, 1911), with both “negative” symptoms (e.g. anosognosia for hemiplegia and limb disownership) and "productive" symptoms (e.g. supernumerary limbs and illusory movements) (Berlucchi & Aglioti, 2010; Gandola et al., 2012; Moro, Pernigo, Zapparoli, Cordioli, & Aglioti, 2011; Vocat, Staub, Stroppini, & Vuilleumier, 2010). Contemporary research on body representations has moved from the mere observation of the effects of brain activity on corporeal perception towards the investigation of how motor disabilities can change high level bodily representations (Glenberg, 2015). There have been seminal studies showing that the amputation of upper (Aglioti, Smania, Atzei, & Berlucchi, 1997) and lower (Aglioti, Bonazzi, & Cortese, 1994) limbs and of the breast (Aglioti, Cortese, Franchini, & Franchini, 1994) induces a neuroplastic reorganization of the sensory-motor cortex and convergent evidence indicates that the brain networks involved in body-related high cognitive functions (e.g. body, space and action representations) are heavily influenced by sensory-motor information coming from the body (Canzoneri, Marzolla, Amoresano, Verni, & Serino, 2013; Conson et al., 2008; Coslett, Medina, Kliot, & Burkey, 2010; Fiori et al., 2013; Fiorio, Tinazzi, & Aglioti, 2006).

A recent series of studies (Pernigo et al., 2012; Scandola, Aglioti, Bonente, Avesani, & Moro, 2016; Scandola, Aglioti, Pozeg, Avesani, & Moro, 2016; Scandola et al., 2014; Tidoni, Grisoni, Liuzza, & Aglioti, 2014; Tidoni, Fusco, et al., 2015) suggested that an investigation of people with spinal cord injury (SCI) may provide important insights on all the above issues. Indeed, information regarding the topography of the damage (i.e. whether the lesion level is above the first thoracic spinal level – T1: tetraplegia or below T1: paraplegia), allows a direct comparison between the cognitive activity relating to the intact body part and the cognitive activity relating to the de-afferented/de-efferented body parts. For example, a topographic remapping across sensory modalities and body parts has been found in visual body discrimination (Pernigo et al., 2012) and in the visual perception of human locomotion (Arrighi, Cartocci, & Burr, 2011). Topographically organized changes in motor imagery and space representation have also been described (Ionta et al., 2016; Manson et al., 2014; Scandola, Aglioti, Bonente, et al., 2016; Scandola, Aglioti, Pozeg, et al., 2016).

Distortion and reorganization processes relating to the perception of one's own body after SCI have been investigated using both experimental (Lenggenhager, Pazzaglia, Scivoletto, Molinari, & Aglioti, 2012; Scandola et al., 2014) and clinical approaches (Conomy, 1973; Curt, Yengue, Hilti, & Brugger, 2011). In the latter, patients report phantom limb sensations and movements and more rarely position illusions and supernumerary phantom limbs (Curt et al., 2011). Misperceptions may be striking and profound and seem to be more frequent in the first days after the lesion onset (Conomy, 1973). However the real incidence and duration of these symptoms remain largely unexplored and have probably been underestimated (Curt et al., 2011).

A SCI may cause adaptive or maladaptive neuroplasticity (Kokotilo, Eng, & Curt, 2009). The understanding of the underlying mechanisms will have impact in rehabilitative trainings and supportive tools, in fact BCI applications are influenced by brain plasticity (Tidoni, Tieri, & Aglioti, 2015).

In this study we investigated a relatively large sample of people with SCI to determine whether corporeal illusions and body misperceptions followed deafferentation and deefferentation. More specifically, the aim was to identify the various different types of corporeal symptoms and illusions and assess their frequency. In addition, we analyzed the effects of personality traits and clinical variables such as the level and completeness of the lesion, the time interval since lesion onset and the presence of neuropathic, visceral or muscular pain. The study capitalizes on the seminal descriptions provided by Conomy (1973) who investigated a sample of 18 cases of SCI in order to study body image disturbances involving the perception of the body in space (Proprioceptive body image), posture and movement (Kinetic body image) and body bulk, size and continuity (Somatic Body image). Using these clinical observations as a starting point, we devised an ad-hoc self-reporting questionnaire to be used in in-depth, individual interviews. Through a battery of questionnaires, emotions and affective feelings that the participants had towards their own body were also recorded.

2. Materials and methods

2.1 Participants

49 people suffering from chronic (> 1 year) spinal cord injury (SCI) and a control group of 24 neurologically healthy subjects (age, gender and education matched) participated in the study. The demographical and clinical data of the participants with SCI were previously described (Scandola, Aglioti, Pozeg, et al., 2016) and are reported in Table 1. The Completeness and Neurological Level of Injury (NLI, ASIA Kirshblum et al., 2011) and daily life functional independency (SCIM-III scale, Invernizzi et al., 2010) were assessed. Based on these clinical variables, four groups were identified: paraplegics with i) complete (n.12) or ii) incomplete (n.12) lesions below T1 and tetraplegics with iii) complete (n.12) or iv) incomplete (n. 13) lesions above T1.

Table 1 near here

The study was approved by the Local Ethics committee (CEP, Prot. N. 40378) and was conducted in accordance with the ethical standards of the 2013 Declaration of Helsinki.

2.2 Materials and Procedure

An in-depth interview was conducted to investigate the presence of body representation disorders and corporeal illusions after SCI. In addition, the presence of visceral, neuropathic or musculoskeletal pain was assessed and personality traits were explored in order to investigate any potential influence on the tendency to experience bodily illusions. The order of the questionnaires was randomized between subjects. Data were collected at the subject's home or in a quiet room at the Department of Rehabilitation in two 45 minute sessions. These two sessions took place either on the same day or on different days, depending on individual needs.

2.2.1 The Questionnaire regarding body feelings and illusions after SCI (BoFI-SCI)

We devised an ad hoc interview based on the study carried out by Conomy (Conomy, 1973) in order to investigate three aspects of bodily misperception, i.e. i) Proprioceptive Body Image (the disordered perception of the body in space), ii) Kinetic body image (the disordered perception of posture and movements) and iii) Somatic body image (the disordered perception of body bulk, size and continuity). We also included a number of questions concerning iv) affective body-related features. After a preliminary general query regarding the presence of any unusual or strange experiences concerning body perception, the patient was asked twenty-one questions (see Appendix A for the whole interview).

2.2.2 Clinical and personality variables in corporeal illusions

In order to investigate whether corporeal illusions are correlated with pain, we analyzed the subjects' responses to questions relating to a scale devised in our laboratory (Scandola, Aglioti, Pozeg, et al., 2016) in order to determine the presence and extent of any neuropathic, neuromuscular and visceral pain. The validation of this scale is currently in progress (Scandola, Brunelli, Avesani, Aglioti, & Moro, n.d.) but preliminary results confirm a high correlation with both the Brief Pain Inventory (BFI, Caraceni et al., 1996) and the *Douleur Neuropathique 4* Question Scale (Bouhassira et al., 2005) (for details, see Scandola, Aglioti, Pozeg, et al., 2016).

Finally, the potential effects on the BoFi-SCI scale of variables linked to the participants' personality traits were checked by means of an Italian translation of the 10-item version of the Big Five Inventory Scale (Rammstedt & John, 2007; BFI 10, Scandola, Aglioti, Pozeg, et al., 2016), the Tellegen Absorption Scale (TAS, Tellegen & Atkinson, 1974) and the Trinity Assessment of Body Plasticity (BodyTAP, Desmond, Horgan, & MacLachlan, 2001).

