Behavioural Brain Research 225 (2011) 259–269

Contents lists available at ScienceDirect

Behavioural Brain Research

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

Research report

Phenomenology and neural correlates of implicit and emergent motor awareness in patients with anosognosia for hemiplegia

Valentina Moro[a,*], Simone Pernigo[a], Paola Zapparoli[b], Zeno Cordioli[b], Salvatore M. Aglioti[c]

[a] Dipartimento di Filosofia, Pedagogia e Psicologia, Università di Verona, Lungadige Porta Vittoria 17, 37129 Verona, Italy
[b] Dipartimento di Riabilitazione, Ospedale SacroCuore, Via Sempreboni 7, Negrar, Verona, Italy
[c] Dipartimento di Psicologia, Università "La Sapienza" and IRCSS Fondazione S. Lucia, Via dei Marsi 6, 00100 Roma, Italy

ARTICLE INFO

Article history:
Received 18 May 2011
Received in revised form 4 July 2011
Accepted 5 July 2011
Available online 12 July 2011

Keywords:
Anosognosia for hemiplegia
Implicit awareness
Emergent awareness
Action planning
Error monitoring

ABSTRACT

Anosognosia for hemiplegia (AH) is characterized by a lack of awareness of motor disorders and appears associated with fronto-temporal-parietal damage. Neuropsychological evidence indicates that behavioral indices of residual forms of motor awareness may co-exist with explicit denial of impairment. Here we explore whether the attempt by AH patients to perform an action may disclose residual forms of motor awareness and whether such forms are underpinned by different neural structures. Twelve hemiplegic patients affected by AH were tested in tasks assessing: (i) implicit awareness (IA), indexed by discrepancies between verbal reports and actual motor behavior; (ii) emergent awareness (EA), indexed by increased verbal awareness induced by the attempt to perform actions. IA and EA were found in five and three patients, respectively. Lesion analysis indicates that while the lack of IA is associated with damage to subcortical white matter anterior to the basal ganglia, lack of EA is linked to damage to cortical regions including insulo-frontal, temporal and parietal structures. Our results indicate that deficits in explicit and implicit awareness are associated with lesions involving different cortico–subcortical structures. Moreover, the results show that the attempt to perform an action may ameliorate body awareness deficits and have implications for rehabilitation.

1. Introduction

The term anosognosia refers to the lack of awareness of neurological and neuropsychological deficits. Thus anosognosic patients do not recognize or underestimate the severity of their motor, sensory or cognitive (i.e. memory, language) impairment [30,48]. Anosognosia *for hemiplegia* (AH) refers to conditions where patients report being able to move a limb that is, however, paralyzed and to cases where the awareness deficit seems to selectively involve motor functions. Although AH typically occurs after right brain lesions and involves the left hemisoma, it has been demonstrated that the left brain may also play a role in the syndrome. Recent evidence supports the hypothesis that the frequency of anosognosia in left brain damaged patients is underestimated [17]. Note that in clinical practice anosognosia has not been investigated systematically in left damaged patients. This may be due to at least two reasons. The first is that assessment of anosognosia has been typically based on linguistic tests that may turn out to be challenging for left brain damaged patients in whom language deficits typically occur. The second is that anognosia for hemiplegia has been typically associated with personal neglect that is observed mainly in right brain damaged patients.

Studies suggest that AH is a specific syndrome which cannot be explained by concomitant neurological deficits such as sensory deafferentation, presence of contralesional spatial neglect, mental confusion or deficits in frontal lobe functions [18,33,37,46]. In particular, anosognosia for sensory and motor neurological deficits is a multi-componential syndrome that may include a number of specific deficits deriving from impairment of anatomo-functionally discrete monitoring systems, each involved in the general control and monitoring of motor, sensory, spatial, memory, and language functions [39,56,63]. The finding that lesions affecting premotor areas, the cortical regions involved in motor planning and control, are also lesioned in AH [9], provides data in support of the hypothesis regarding deficits in domain-specific awareness modules [63].

