Neuropsychologia 96 (2017) 61–69

Contents lists available at ScienceDirect

Neuropsychologia

journal homepage: www.elsevier.com/locate/neuropsychologia

Body schema plasticity after stroke: Subjective and neurophysiological correlates of the rubber hand illusion

Roberto Llorens[a,b,*], Adrián Borrego[a], Priscila Palomo[c], Ausiàs Cebolla[c,d], Enrique Noé[b], Sergi Bermúdez i Badia[e], Rosa Baños[c,d]

[a] Neurorehabilitation and Brain Research Group, Instituto de Investigación e Innovación en Bioingeniería, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain
[b] Servicio de Neurorrehabilitación y Daño Cerebral de los Hospitales NISA, Fundación Hospitales NISA, Río Tajo 1, 46011 Valencia, Spain
[c] Universitat de València, Av. Blasco Ibáñez, 13, 46010 Valencia, Spain
[d] Fisiopatología de la Obesidad y la Nutrición (CIBERobn), Madrid, Spain
[e] Madeira-ITI, Universidade da Madeira, Campus universitario da Penteada, 9020-105 Funchal, Portugal

ARTICLE INFO

Abbreviations:
RHI: rubber hand illusion
GSR: galvanic skin response
sEMG: surface electromyographic activity

Keywords:
Body schema
Body-ownership
Embodiment
Rubber hand illusion
Stroke
Neurophysiology

ABSTRACT

Stroke can lead to motor impairments that can affect the body structure and restraint mobility. We hypothesize that brain lesions and their motor sequelae can distort the body schema, a sensorimotor map of body parts and elements in the peripersonal space through which human beings embody the reachable space and ready the body for forthcoming movements. Two main constructs have been identified in the embodiment mechanism: body-ownership, the sense that the body that one inhabits is his/her own, and agency, the sense that one can move and control his/her body. To test this, the present study simultaneously investigated different embodiment subcomponents (body-ownership, localization, and agency) and different neurophysiological measures (galvanic skin response, skin temperature, and surface electromyographic activity), and the interaction between them, in clinically-controlled hemiparetic individuals with stroke and in healthy subjects after the rubber hand illusion. Individuals with stroke reported significantly stronger body-ownership and agency and reduced increase of galvanic skin response, skin temperature, and muscular activity in the stimulated hand. We suggest that differences in embodiment could have been motivated by increased plasticity of the body schema and pathological predominance of the visual input over proprioception. We also suggest that differences in neurophysiological responses could have been promoted by a suppression of the reflex activity of the sympathetic nervous system and by the involvement of the premotor cortex in the reconfiguration of the body schema. These results could evidence a body schema plasticity promoted by the brain lesion and a main role of the premotor cortex in this mechanism.

1. Introduction

Embodiment is a multi-component psychological construct that has been explained as the sense of one's own body (Arzy et al., 2006), as the bodily self-consciousness (Legrand, 2006), or as corporeal awareness (Berlucchi and Aglioti, 1997). Although different definitions have been proposed, embodiment could be understood as the representation of an element (bodily or not) within the body schema (de Vignemont, 2011). Recent research has focused on unifying aspects of the embodied cognition theories and on identifying its subcomponents, such as body-ownership and agency (Kalckert and Ehrsson, 2012; Longo et al., 2008). Body-ownership can be defined as the sense that the body that one inhabits is his/her own (Tsakiris, 2010). Agency refers to the sense that one can move and control his/her body (Tsakiris, 2010). Consequently, body-ownership should be continuous and omnipresent and, in contrast, only voluntary actions, fired by efferent signals, should elicit agency. Both constructs have been postulated as dissociated concepts (Kalckert and Ehrsson, 2012; Tsakiris et al., 2010), but this is still a matter of debate (Ma and Hommel, 2015).

The Rubber Hand Illusion (RHI) is an experiment that allows investigating body-ownership in the absence of movement (Botvinick and Cohen, 1998). This phenomenon involves cross-modal interaction of sight, touch, and proprioception to create a convincing feeling of body-ownership over an external body part (Lloyd et al., 2013). Although this experiment has been widely replicated in neuroscience studies to determine the influence of sensory inputs on body repre-

* Corresponding author at: Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, Spain.
E-mail address: rllorens@lableni.com (R. Llorens).

http://dx.doi.org/10.1016/j.neuropsychologia.2017.01.007
Received 1 August 2016; Received in revised form 14 December 2016; Accepted 6 January 2017
Available online 08 January 2017

sentation (Ramakonar et al., 2011), the neural signatures of this illusion still remain unclear. Preliminary research points to the right insula (Tsakiris et al., 2007, 2010), the posterior cingular cortex (Guterstam et al., 2015), and the premotor cortex (Bekrater-Bodmann et al., 2014; Gentile et al., 2015; Limanowski and Blankenburg, 2015; Petkova et al., 2011; Zeller et al., 2011) as having a major role in the RHI. Additionally, many different studies have investigated the underlying neurophysiological correlates of the phenomenon under different conditions, mainly examining variations in the skin temperature (Hohwy and Paton, 2010; Kammers et al., 2011; Moseley et al., 2008a; Rohde et al., 2013; Salomon et al., 2013; Thakkar et al., 2011; van Stralen et al., 2014), and the Galvanic Skin Response (GSR) (Armel and Ramachandran, 2003; D'Alonzo and Cipriani, 2012; Ehrsson et al., 2008; Ma and Hommel, 2013; Reinersmann et al., 2013), which represent autonomic nerve responses to the sweat gland function. However, these variables only reflect the function of the sympathetic nervous system. The influence of the RHI in other systems, and the interaction between these variables still remain unexplored.