3. Results

3.1. BoFI-SCI questionnaire

In order to analyze the presence of corporeal illusions arising after spinal lesion, only the data from the SCI participants were considered. Their responses to the BoFI-SCI questionnaire were grouped by means of an Exploratory Factor Analysis (EFA). The number of factors was determined by means of Parallel Analysis which is considered to be one of the best methods (Zwick & Velicer, 1986) of carrying out this task. In order to avoid spurious results, the questions to which less than 4 SCI participants (5% of the total) provided affirmative responses were excluded from the analysis (question/number of responses: 2.4/2; 2.7/3; 2.8/0; 2.10/1; 3.7/2). As the answers were binomially distributed (Yes/No), we computed the tetrachoric correlation matrix, applying the EFA with VARIMAX rotation (Kaiser, 1958) thereby obtaining the factor structure and the question loadings (i.e. the correlation between a question and a factor). The factors were then named by reading the top loading questions on the factor. To compute the score of each factor, a sum of all the questions weighted for their loading values greater than 0.5 or lower than -0.5 was executed (DiStefano, Zhu, & Mîndrilă, 2009, page 3).

Clinical data from the ASIA scale were treated as follows: the lesion Completeness was considered as a categorical factor (Absence/Presence) and the NLI was calculated basing on the position of the most rostral spinal cord segment with sensorimotor functions intact (1 corresponding to the C1 segment and 30 corresponding to the S5 segment). The interval between the injury and the interview was treated as an integer representing the number of years which had passed since the injury (range: 1 - 44).

The data from the scales relating to pain were treated as categorical factors (presence/absence of pain). Finally, the personality questionnaire scores were computed following indications reported by the authors (Desmond et al., 2001; Rammstedt & John, 2007; Tellegen & Atkinson, 1974).

All the analyses were computed via the R framework for statistical analyses (R Core Team, 2015). We used the *ggplot2* (Wickham, 2009) package for graphical representations, the *coin* (Hothorn, Hornik, van de Wiel, & Zeileis, 2006) package to compute the *r* effect sizes for the Mann-Whitney tests and the *psych* (Revelle, 2015) package to compute the parallel analysis and the Exploratory Factor Analysis (EFA).

The analyses were organized in three phases. Firstly, the results from the EFA of the BoFI-SCI questionnaire were considered. Next, comparisons were made between the two groups regarding demographical and clinical data (a t-test, using Cohen's *d* as the effect size and χ^2 tests, using an odds ratio (OR) as the effect size) and personality traits (Mann-

Whitney tests, with the *r* index as the effect size). When any statistically significant differences were found, these were tested in order to identify potential correlations with BoFI-SCI factors in the SCI group.

The BoFI-SCI factors were analyzed by means of ANCOVA tests. In these analyses the completeness of the lesion, the presence of neuropathic, visceral, and musculoskeletal pain, the NLI and the interval since the lesion onset were considered as continuous variables. For main and interaction effects, η^2 was used as the effect size. Post-hoc analyses were computed by means of pairwise t-tests or additional regression analyses, Bonferroni corrected.

3.1.1 Results

According to the parallel analysis, a 6 factor structure emerged from the BoFI-SCI scale. The structure resulting from the loadings via EFA is shown in Table 2.

Table 2 near here

The six factors were:

Body loss **-** sensations of body parts disappearing and missing;

Illusory motion **-** sensations of motion that are not voluntarily controlled and muscular fatigue after illusionary movements (with a smaller loading for sensations of swelling);

Body part misperception **-** the feeling of having some body parts in a position which is different to the actual position.

Misoplegia **-** aversive feelings towards a given body part;

Disownership-like feelings - the feeling that body parts do not belong to the person.

Somatoparaphrenia-like sensations **-** the feelings that body parts are "alien", or detached from the body.

The correlation matrix (Table 2, at the bottom) shows only one significant correlation between Disownership-like and Somatoparaphrenia-like sensations (Pearsons' $r = .282$, $p < .05$ Bonferroni corrected).

The frequencies and scores for the four SCI groups and a comparison between the SCI group and the Controls are reported in Table 3. No significant differences were found (Wilcoxon Signed-Rank test).

Table 3 near here

3.2. Comparison between SCI and Control groups

The SCI and control groups were different in all but the “Body Loss” BoFI-SCI factors (Table 3). The two groups did not differ in Personality traits except for the Extraversion trait (Scandola, Aglioti, Pozeg, et al., 2016).

The two groups did not differ in age (control: 40.9 ± 14.7; SCI: 43.04 ± 12.5; $t_{(79)} = .647$, $p = .52$, d = .16), education (W = 471.5, $p = .236$, $r = .14$), and gender ($\chi^2_{(1)} = 2.84$, $p = .09$, OR = .31).

Neuropathic and the musculoskeletal pain were more frequent in the SCI participants than in the controls, while there were no differences for visceral pain (Scandola, Aglioti, Pozeg, et al., 2016).

3.3. Effects of the clinical variables on the BoFI-SCI scores

The scores obtained in the BoFI-SCI scale and the data relating to clinical variables were analyzed by means of ANCOVAs, taking into consideration only the interactions that guaranteed a well-distributed number of observations among the cells. The categorical, 2 level (presence= +, absence = -) independent variables were: Neuropathic pain (NP: NP+/NP); Musculoskeletal pain (MP: MP+/MP-); Visceral pain (VP: VP+ /VP-) and Completeness of lesion (Lesion, L+ /L-). The two continuous variables were: Interval of time since lesion onset (Years, range: 1-44) and Neurological Level of Injury (NLI, range: 1-30). The following interactions were considered: NP and NLI; NP and Years; MP and NLI; MP and Years; VP and NLI; VP and Years; Lesion and NLI; Lesion and Years; NP and MP; NP and lesion; MP and VP; MP and Lesion and lastly VP and Lesion.

3.3.1. Results

3.3.1.1 Body loss

For this factor, the interaction between VP and NLI ($F_{(1,29)}$ = 4.857, p = .036, η^2 = .143) turned out to be significant: participants with SCI suffering from Visceral Pain (VP+) and more caudal lesions more frequently experienced sensations of body loss, while in participants without Visceral Pain (VP-) the trend was linear (Figure 1a).

Furthermore, the interaction between MP and VP was significant ($F_{(1,29)}$ = 6.529, p = .016, η^2 = .184). However, even though at a qualitative observation VP+MP- participants had lower scores for Body Loss (.85 +- 1.19) than VP+MP+ subjects (-.16+-.66), VP-MP- (.21 +- .62) and VP-MP+ subjects (.37 +- 1.06), pairwise t-tests did not resist when the Bonferroni correction was carried out.

Figure 1 near here

3.3.1.2 Illusory motion

In the case of Illusory motion there were two significant interactions: between NP and Years ($F_{(1,29)}$ = 4.760, p = .037, η^2 = .141) and between MP and Lesion ($F_{(1,29)}$ = 8.047, p = .008, η^2 = .217). SCI participants without neuropathic pain (NP-) and with older lesions scored higher than participants with more recent lesions. The opposite trend was observable for SCI participants with neuropathic pain (NP+) (Figure 1b).

Bonferroni corrected pairwise t-tests showed that MP+L- participants had higher scores (N= 9, score=1.03±.94) than MP+L+ (N= 11, score=.35±.48, p < .05) and MP-L- (N= 16, score=.31±.69, p < .05), while a comparison with MP-L+ did not reach statistical significance (N= 13, score=.85±.81).

3.3.1.3 Body-part misperceptions

The analysis revealed a significant interaction between VP and NLI ($F_{(1,29)}$ = 4.741, p = .038, η^2= .141) and between NP and MP ($F_{(1,29)}$ = 6.952, p = .013, η^2 = .193). SCI participants with VP and more caudal lesions were subject to more frequent body part misperceptions, while the results for participants without VP showed the opposite trend (see Figure 1c).

By analysing the interaction between NP and MP, Bonferroni corrected pairwise t-tests showed that when MP+ and NP+ were present together, participants had more body-part misperceptions (MP+NP+: N= 11, score= 1.77± .00;MP-NP+: N= 17, score=.84± .89, p = .012; MP+NP-: N= 9, score=.78 ± .82, p = .021).

3.3.1.4 Somatoparaphrenia-like sensations

There was a significant effect as a result of the interaction between Lesion and NLI ($F_{(1,29)} = 4.824$, $p = .036$, $\eta^2 = .143$) and a main effect on NLI ($F_{(1,29)} = 6.722$, $p = .015$, $\eta^2 = .188$). L- participants with more caudal lesions had higher scores for Somatoparaphrenia-like sensations than L- participants with more rostral lesions. A linear trend was evident for L+ participants (see Figure 1d).