Seminal studies suggest that AH may arise from the patient's inability to form motor intentions [30]. It is considered that the intention to execute an action calls into play a forward model that generates accurate predictions about the impending sensory feedback. If an intended movement is not performed as planned, a "comparator" will detect a mismatch between the predicted and

* Corresponding author. Tel.: +39 45 8028370; fax: +39 45 8028790.
E-mail addresses: valentina.moro@univr.it (V. Moro), simone.pernigo@univr.it (S. Pernigo), paola.zapparoli@sacrocuore.it (P. Zapparoli), zeno.cordioli@sacrocuore.it (Z. Cordioli), salvatoremaria.aglioti@uniroma1.it (S.M. Aglioti).

0166-4328/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.bbr.2011.07.010

actual sensory feedback [30]. If the comparator fails, subjects are unable to recognize inaccurate movements or to consider actions as having been executed, even when no movement has actually been initiated. In this hypothesis the role of action in awareness is thus largely emphasized.

Nevertheless, AH has been investigated mainly by interviewing patients about their complaints and motor deficits (e.g. "Would you like to raise your hand?" "Have you done it?") [11,22,32,58] rather than by direct behavioral observation of their action or attempt to act. Thus until now mainly verbal, declarative awareness has been investigated and information about other possible forms of awareness has been comparatively meager until very recently. Interestingly, studies have now started to address more systematically the influence of motor intentions on the phenomenology of AH [16,26,34].

In the present study, we investigated whether the attempt to perform everyday actions may highlight residual forms of awareness in AH. To this aim, we capitalized on two notions. The first is that in AH implicit forms of awareness may co-exist with deficits of declarative, explicit awareness [39,51,66]. We therefore devised a task to disclose whether the performance of the unaffected limb of AH patients was implicitly influenced by the presence of the paralyzed limb. In particular, we expected that patients who are totally unaware of their left paralysis would grasp a large, heavy object by positioning their right hand to the right of the object, as though they were performing the action bimanually. In contrast, patients showing implicit awareness would shift their right hand towards the center of the object in order to perform the task effectively.

The second notion at the basis of our study is related to models of awareness [21,44] based on a three level hierarchy that comprises: (i) intellectual awareness, i.e. the generic ability to recognize a deficit; (ii) emergent awareness, a condition in which a patient becomes declaratively aware of his/her deficits only when pushed to perform an action with the affected body part; (iii) anticipatory awareness, i.e. the ability to anticipate a deficit before it occurs and to set up compensatory strategies. Typically, AH patients do not show anticipatory awareness. However they may exhibit a certain degree of intellectual awareness. For example, they can report that they are in hospital and participating in a rehabilitative program. We thus devised a task to distinguish anticipatory from emergent awareness in order to test whether verbal reports indexing anosognosia were influenced by the specific request to perform a given action also involving the paralytic limb. Any change in the linguistic report of one's own motor deficits induced by the attempt to move is considered an index of emergent awareness. For example, reporting being able to drive a car, but admitting that this is not the case in relation to the attempt to actually perform the task would hint at the presence of emergent awareness.

While it has been shown that the neural structures associated with anosognosia for hemiplegia may vary according to the length of time since injury [35,65], only one study has explored the neural substrates of implicit awareness [24]. Moreover, to the best of our knowledge, no study has investigated thus far whether implicit and emergent awareness are underpinned by different neural substrates. To this aim, using advanced brain lesion mapping procedures [5,53], we explored whether lesions to different nodes of the network underpinning body awareness are causatively associated with lack of implicit and emergent awareness.

2. Methods

2.1. Participants

Twelve patients affected by severe hemiplegia (no movements at upper arm) and AH were recruited at the Rehabilitation Unit of the Sacro Cuore Hospital (Negrar, Verona, Italy) over a 36-month period. None of them had a history of psychiatric diseases or a previous neurological history. The anosognosia for hemiplegia was ascertained by means of a clinical examination in which subjects were asked to touch the examiner's hand with their paralyzed hand and to state whether or not they had succeeded in performing the requested act (score 0: patient acknowledges motor deficit; 1: patient does not acknowledge motor deficit but recognizes that he/she has not touched the examiner's hand; 2: patient denies motor deficit and the failure to touch the examiner's hand) [10]. Patients were considered to be anosognosic when at this clinical interview their score was 1 or 2 [4,26], corresponding (although not perfectly) to a score of 2 or 3 on the Bisiach scale [11].

The results of neuropsychological screening and the extent and site of the lesion in AH patients (AHG) were compared with the data of twelve subjects affected by hemiplegia but without any signs of anosognosia, either at the moment of assessment or in the acute phase of their clinical history (CG).