Different studies have also assessed the effect of the RHI in different populations (Ehrsson et al., 2008; Reinersmann et al., 2013; Thakkar et al., 2011; van Stralen et al., 2014). The nature of stroke and its derived impairments could provide an interesting framework to study the embodiment constructs (de Vignemont, 2011). In fact, stroke has been posed to be a common cause of disorders of body schema (Corbett and Shah, 1996), a neural representation of the body parts relative to each other and objects in the environment from the integration of visual, vestibular, and proprioceptive inputs (Corbett and Shah, 1996; Haggard and Wolpert, 2005). Motor impairments such as hemiparesis, a consequence of injuries to the pyramidal tract above the medulla that shows up as muscle weakness during voluntary movements in 50% of stroke survivors six months after onset (Kelly-Hayes et al., 2003), could exacerbate the incidence of these disorders. However, literature about the effect of stroke on embodiment is scant and to date few empirical studies exist. A big study involving also healthy participants initially reported that individuals with stroke were less likely to feel the illusion (Zeller et al., 2011). In contrast, more recent RHI studies in a subject with hand disownership (van Stralen et al., 2013) and in pure hemiplegic subjects (Burin et al., 2015) showed stronger illusion on the affected hand than in the less affected hand, which could evidence an impaired sense of ownership or a tendency to gain ownership over external body parts in the hemiparetic side. More studies controlling the clinical variables that may affect the results and including neurophysiological recordings are needed to confirm this hypothesis and to elaborate a common rationale for the underlying neural processes that promote these effects. In addition, although a few attempts have been made to assess body-ownership after stroke, other sub-components of embodiment have been ignored.

We hypothesize that the functional and neurophysiological alterations derived from stroke would promote alterations in the body schema that would facilitate an intensification of the embodiment sub-components during the RHI compared to healthy individuals. We conjecture, in light of the existing evidence that supports the involvement of the premotor cortex in the brain mechanisms of the illusion, that the experiment would elicit different neurophysiological responses in both groups, not only in the skin temperature and the GSR but also in the muscular activity. The aim of this study is therefore to investigate the subjective (body-ownership, localization, and agency) and neurophysiological responses (skin temperature, GSR, and electromyography) to the RHI, and the relationship between them, in healthy subjects and clinically-controlled individuals with stroke.

2. Methods

2.1. Participants

Both hemiparetic individuals following a first time stroke and healthy subjects were recruited. Inclusion criteria in the stroke group were 1) age ≥50 and ≤80 years old; 2) chronicity > 6 months; 3) absence of severe cognitive impairment as defined by Mini-Mental State Examination (Folstein et al., 1975) > 23; and 4) able to follow instructions as defined by the receptive language subscale of the Mississippi Aphasia Screening Test (Romero et al., 2012) ≥45. Individuals were excluded if they had 1) increase in muscle tone as defined by Modified Ashworth Scale (Bohannon and Smith, 1987) > 3; 2) joint stiffness that prevented arm positioning according to the requirements of the study; 3) peripheral nerve damage affecting the upper extremities; 4) orthopedic alterations or pain syndrome of the upper limbs; 5) visual or hearing impairment that did not allow possibility of interaction; 6) unilateral spatial neglect; and 7) asomatognosia. Individuals with stroke were recruited from the total pool of outpatients who had suffered a stroke and were attending a long-term rehabilitation program in the Brain Injury Service of NISA Hospital Valencia al Mar (Valencia, Spain). Participants were included in the healthy group if they were 50–80 years old and had no motor or cognitive impairment. These participants were recruited using advertisements on social media and community outreach.

Twenty individuals with stroke and 21 healthy individuals satisfied inclusion and exclusion criteria and accepted to participate in the study (Table 1). After inclusion in the study, motor impairment of the participants with stroke was assessed with the Motricity Index (Kopp et al., 1997), and their sensory impairment in the hand and wrist was assessed with the Nottingham Sensory Assessment (Lincoln et al., 1998), a standardized tool for multi-modal sensory examination that evaluates tactile sensation (light touch, pressure, pinprick sensation, temperature discrimination, tactile localization, and bilateral simultaneous stimulation), kinesthesia, and stereognosis. Handedness of healthy participants was assessed using the Edinburgh Handedness Inventory (Oldfield, 1971), as in previous studies (Ocklenburg et al., 2011).

The experimental protocol was approved by the Institutional Review Board of NISA Hospitals. All of the participants provided written informed consent prior to enrollment in the study.

2.2. Materials

The experiment was performed in a quiet room free of distractors where a conventional table (120×60×75 cm) with a movable wooden vertical board (50×40×4 cm) was arranged. Instrumentation included a man's and a woman's right and left rubber hand with forearm, two equal small brushes with a head diameter of 0.5 cm, and a hammer. In addition, a black oversized tee was used to cover participants' both arms down to just above the forearms. A hole was made to introduce the arm of the rubber hand during the experiment.

Sensorization included a wearable wireless bracelet that measured the GSR and skin temperature (Affectiva®, Waltham, MA, USA), two extra sensors that also estimated the GSR (Twente Medical Systems International B.V., Oldenzaal, Netherlands), and two Ag-AgCl sensors to estimate the surface electromyographic activity (sEMG) (Twente Medical Systems International B.V., Oldenzaal, Netherlands). A fake bracelet was handcrafted and fixed to the rubber hand to simulate the real one.