3.3.1.5 Misoplegia and Disownership-like sensations

Participants with MP+ had greater scores for Misoplegia (.65 ± .67) than MP- (.25 ± .45) ($F_{(1,29)}=5.496$, $p = .026$, $\eta^2 = .159$), while no statistically significant interactions with clinical variables were found for Disownership-like sensations.

4. Discussion

The analysis of the responses to the BoFI-SCI indicates that corporeal illusions after SCI are frequent and not limited to short term windows after the lesion onset. Various typologies of misperceptions were identified in our sample, namely, Sensations of Body loss, Illusory Motion, Body-part misperceptions, Misoplegia, Disownership-like feelings and Somatoparaphrenia-like feelings. SCI participants had greater scores than the controls in all the scales relating to the above phenomena, with the exception of only Body Loss sensations. Clinical variables such as the presence of pain, the interval of time since the lesion and the lesion completeness seem to influence these symptoms.

To the best of our knowledge, only two studies have thus far investigated corporeal illusions in a relatively large sample of patients. Bors (1951) reported that all of his 50 patients complained of phenomena such as cutaneous sensations or postural hallucinations but he did not find any cases of misperception regarding the size of body components or telescoping phenomena. Subsequently Conomy (1973) compared 18 people with SCI with 11 patients suffering from non-traumatic myelopathy (multiple sclerosis, progressive cord compression due to metastatic tumor, tabes dorsalis, anterior progressive myelopathy, lumbar myelomeningocoele and pernicious anaemia). None of the people in the latter group reported experiences of corporeal illusions such as those referred to by the people with SCI (but see Evans, 1962), although various symptoms of paresthesia were described. Only one non-traumatic patient had kinetic hallucinations and he was the only one suffering from a sudden onset of plegia. Thus, the sudden, non-progressive onset of a lesion might be a crucial factor for corporeal illusions. The high frequency of misperceptions found in our patients may therefore depend on the traumatic aetiology. Crucially, at the time of the interview the SCI participants in our study were in sub-acute and chronic phases, suggesting that these phenomena are not limited to acute post-lesional phases.

4.1. *Various different kinds of corporeal illusions*

The EFA executed on the responses of the SCI participants allowed us to identify six categories of corporeal illusions: Body part misperceptions; Illusory Motion; Disownership-like feelings; Somatoparaphrenia-like feelings; Sensations of Body Loss and Misoplegia. These will be discussed below.

The feeling of having body parts in different positions compared to their actual position (Body part misperceptions) is the most frequent sensation (from 100% in TC to 61% in TI) with the SCI participants showing the highest mean score (1.11 ± 0.79). This probably corresponds to Conomy's study (Conomy, 1973) on Proprioceptive Body Image disorders and Bors' Postural hallucinations (Bors, 1951), as they also found this to be the most common form of body image disorder. These feelings frequently occur immediately at the instant of the injury but, as our data demonstrate, can persist over time (one of Conomy's patients still reported this sensation at 25 years from lesion 1973; Curt et al., 2011; Ettlin, Seiler, & Kaeser, 1980).

It has been suggested that proprioceptive/postural disturbances found immediately after the lesion onset may be influenced by the position of the limbs immediately before the trauma, constituting a sort of sensory memory (Guttman, 1969). Unfortunately we did not specifically investigate the memories of bodily sensations which occurred in acute stages, but the possibility that people who have SCI spontaneously refer to sensory and visual memories to build (and rebuild) their body representations and to imagine currently impossible actions is confirmed by previous results relating to motor imagery (Scandola, Aglioti, Pozeg, et al., 2016).

Phenomena related to sensations of involuntary motion and consequent muscular fatigue (Illusory motion) were frequently reported by our participants confirming Conomy's study on disorders in Kinetic body image (Conomy, 1973). However, there is a possibility that these corporeal illusions change over time. In our sample, these misperceptions reduced over time but only when neuropathic pain was present.

We also recorded Disownership-like feelings, i.e. the sensation that body parts do not belong to the person, often associated with the sensation that the arms are detached from the shoulders. While sensations of body part detachment were found in previous studies, disownership feelings seem to be less frequent (1 partincipant in Conomy, 1973; Riddoch, 1941). In our sample, these sensations were more frequent in the paraplegic participants (in particular those with incomplete lesions) than in those who were tetraplegic.

Correlated to this factor, we found Somatoparaphrenia-like sensations, i.e. feelings that paralyzed limbs are alien or foreign, that the legs are not attached to hips or the toes are in a strange position. While Disownership-like sensations are not modulated by any clinical variables, somatoparaphrenia-like sensations are modulated by the completeness of the lesion and the lesion level. In fact, in the presence of incomplete lesions (in contrast to cases of complete lesion), more cases of caudal lesion were associated with the feeling that the paralyzed body part was alien or foreign. This may at least in part be due to uncontrolled sensations coming from residual connections spared in incomplete lesions.

Supernumerary phantom limbs have been reported in a single case study regarding a patient with an incomplete lesion[26]. The symptoms, present in the acute post-lesional phase, went away in the few first months in parallel with the patient's motor recovery (Curt et al., 2011). None of our participants spontaneously reported supernumerary phantom limbs, but further investigations are necessary to specifically investigate this symptom.

Finally , less than 4 participants reported sensations regarding the Bulk and size of their body (Somatic body image in Conomy, 1973). Reductions in the size of the trunk, extremities or perineal structures were not reported by our patients who only described a sensation of abdomen swelling even when disturbances of gastrointestinal functions had been treated. This contrasts with the results of a previous study (Fuentes, Pazzaglia, Longo, Scivoletto, & Haggard, 2013) where participants were asked to localize specific body parts with respect to an anchoring stimulus shown on a computer screen. The SCI subjects positioned the body parts as if their torso and limbs were elongated relative to their body width, suggesting the presence of body size misperceptions. Although interesting, these results only partially measure body representation, as the task involved significant components of visuo-spatial perception and mental imagery (Fuentes et al., 2013).

A novelty in the present study is that we also investigated the emotions and affective feelings of the SCI participants towards their own body. Feelings of hate towards the affected parts and a desire not to have them emerged from the interviews (Misoplegia). These emotional aspects of body awareness are probably underestimated or attributed to personality and mood variables in clinical examinations. Significantly we found that the presence of musculoskeletal pain had a worsening effect on Misoplegia, suggesting that pain (and its management) may have an impact on affective feelings towards the body. Although these components may be crucial in terms of how the effects of severe disability are dealt with, we did not find any correlations between corporeal illusions and personality traits. Rather, we suggest that in people with SCI, multiple elements linked to changes in somato-sensory perception play a role in their affective/emotional attitudes towards their body, including autonomic dysregulation (e.g. thermal dysregulation Song, Won, Park, Ko, & Seo, 2015), modifications in the appearance of the body (e.g. the thinning of limbs and global obesity, Hatchett, Mulroy, Eberly, Haubert, & Requejo, 2016) and autobiographic memories and desires (Lomman & Kirk, 2006; Saurat, Agbakou, Attigui, Golmard, & Arnulf, 2011). Elements of depersonalization in people with SCI (i.e. the feeling that one's own experiences are detached, distant, not one's own or somehow lost) have been reported by

Lenggenhager and colleagues (2012) who investigated this topic by means of the Cambridge Depersonalization Scale (Sierra & Berrios, 2000). Crucially, the authors did not find indications of global processes of detachment from daily life experiences (i.e. the sensation that one's own experiences do not belong to oneself). Conversely, they found distortions relating to bodily and corporeal experiences. In fact, their patients reported that they had lost some bodily sensations (e.g. hunger, "when I eat or drink it feels like an automatic routine", Lenggenhager et al., 2012, p. 4), they felt as if their body did not belong to them and they felt it necessary to touch themselves to make sure that they had a body. All these reports are consistent with the hypothesis regarding the presence of corporeal illusions in people with SCI.