All patients gave their informed consent to participate in the study. The procedures were approved by the local ethics committee and the study was carried out in accordance with the guidelines of the Declaration of Helsinki.

The two groups were matched for age (AHG = M: 62.42 years, SD: 13.15; range: 40–78; CG = M: 66.08 years; SD: 8.62; range: 51–79, $t_{22} = -0.81$, $p = 0.43$), education (AHG = M: 5.92 years; SD: 1.97; range: 3–8; CG = M: 6.25 years; SD:1.54; range:5–8, $t_{22} = -0.46$, $p = 0.65$) and interval between lesion and assessment (AHG = M: 74.58 days; SD: 51.34; range: 22–177; CG = M: 94.25 days; SD: 56.71; range: 27–210, $t_{22} = 0.89$, $p = 0.38$). All the patients resulted right-handed in the test for handedness [14]. However, the only patient who sustained a left hemisphere lesion (patient FG, Fig. 1E) declared he was originally left-handed but had been forced in childhood to use his right hand. This patient did not show spatial disorders or specific deficits of language (AAT) [38] but clear signs of frontal damage. Lesion site and size in AHG and CG patients were documented by means of CT (see Fig. 1 and Table S1). Additional demographical and clinical data concerning the two patient groups are shown in Table 1.

2.2. Preliminary neuropsychological examination

All the patients underwent a neuropsychological assessment, using a battery of standardized tests. As shown in Table 2, the performance of the AHG in the tests regarding general cognitive abilities (MMSE [23]; frontal assessment battery – FAB [3]; digit span and story recall [57]) was significantly worse than the performance of the CG (all t-tests $p < .05$ except story recall). It is worth noting, however, that three patients in the CG group also exhibited signs of mental deterioration (MMSE). Deficits of frontal functions as inferred from the FAB [3] were found in the AHG.

The frequency of extrapersonal (drawing on copy tests [67]), personal neglect (comb and razor test [40]) and visual and tactile extinction [1,36] was greater in the AHG than in the CG. No significant differences were found between the groups in the Beck Depression Inventory (BDI [6]) and the State-Trait Anxiety Inventory (Form Y [55]). In addition, all patients went through the Affective Story Recall test [62] where they were asked to recall personal events that match a particular emotional category (e.g. "Try and recall an event in your life which caused you to feel anger or rage"). The control patients tended to link their emotions of fear and sadness to their disabilities (score 1 or 2). Interestingly, in keeping with previous reports [62], only one of the anosognosic patients referred their emotional experiences to illness; the others did not, even when asked specific, direct questions (score = 0). In addition, behavioral and emotional reaction changes were evaluated by means of a short interview with the patients' relatives (e.g. "Does the patient get angry more frequently now than before the illness?"). Referred emotional changes were reported for six patients, three for each group. It is worth noting that the Affective Recall Test is a verbal task, requiring declarative awareness of the disease and may not distinguish between cognitive and emotional deficits [54].

2.3. Assessment of anosognosia for hemiplegia

The neuropsychological assessment of AH aimed to investigate the existence of various forms of unawareness for motor deficits. The initial clinical interview used for categorizing the patients into two groups (with or without anosognosia for hemiplegia AHG and CG), consisted of the Berti and colleagues' interview [10]. It was followed up with a modified version of the Marcel and colleagues' interview [39] that was proposed to the groups with the aim of ascertaining the presence of various aspects of AH, namely: (a) general awareness of the disease; (b) awareness of the sensory-motor abilities of upper or lower limbs and (c) awareness of one's own abilities in everyday activities (i.e. using a knife and fork, getting dressed, having a wash and walking). The CG patients did not show any signs of anosognosia in any of the interviews.

As shown in Table 3 (general interview), the patients exhibited varying degrees and forms of AH, ranging from very mild to very severe deficits. The degree of anosognosia as indicated by the score in the Marcel et al. modified interview [39] did not correlate either with the interval from lesion onset ($R = 0.3$, $p = 0.35$) or with the interval from CT exam ($R = 0.14$, $p = 0.68$). While some patients presented with complete unawareness of paralysis and of its effects on the ability to carry out everyday activities, others were aware of specific sensory-motor deficits but unable to recognize the possible effects of their paralysis on everyday activities (e.g. patient TD). An examination of Table 3 also reveals different topographies of the deficit in the case