4.2. Multiple contributions to corporeal illusions

The first explanations of corporeal illusions after SCI referred to information coming to the brain from the most distal segment of the intact portion of spinal cord, the preservation of a few intact axons and the existence of regenerative uncontrolled processes at spinal level, all of which might mediate disorders in body image (Conomy, 1973).

The discovery of the occurrence of plastic functional and structural reorganization after deafferentation and deefferentation, not only at spinal level but also in brain networks (Aguilar et al., 2010; Freund et al., 2013; Freund, Rothwell, Craggs, Thompson, & Bestmann, 2011) has changed the approach towards these phenomena. Unfortunately, less is known about whether these plastic changes are inherently adaptive or largely maladaptive (Kokotilo et al., 2009; Nishimura & Isa, 2009). It is however plausible that reorganization processes do not only impact the sensory-motor systems but also the networks involved in high cognitive functions.

Our results show that corporeal illusions are not modulated by personality aspects but are influenced by clinical factors, in particular the interval of time since lesion onset, the level of the lesion and the presence/absence of pain. These variables have been shown to have an effect on neuroplasticity processes. Chronic pain is correlated with plasticity in cerebral (Melzack, Coderre, Katz, & Vaccarino, 2006; Woolf, 2000) and spinal (Ji & Woolf, 2001; Pockett, 1995) networks. Furthermore, the length of time since the lesion onset is connected with brain plasticity (Freund et al., 2013) and the level of the lesion changes (Freund et al., 2013; Henderson, Gustin, Macey, Wrigley, & Siddall, 2011) the extent of the areas of the brain which are involved in neuroplastic modifications. Altogether, these data suggest that corporeal sensations may reflect aspects of maladaptive neuroplastic modifications in the neural networks involved in body representations. An in-depth assessment of these symptoms would therefore be useful as an index of neuroplasticity following SCI. Further MRI studies would provide information on the neural correlates of corporeal illusions.

In previous studies, a precise topography of cognitive changes after SCI (body, action and space perception, motor imagery) was identified. These specifically relate to the affected body parts (Pernigo et al., 2012; Scandola, Aglioti, Pozeg, et al., 2016; Scandola et al., 2014). With regard to corporeal misperceptions, we did not find a specific topographical organization (i.e. sensations reported by paraplegic but not by tetraplegic patients or viceversa). Nevertheless, our results show that body part misperceptions are influenced by the lesion level (in particular when associated with various typologies of pain).

Thus we cannot exclude the possibility that the interaction between multiple bottom-up (somato-sensory, interoceptive and vestibular inputs) and top-down (memory, motor and visual imagery) components may have an influence on the neuroplastic processes which are probably correlated to experiences of corporeal misperceptions. A mismatch between a pre-existing body model and actual sensory inputs probably occurs (Bors, 1951; Burke & Woodward, 1969; Curt et al., 2011) and in this mismatch somato-sensory afferences play a role, as do interoceptive information, post-lesional motor strategies adopted to achieve autonomy, changes in the perception of space and semantic, visual and sensory memories related to the body. Indeed, the body-brain relationship is bidirectional: on the one hand some cognitive functions are at least partially based on body perceptions and actions and on the other hand we can assume that body representations and awareness are shaped by both sensory-motor and high cognitive functions.

In order to better understand the extent of the influence of brain neuroplasticity and cognitive aspects, further studies are required.

5. Conclusions

A complex pattern of corporeal illusions in cases of SCI emerged from this investigation. These involved body form (Body Loss and Body Part Misperceptions), movements (Illusory motion) and the sense of ownership of one's own body (Disownership-like sensations, Somatoparaphrenia-like sensations, Misoplegia). The illusions are influenced by clinical variables and change over time but they are not correlated to personality variables. Our results indicate that there is a possibility that corporeal illusions are the effect of uncontrolled neuroplastic changes. Further studies are necessary in order to understand whether specific rehabilitative training may help people with SCI in order to reduce these misperceptions and their effect on the quality of life.

Conflict of Interest Statement

The Authors declare that there is no conflict of interest.

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References:

Aglioti, S. M., Bonazzi, A., & Cortese, F. (1994). Phantom lower limb as a perceptual marker of neural plasticity in the mature human brain. *Proceedings of the Royal Society of London. Series B: Biological Sciences*, *255*(1344), 273–8. http://doi.org/10.1098/rspb.1994.0039

Aglioti, S. M., Cortese, F., Franchini, M., & Franchini, C. (1994). Rapid sensory remapping in the adult human brain as inferred from phantom breast perception. *Neuroreport*, *5*(4), 473–476.

Aglioti, S. M., Smania, N., Atzei, A., & Berlucchi, G. (1997). Spatio-temporal properties of the pattern of evoked phantom sensations in a left index amputee patient. *Behavioral Neuroscience*, *111*(5), 867–72. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/9383509

Aguilar, J., Humanes-Valera, D., Alonso-Calviño, E., Yague, J. G., Moxon, K. a, Oliviero, A., & Foffani, G. (2010). Spinal cord injury immediately changes the state of the brain. *The Journal of*

Neuroscience : The Official Journal of the Society for Neuroscience, *30*(22), 7528–7537. http://doi.org/10.1523/JNEUROSCI.0379-10.2010

Arrighi, R., Cartocci, G., & Burr, D. (2011). Reduced perceptual sensitivity for biological motion in paraplegia patients. *Current Biology*, *21*(22), R910–911. http://doi.org/10.1016/j.cub.2011.09.048

Berlucchi, G., & Aglioti, S. M. (2010). The body in the brain revisited. *Experimental Brain Research. Experimentelle Hirnforschung. Expérimentation Cérébrale*, *200*(1), 25–35. http://doi.org/10.1007/s00221-009-1970-7

Bors, E. (1951). Phantom limbs of patients with spinal cord injury. *Archives of Neurology And Psychiatry*, *66*(5), 610. http://doi.org/10.1001/archneurpsyc.1951.02320110075007

Bouhassira, D., Attal, N., Alchaar, H., Boureau, F., Brochet, B., Bruxelle, J., … Vicaut, E. (2005). Comparison of pain syndromes associated with nervous or somatic lesions and development of a new neuropathic pain diagnostic questionnaire (DN4). *Pain*, *114*(1-2), 29–36. http://doi.org/10.1016/j.pain.2004.12.010

Burke, C. D., & Woodward, I. M. (1969). Pain and phantom sensation in spinal cord paralysis. Retrieved from http://philpapers.org/rec/BURPAP-7

Canzoneri, E., Marzolla, M., Amoresano, A., Verni, G., & Serino, A. (2013). Amputation and prosthesis implantation shape body and peripersonal space representations. *Scientific Reports*, *3*, 2844. http://doi.org/10.1038/srep02844

Caraceni, A., Mendoza, T. R., Mencaglia, E., Baratella, C., Edwards, K., Forjaz, M. J., … Cleeland, C. S. (1996). A validation study of an Italian version of the Brief Pain Inventory (Breve Questionario per la Valutazione del Dolore). *Pain*, *65*(1), 87–92. http://doi.org/10.1016/0304-3959(95)00156-5

Conomy, J. P. (1973). Disorders of body image after spinal cord injury. *Neurology*, *23*(8), 842. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/4737080

Conson, M., Sacco, S., Sarà, M., Pistoia, F., Grossi, D., & Trojano, L. (2008). Selective motor imagery defect in patients with locked-in syndrome. *Neuropsychologia*, *46*(11), 2622–2628. http://doi.org/10.1016/j.neuropsychologia.2008.04.015

Coslett, H. B., Medina, J., Kliot, D., & Burkey, A. R. (2010). Mental motor imagery indexes pain: The hand laterality task. *European Journal of Pain*, *14*(10), 1007–1013. http://doi.org/10.1016/j.ejpain.2010.04.001

Curt, A., Yengue, C. N., Hilti, L. M., & Brugger, P. (2011). Supernumerary phantom limbs in spinal cord injury. *Spinal Cord*, *49*(5), 588–95. http://doi.org/10.1038/sc.2010.143

Desmond, D., Horgan, O., & MacLachlan, M. (2001). Body boundary appraisals and the measurement of plasticity: development of the Trinity Assessment of Body Plasticity (TABP). In *10th World Congress of the International Society for Prosthetics and Orthotics, Glasgow*.

DiStefano, C., Zhu, M., & Mîndrilă, D. (2009). Understanding and Using Factor Scores: Considerations for the Applied Researcher. *Practical Assessment, Research & Evaluation*, *14*(20), 1–11.

Ettlin, T. M., Seiler, W., & Kaeser, H. E. (1980). Phantom and amputation illusions in paraplegic patients. *European Neurology*, *19*(1), 12–19. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/7371649

Evans, J. H. (1962). On Disturbance of the Body Image in Paraplegia. *Brain*, *85*(4), 687–700. http://doi.org/10.1093/brain/85.4.687

Fiori, F., Sedda, A., Ferrè, E. R., Toraldo, A., Querzola, M., Pasotti, F., … Bottini, G. (2013). Exploring motor and visual imagery in Amyotrophic Lateral Sclerosis. *Experimental Brain Research*, *226*(4), 537–47. http://doi.org/10.1007/s00221-013-3465-9

Fiorio, M., Tinazzi, M., & Aglioti, S. M. (2006). Selective impairment of hand mental rotation in patients with focal hand dystonia. *Brain: A Journal of Neurology*, *129*(1), 47–54. http://doi.org/10.1093/brain

Freund, P., Rothwell, J., Craggs, M., Thompson, A. J., & Bestmann, S. (2011). Corticomotor representation to a human forearm muscle changes following cervical spinal cord injury. *The European Journal of Neuroscience*, *34*(11), 1839–1846. http://doi.org/10.1111/j.1460-9568.2011.07895.x

Freund, P., Weiskopf, N., Ashburner, J., Wolf, K., Sutter, R., Altmann, D. R., … Curt, A. (2013). MRI investigation of the sensorimotor cortex and the corticospinal tract after acute spinal cord injury: a prospective longitudinal study. *Lancet Neurology*, *12*(9), 873–881. http://doi.org/10.1016/S1474-4422(13)70146-7

Fuentes, C. T., Pazzaglia, M., Longo, M. R., Scivoletto, G., & Haggard, P. (2013). Body image distortions following spinal cord injury. *Journal of Neurology, Neurosurgery & Psychiatry*, *84*(2), 201–207. http://doi.org/10.1136/jnnp-2012-304001

Gandola, M., Invernizzi, P., Sedda, A., Ferrè, E. R., Sterzi, R., Sberna, M., … Bottini, G. (2012). An anatomical account of somatoparaphrenia. *Cortex; a Journal Devoted to the Study of the Nervous System and Behavior*, *48*(9), 1165–78. http://doi.org/10.1016/j.cortex.2011.06.012

Glenberg, A. M. (2015). Few believe the world is flat: How embodiment is changing the scientific understanding of cognition. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Exp{é}rimentale*, *69*(2), 165.

Guttman, L. (1969). Symptomatology of Spinal cord lesions. In P. J. Vinken & G. W. Bruyn (Eds.), *Handbook of clinical neurology, vol. 2* (pp. 178–216). Amsterdam: North Holland Publishing Company.

Hatchett, P. E., Mulroy, S. J., Eberly, V. J., Haubert, L. L., & Requejo, P. S. (2016). Body mass index changes over 3 years and effect of obesity on community mobility for persons with chronic spinal cord injury. *The Journal of Spinal Cord Medicine*. http://doi.org/10.1080/10790268.2015.1133482

Head, H., & Holmes, G. (1911). Sensory disturbances from cerebral lesions. *Brain*, *34*(2-3), 102–254. http://doi.org/10.1093/brain/34.2-3.102

Henderson, L. A., Gustin, S. M., Macey, P. M., Wrigley, P. J., & Siddall, P. J. (2011). Functional Reorganization of the Brain in Humans Following Spinal Cord Injury: Evidence for Underlying Changes in Cortical Anatomy. *The Journal of Neuroscience*, *31*(7), 2630 –2637. http://doi.org/10.1523/JNEUROSCI.2717-10.2011

Hothorn, T., Hornik, K., van de Wiel, M. A., & Zeileis, A. (2006). A Lego System for Conditional Inference. *The American Statistician*, *60*(3), 257–263. http://doi.org/10.1198/000313006X118430

Invernizzi, M., Carda, S., Milani, P., Mattana, F., Fletzer, D., Iolascon, G., … Cisari, C. (2010). Development and validation of the Italian version of the Spinal Cord Independence Measure III. *Disability and Rehabilitation*, *32*(14), 1194–1203. http://doi.org/10.3109/09638280903437246

Ionta, S., Villiger, M., Jutzeler, C. R., Freund, P., Curt, A., & Gassert, R. (2016). Spinal cord injury affects the interplay between visual and sensorimotor representations of the body. *Scientific Reports*, *6*, 20144. http://doi.org/10.1038/srep20144

Ji, R. R., & Woolf, C. J. (2001). Neuronal plasticity and signal transduction in nociceptive neurons: implications for the initiation and maintenance of pathological pain. *Neurobiology of Disease*, *8*(1), 1–10. http://doi.org/10.1006/nbdi.2000.0360

Kaiser, H. F. (1958). The varimax criterion for analytic rotation in factor analysis. *Psychometrika*, *23*(3), 187–200. http://doi.org/10.1007/BF02289233

Kirshblum, S. C., Burns, S. P., Biering-Sorensen, F., Donovan, W., Graves, D. E., Jha, A., … Waring, W. (2011). International standards for neurological classification of spinal cord injury (Revised 2011). *The Journal of Spinal Cord Medicine*, *34*(6), 535–546. http://doi.org/10.1179/204577211X13207446293695

Kokotilo, K. J., Eng, J. J., & Curt, A. (2009). Reorganization and preservation of motor control of the brain in spinal cord injury: a systematic review. *Journal of Neurotrauma*, *26*(11), 2113–2126. http://doi.org/10.1089/neu.2008.0688

Lenggenhager, B., Pazzaglia, M., Scivoletto, G., Molinari, M., & Aglioti, S. M. (2012). The sense of the body in individuals with spinal cord injury. *PloS One*, *7*(11), e50757. http://doi.org/10.1371/journal.pone.0050757

Lomman, D., & Kirk, B. (2006). Motorcycling Freedom: A Paraplegics Dream. *Australasian Physical & Engineering Sciences in Medicine*, *29*(1), 62. Retrieved from http://search.informit.com.au/documentSummary;dn=456619000866614;res=IELENG

Manson, G. A., Sayenko, D. G., Masani, K., Goodman, R., Wong, L., Popovic, M. R., … Welsh, T. N. (2014). Action possibility judgments of people with varying motor abilities due to spinal cord injury. *PloS One*, *9*(10), e110250. http://doi.org/10.1371/journal.pone.0110250

Melzack, R., Coderre, T. J., Katz, J., & Vaccarino, A. L. (2006). Central Neuroplasticity and Pathological Pain. *Annals of the New York Academy of Sciences*, *933*(1), 157–174.

http://doi.org/10.1111/j.1749-6632.2001.tb05822.x

Moro, V., Pernigo, S., Zapparoli, P., Cordioli, Z., & Aglioti, S. M. (2011). Phenomenology and neural correlates of implicit and emergent motor awareness in patients with anosognosia for hemiplegia. *Behavioural Brain Research*, *225*(1), 259–269. http://doi.org/10.1016/j.bbr.2011.07.010

Nishimura, Y., & Isa, T. (2009). Compensatory changes at the cerebral cortical level after spinal cord injury. *The Neuroscientist: A Review Journal Bringing Neurobiology, Neurology and Psychiatry*, *15*(5), 436–444. http://doi.org/10.1177/1073858408331375

Pernigo, S., Moro, V., Avesani, R., Miatello, C., Urgesi, C., & Aglioti, S. M. (2012). Massive somatic deafferentation and motor deefferentation of the lower part of the body impair its visual recognition: a psychophysical study of patients with spinal cord injury. *The European Journal of Neuroscience*, *36*(11), 3509–3518. http://doi.org/10.1111/j.1460-9568.2012.08266.x

Pockett, S. (1995). Spinal Cord Synaptic Plasticity and Chronic Pain. *Anesthesia & Analgesia*, *80*(1), 173–179. Retrieved from http://journals.lww.com/anesthesia-analgesia/Citation/1995/01000/Spinal_Cord_Synaptic_Plasticity_and_Chronic_Pain.26.aspx

R Core Team. (2015). R: A Language and Environment for Statistical Computing. Vienna, Austria. Retrieved from http://www.r-project.org

Rammstedt, B., & John, O. P. (2007). Measuring personality in one minute or less: A 10-item short version of the Big Five Inventory in English and German. *Journal of Research in Personality*, *41*(1), 203–212. http://doi.org/10.1016/j.jrp.2006.02.001

Revelle, W. (2015). psych: Procedures for Psychological, Psychometric, and Personality Research. Evanston, Illinois. Retrieved from http://cran.r-project.org/package=psych

Riddoch, G. (1941). Phantom limbs and body shape. *Brain*, *64*, 197–222. http://doi.org/10.1093/brain/64.4.197

Saurat, M.-T., Agbakou, M., Attigui, P., Golmard, J.-L., & Arnulf, I. (2011). Walking dreams in congenital and acquired paraplegia. *Consciousness and Cognition*, *20*(4), 1425–32. http://doi.org/10.1016/j.concog.2011.05.015

Scandola, M., Aglioti, S. M., Bonente, C., Avesani, R., & Moro, V. (2016). Spinal cord lesions shrink peripersonal space around the feet, passive mobilization of paraplegic limbs restores it. *Scientific Reports*, *6*(April), 24126. http://doi.org/10.1038/srep24126

Scandola, M., Aglioti, S. M., Pozeg, P., Avesani, R., & Moro, V. (2016). Motor imagery in spinal cord injured people is modulated by somato-topic coding, perspective taking and post-lesional chronic pain. *Journal of Neuropsychology*, n/a–n/a. http://doi.org/10.1111/jnp.12098

Scandola, M., Brunelli, G., Avesani, R., Aglioti, S. M., & Moro, V. (n.d.). *VR Pain Inventory*.

Scandola, M., Tidoni, E., Avesani, R., Brunelli, G., Aglioti, S. M., & Moro, V. (2014). Rubber hand illusion induced by touching the face ipsilaterally to a deprived hand: evidence for plastic “somatotopic” remapping in tetraplegics. *Frontiers in Human Neuroscience*, *8*, 404. http://doi.org/10.3389/fnhum.2014.00404

Sierra, M., & Berrios, G. E. (2000). The Cambridge Depersonalisation Scale: a new instrument for the measurement of depersonalisation. *Psychiatry Research*, *93*(2), 153–164. http://doi.org/10.1016/S0165-1781(00)00100-1

Song, Y.-G., Won, Y. H., Park, S.-H., Ko, M.-H., & Seo, J.-H. (2015). Changes in body temperature in incomplete spinal cord injury by digital infrared thermographic imaging. *Annals of Rehabilitation Medicine*, *39*(5), 696–704. http://doi.org/0.5535/arm.2015.39.5. 696

Tellegen, A., & Atkinson, G. (1974). Openess to absorbing and self-altering experiences (“absorption”), a trait related to hypnotic susceptibility. *Journal of Abnormal Psychology*, *83*(3), 268–277. http://doi.org/10.1037/h0036681

Tidoni, E., Fusco, G., Leonardis, D., Frisoli, A., Bergamasco, M., & Aglioti, S. M. (2015). Illusory movements induced by tendon vibration in right- and left-handed people. *Experimental Brain Research*, *233*(2), 375–83. http://doi.org/10.1007/s00221-014-4121-8

Tidoni, E., Grisoni, L., Liuzza, M. T., & Aglioti, S. M. (2014). Rubber hand illusion highlights massive visual capture and sensorimotor face-hand remapping in a tetraplegic man. *Restorative Neurology and Neuroscience*, *32*(5), 611–622. http://doi.org/10.3233/RNN-130385

Tidoni, E., Tieri, G., & Aglioti, S. M. (2015). Re-establishing the disrupted sensorimotor loop in deafferented and deefferented people: The case of spinal cord injuries. *Neuropsychologia*, *79*, 301–309. http://doi.org/10.1016/j.neuropsychologia.2015.06.029

Vocat, R., Staub, F., Stroppini, T., & Vuilleumier, P. (2010). Anosognosia for hemiplegia: a clinical-anatomical prospective study. *Brain : A Journal of Neurology*, *133*(Pt 12), 3578–97. http://doi.org/10.1093/brain/awq297

Wickham, H. (2009). *ggplot2: elegant graphics for data analysis*. Springer New York. Retrieved from http://had.co.nz/ggplot2/book

Woolf, C. J. (2000). Neuronal Plasticity: Increasing the Gain in Pain. *Science*, *288*(5472), 1765–1768. http://doi.org/10.1126/science.288.5472.1765

Zwick, W. R., & Velicer, W. F. (1986). Comparison of five rules for determining the number of components to retain. *Psychological Bullettin*, *99*, 432–442.

Appendix A: Bodily Feelings and Illusions in patients affected by Spinal Cord Injury (BoFI-SCI)

Question	Yes	No	Description
1.1) After your spinal cord injury, have you ever felt strange sensations in your body?			Which and when?
2.1) Does it ever feel like any body parts do not belong to you?			When?
2.2) Does it ever feel like your arms are not attached to your shoulders?			When?
2.3 Does it ever feel like your legs are not attached to your hips?			When?
2.4) Does it evet feel like your legs are in elsewhere in the room/in space?			When?
2.5) Do you ever feel that a part of your body (e.g. your arms or legs) is missing?			When?
2.6) Do you ever feel that a part of your body (e.g. your arms or legs) has disappeared?			When?
2.7) Do you ever feel that your legs have become longer?			When?
2.8) Do you ever feel that your arms have become longer?			When?
2.9) Do you ever feel any body parts swelling?			When?
2.10) Does it you ever feel like any parts of your body have become smaller?			Which and when?
2.11) Do you ever feel the desire not to have a particular body part?			Which and when?
2.12) Does it ever feel like some body parts are alien or foreign?			Which and when?
2.13) Do you ever feel hate for any body parts?			Which and when?
3.1) Does it ever feel like any parts of your body (e.g. arms or legs) are in a different positions with respect to where you see them?			When?
3.2) Does it ever feel like you are in a different position with respect to your real posture?			When?
3.3) Does it ever feel like your knees and hips are bent when instead they are totally extended?			When?
3.4) Does it ever feel like your toes are in a strange position, for example curved inwards?			When?
3.5) Does it ever feel like any body parts move involuntarily?			When?

3.6) Do you ever have the feeling that your muscles are moving with subsequent tiredness?			When?
3.7) Does it ever feel like each digit was twisted so that each toe or finger points in a different direction?			When?
3.8) Does it ever feel like your fingers or toes are clenched or overlapping one other?			When?

Highlights:

- Spinal cord injuries may lead to corporeal illusions
- Six different corporeal illusions have been found
- Corporeal illusions may be modulated by clinical factors

Subject	AIS	NLI	G	age	Ed	Hd	Job	Int	D	SCIM-3	Pain	BFI	TAS	Body TAP
Pc 1	A	T8	M	44	8	R	6	1		54	MP;	(6;10;7;10;9)	28	71
Pc 2	A	T7	M	48	13	R	3	4	T	75	NP	(8;5;10;4;7)	36	65
Pc 3	A	T6	M	29	8	R	-	7	T	75	MP; VP; NP	(10;7;6;3;6)	23	61
Pc 4	A	T4	M	72	5	R	6	3	T	35	MP;	(5;7;10;6;8)	47	61.5
Pc 5	A	T10	M	44	8	R	1	3	T	74	NP	(7;4;9;8;5)	22	64
Pc 6	A	T9	M	43	8	R	-	3	T	71	MP; NP	(6;9;7;8;8)	43	60.5
Pc 7	A	T5	M	28	8	R	4	4	T	68	MP;	(6;6;10;3;5)	28	84
Pc 8	A	T5	M	48	8	R	-	25	T	75	MP; VP; NP	(8;7;6;6;7)	23	66
Pc 9	A	T10	F	54	13	R	4	31	T	72	MP; NP	(6;9;10;3;8)	29.5	70
Pc 10	A	T3	M	34	13	R	3	2	T	71		(9;6;9;3;9)	22	72
Pc 11	A	T11	M	48	13	R	6	29	T	72		(7;10;8;7;10)	53	67
Pc 12	A	T7	M	34	8	R	-	2	T	72	MP; VP; NP	(5;8;6;9;9)	70	53
Pi 1	B	T7	M	41	17	R	9	2	T	36	VP; NP	(8;9;10;3;9)	16	68
Pi 2	B	T3	M	25	13	R	3	10	T	76	MP;	(7;4;8;6;7)	38	71
Pi 3	B	T5	M	61	17	R	4	2	p Sur	72	MP; NP	(7;10;6;3;10)	26	51
Pi 4	B	T7	F	64	8	R	R	2	p Sur	39	VP; NP	(5;7;9;6;5)	31.5	67.5
Pi 5	B	T5	M	24	8	R	4	2	T	73	MP; NP	(10;9;6;5;6)	34	107
Pi 6	B	T11	M	39	17	R	2	17	T	73	NP	(6;5;6;10;9)	50	68
Pi 7	C	L2	M	50	13	R	3	27	T	73		(10;6;9;6;6)	16	87
Pi 8	D	L3	M	26	8	R	-	2	T	89	MP;	(9;8;10;5;4)	15	93
Pi 9	D	L3	M	34	8	R	6	9	T	100	NP	(8;9;7;6;8)	12	93
Pi 10	B	L2	M	46	8	R	4	29	T	75	NP	(8;7;7;9;8)	27	71
Pi 11	B	L1	M	42	8	R	-	8	T	60	MP; VP; NP	(8;10;5;2;2)	18	69
Pi 12	D	L3	F	42	13	R	3	23	T	100		(5;8;10;4;6)	53	67
Tc 1	A	C5	F	30	8	R	4	15	T	15	VP; NP	(8;6;8;8;9)	63	77
Tc 2	A	C4	M	72	5	R	R	3	T	15	MP; NP	(6;6;6;7;4)	8	57
Tc 3	A	C5	M	46	8	R	6	1	T	24	MP;	(10;10;10;2;5)	10	66
Tc 4	A	C5	M	30	17	R	3	12	T	48		(8;7;8;4;5)	38	63
Tc 5	A	C7	M	44	13	R	4	27	T	54	MP; VP; NP	(10;9;9;3;10)	63	59
Tc 6	A	C7	M	37	17	R	3	12	T	64	VP;	(7;7;10;3;10)	9	80
Tc 7	A	C5	M	63	13	R	1	44	T	63	NP	(10;6;9;4;7)	34	52
Tc 8	A	C7	M	39	8	R	6	8	T	67	NP	(10;5;10;9;9)	29	68
Tc 9	A	C4	M	51	8	R	-	33	T	19		(6;6;3;3;5)	58	88
Tc 10	A	C7	M	45	8	R	4	27	T	67	NP	(8;6;9;4;9)	33	71
Tc 11	A	C7	M	39	17	R	4	8	T	50	NP	(9;6;10;10;3)	11	78
Tc 12	A	C4	M	43	17	R	2	16	T	15		(10;6;10;6;10)	58	52
Ti 1	B	C6	M	29	13	R	-	7	T	47	MP;	(8;6;7;6;6)	27	67
Ti 2	B	C5	M	48	8	R	-	1	T	61	NP	(6;7;10;2;9)	48	59

Ti 3	D	C5	M	41	8	R	-	3	T	85	MP; NP	(6;7;6;8;8)	20	71
Ti 4	D	C4	M	21	13	R	-	6	T	99		(5;9;7;2;6)	44	58
Ti 5	B	C7	M	37	13	R	-	18	T	74		(10;5;6;7;6)	7	93
Ti 6	C	C6	M	20	13	R	S	6	T	66	NP	(7;6;5;7;6)	18	77
Ti 7	D	C6	M	57	8	R	8	6	T	99	NP	(8;3;10;2;10)	47	80
Ti 8	B	C5	F	54	13	R	R	14	T	31		(4;8;9;4;8)	32	57
Ti 9	B	C5	M	26	13	R	-	24	T	75	MP;	(5;4;6;3;6)	44	82.5
Ti 10	B	C7	M	55	17	R	R	13	T	58	NP	(10;10;8;4;10)	41	46.5
Ti 11	B	C5	M	34	13	R	3	11	T	67	VP; NP	(9;6;10;2;6)	21	62
Ti 12	C	C6	F	40	13	R	-	23	T	75		(7;6;9;3;10)	55	54
Ti 13	C	C5	F	55	13	R	-	29	T	67	MP;	(6;4;8;3;9)	39	46

Table 1. SCI clinical, demographic and personality data.

Pc = complete paraplegia (AIS=A); Pi = incomplete paraplegia; Tc = complete tetraplegia; Ti = incomplete tetraplegia; AIS = Asia Impairment Scale; NLI = neurological level of injury; G = gender; Ed = education; Hd = handedness (R = right);

Job = numbers correspond to the job categories of the ISTAT (Italian National Institute of Statistic): 1:managers, 2:intellectual and scientific jobs, 3:technical jobs; 4:secretarial jobs, 5: commercial jobs, 6:artisans, specialized workers and farmers; 7: industrial worker; 8: unskilled jobs; 9: armed forces; R = retired; - = unemployed; Int = Interval since lesion in years; D = damage; T = traumatic; p-Sur = post Surgery

SCIM-3 = spinal cord independence measure, ranged from a minimum of 0 (complete dependence) to a maximum of 100 (complete independence); Pain = MP Musculoskeletal Pain; VP Visceral Pain; NP Neuropathic Pain; BFI = Big Five Inventory (Extraversion, Agreeableness, Conscientiousness, Neuroticism, Openness); TAS = Tellegen Absorption Scale ; Body TAP = Trinity Assessment of Body Plasticity

	Body Loss	Illusory Motion	Body-parts misproprioception	Misoplegia	Disownership-like sensations	Somatoparaphrenia-like sensations
2.1) Does it ever feel like any body parts do not belong to you?					0.86	
2.2) Does it ever feel like your arms are not attached to your shoulders?					0.84	
2.3 Does it ever feel like your legs are not attached to your hips?						0.63
2.5) Do you ever feel that a part of your body (e.g. your arms or legs) is missing?	0.93					
2.6) Do you ever feel that a part of your body (e.g. your arms or legs) has disappeared?	0.87					
2.9) Do you ever feel any body parts swelling?		0.6				
2.11) Do you ever feel the desire not to have a particular body part?	-0.58			0.55		
2.12) Does it ever feel like some body parts are alien or foreign?						0.59
2.13) Do you ever feel hate for any body parts?				0.96		
3.1) Does it ever feel like any parts of your body (e.g. arms or legs) are in a different positions with respect to where you see them?			0.86			
3.2) Does it ever feel like you are in a different position with respect to your real posture?	0.67					
3.3) Does it ever feel like your knees and hips are bent when instead they are totally extended?			0.91			
3.4) Does it ever feel like your toes are in a strange position, for example curved inwards?						0.64
3.5) Does it ever feel like any body parts move involuntarily?		0.92				

3.6) Do you ever have the feeling that your muscles are moving with subsequent tiredness?		0.88				
3.8) Does it ever feel like your fingers or toes are clenched or overlapping one other?			-0.52			
SS loadings	2.710	2.540	2.230	2.030	1.900	1.700
Proportion Var	.170	.160	.140	.130	.120	.110
Cumulative Var	.170	.330	.470	.590	.710	.820
Proportion Explained	.210	.190	.170	.160	.150	.130
Cumulative Proportion	.210	.400	.570	.730	.870	1.000

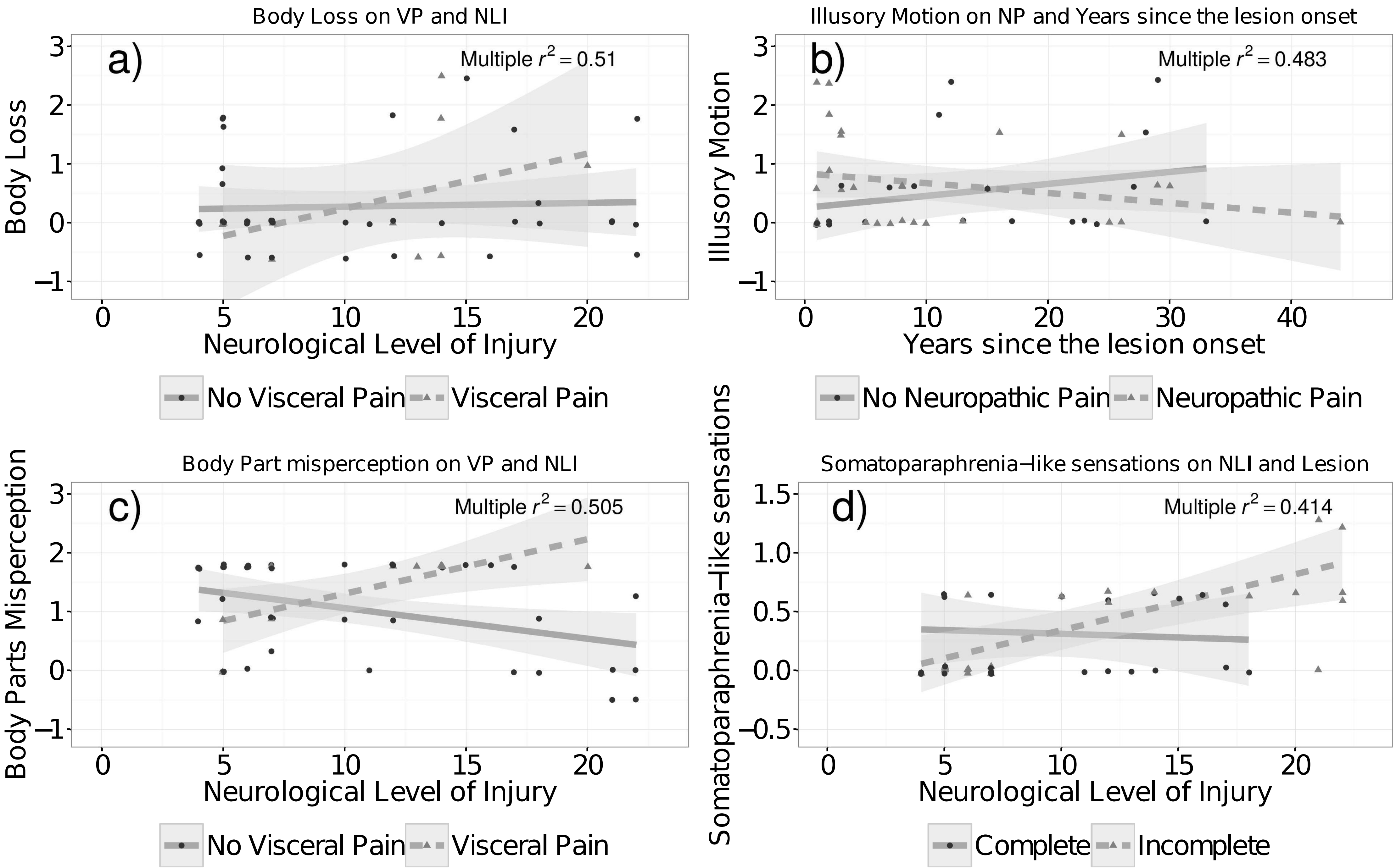
CORRELATION MATRIX

	Body Loss	Illusory Motion	Body-part misproprioce ption	Misoplegia	Disownership -like sensations	Somatoparap hrenia-like sensasiont
Body Loss	1					
Illusory Motion	0.056	1				
Body-part misproprioception	0.06	-0.031	1			
Misoplegia	-0.174	0.058	0.154	1		
Disownership-like sensations	0.217	-0.071	0.045	0.119	1	
Somatoparaphrenia-like sensations	0.173	0.136	0.114	0.208	0.282*	1

Table 2: Factor loading scores for EFA analysis and correlation matrix with Bonferroni corrected significance. * = p < .05. Loadings ranged between 0.5 and -0.5 are not reported. The correlation matrix is in the lower part of the table and the questionnaire items are reported in the columns.

		Paraplegics Complete (n12) N(%)	Paraplegics Incomplete (n12) N(%)	Tetraplegics Complete (n12) N(%)	Tetraplegics Incomplete (n13) N(%)	SCI (mean ± SD)	Controls (mean ± SD)	SCI vs. Controls	
Body Loss	*Score > 0*	3 (25)	5 (42)	2 (17)	3 (23)	.29 ± .85	-.05 ± .16	W = 816, p = .32, r = 0.11	ns
	Score < 0	3 (25)	3 (25)	3 (25)	1 (8)				
Illusory Motion	*Score > 0*	7 (58)	8 (67)	7 (58)	3 (23)	.60 ± .77	.12 ± .25	W = 680,5, p < .01, r = 0.62	**
	Score < 0	0 (0)	0 (0)	0 (0)	0 (0)				
Body-part misperception	*Score > 0*	9 (75)	8 (67)	12 (100)	8 (61)	1.11 ± 0.79	0	W = 468, p < .001, r = 0.62	***
	Score < 0	0 (0)	2 (17)	0 (0)	0 (0)				
Misoplegia	*Score > 0*	5 (42)	6 (50)	5 (42)	3 (23)	.41 ± .57	.08 ± .32	W = 707,5, p < .01, r = 0.31	**
	Score < 0	0 (0)	0 (0)	0 (0)	0 (0)				
Disownership-like feelings	*Score > 0*	6 (50)	8 (67)	3 (25)	6 (46)	.49 ± .58	.07 ± .24	W = 647, p < .001, r = 0.40	***
	Score < 0	0 (0)	0 (0)	0 (0)	0 (0)				
Somatoparaphrenia-like feelings	*Score > 0*	6 (50)	11 (92)	4 (33)	1 (8)	.36 ± .48	.05 ± .25	W = 656, p < .01, r = 0.39	***
	Score < 0	0 (0)	0 (0)	0 (0)	0 (0)				

Table 3: On the left: Number and percentage of SCI participants whose scores were greater or less than 0 in each factor. On the right: mean and Standard Deviation for the healthy Controls and all SCI participants. In the last column is the statistical comparison made by means of Wilcoxon Rank Sum comparisons on the scores. ns p > .05, * p < .05, ** p < .01, *** p < .001.



Body Loss on VP and NLI
a)
Multiple r² = 0.51
Body Loss
Neurological Level of Injury
No Visceral Pain
Visceral Pain
Illusory Motion on NP and Years since the lesion onset
b)
Multiple r² = 0.483
Illusory Motion
Years since the lesion onset
No Neuropathic Pain
Neuropathic Pain
Body Part misperception on VP and NLI
c)
Multiple r² = 0.505
Body Parts Misperception
Neurological Level of Injury
No Visceral Pain
Visceral Pain
Somatoparaphrenia−like sensations on NLI and Lesion
d)
Multiple r² = 0.414
Somatoparaphrenia−like sensations
Neurological Level of Injury
Complete
Incomplete