Received: 31 January 2024 | Accepted: 3 June 2024

DOI: 10.1111/jnp.12378

RESEARCH ARTICLE

the british psychological society
promoting excellence in psychology

What I think she thinks about my paralysed body: Social inferences about disability-related content in anosognosia for hemiplegia

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Funding information
Canadian Institute for Advanced Research; Ministero dell'Istruzione, dell'Università e della Ricerca, Grant/Award Number: PRIN Edit. 2017 and Prot. 2017N7WCLP; British Psychological Society; British Neuropsychological Society; National Research Foundation, Grant/Award Number: 150745; Ernest Oppenheimer Memorial Trust; European Research Council, Grant/Award Number: 313755

Abstract
The neuropsychological disorder of anosognosia for hemiplegia (AHP) can offer unique insights into the neurocognitive processes of body consciousness and representation. Previous studies have found associations between selective social cognition deficits and anosognosia. In this study, we examined how such social cognition deficits may directly interact with representations of one's body as disabled in AHP. We used a modified set of previously validated Theory of Mind (ToM) stories to create disability-related content that was related to post-stroke paralysis and to investigate differences between right hemisphere damage patients with ($n = 19$) and without ($n = 19$) AHP. We expected AHP patients to perform worse than controls when trying to infer paralysis-related mental states in the paralysis-related ToM stories and explored whether such differences depended on the inference patients were asked to perform (e.g. self or other referent perspective-taking). Using an advanced structural neuroimaging technique, we expected selective social cognitive deficits to be associated with posterior parietal cortex lesions and deficits in self-referent perspective-taking in paralysis-related mentalising to be associated with frontoparietal disconnections. Group- and individual-level results revealed that AHP patients performed worse than HP controls when trying to infer paralysis-related mental states. Exploratory lesion analysis results revealed some of the hypothesised lesions, but also unexpected white matter

disconnections in the posterior body and splenium of the corpus collosum associated with a self-referent perspective-taking in paralysis-related ToM stories. The study has implications for the multi-layered nature of body awareness, including abstract, social perspectives and beliefs about the body.

KEYWORDS

body representation, perspective-taking, self-awareness, social cognition, white matter disconnection

INTRODUCTION

In recent decades, neuropsychology and cognitive neuroscience have specified the multisensory, sensorimotor and other cognitive mechanisms that contribute to the dynamic representation of our body in our minds (Schwabe & Blanke, 2007; Tsakiris, 2017). Disorders of body awareness, such as anosognosia for hemiplegia (AHP, defined as the apparent unawareness of paralysis typically following lesions to the right hemisphere; Moro et al., 2021 – but see Cocchini et al., 2009), have been key in revealing some of these neurocognitive mechanisms (Fotopoulou, 2015; Orfei et al., 2007; Pacella et al., 2019). Furthermore, recent studies on AHP have revealed that a realistic appreciation of our motor abilities relies not only on sensorimotor integration but also on higher-order deficits of metacognition (Kirsch et al., 2021; Pacella & Moro, 2022; Vocat et al., 2010), emotional regulation (Besharati et al., 2014; D'Imperio et al., 2017), and social cognition (Besharati et al., 2016, 2022). While deficits in metacognition and emotional regulation have been directly linked to the emergence of anosognosic beliefs via experimental manipulations of beliefs under different cognitive or emotional contexts (D'Imperio et al., 2017; Kirsch et al., 2021), only generic social cognition deficits have been studied in AHP and merely correlated with the presence and severity of symptoms, as explained below and better targeted in the present study.

Previous seminal studies drawing on clinical case-series investigations (see Ramachandran & Rogers-Ramachandran, 1996) demonstrated that in some cases, the unawareness of motor paralysis in AHP extends to other patients. These differences in self-referent and other-referent awareness in AHP were later experimentally demonstrated (see Besharati et al., 2022; Moro et al., 2011). In a pioneering study conducted by Marcel et al. (2004), AHP patients also showed more awareness of their paralyses when asked to make verbal judgements from a third-person perspective. Building on these initial predications, Besharati et al. (2016) administered visuospatial and verbal tests of social cognition that required participants to take the perspective of another individual (either in a visual task or in an imaginative, verbal story) and make inferences about mental states (testing 'Theory of Mind', or ToM abilities; Frith & Frith, 2007). They found that patients with AHP do not have deficits in the simpler aspects of visuospatial perspective-taking compared to matched right-hemisphere controls, but they do present with selective deficits when asked to verbally take the perspective of another person and then make inferences about mental states, particularly when the latter are directed towards a second character in the story. This latter ability is called 'allocentric inference' in the social cognition literature (e.g. as in the inference 'Thandi felt that Sergio was happy to see her') and is contrasted with 'egocentric inference' where the target of the mental states to be inferred is the self, as for example when one thinks that someone else is 'happy to see me' (Besharati et al., 2022; Frith & De Vignemont, 2005). Deficits in the third person and allocentric inference were found to correlate mostly with the degree of anosognosic symptoms.

Based on this work and related findings about the temporary effects of perspective-taking (Marcel et al., 2004; Jenkinson et al., 2011), reference (Moro et al., 2011), or spatial cognition manipulations (Kirsch et al., 2021), it has been suggested that first person/egocentric inferences need to integrate dynamically with other perspectives on the self, for example third-person or allocentric inferences, in order for self-awareness to be veridical (Fotopoulou & Besharati, 2023). However, it is unclear whether the content of the experimental material influences ToM and perspective-taking abilities in AHP. In related studies, when experimental tasks consisted of content that was disability-related (i.e. containing hemiplegic-related material), AHP patients presented with greater errors and slower response rates in an attentional capture task (Nardone et al., 2008) and a verbal inhibition experiment (Fotopoulou et al., 2010). Nevertheless, none of these previous studies have used paralysis-related content in regards to perspective-taking or social cognition. Therefore, in light of the above research traditions – (1) self and other referent awareness in anosognosia, (2) perspective-taking and social cognition in AHP, and (3) variations in motor awareness using disability-related experimental content – the current study combines these approaches in a novel way to explore how social cognition deficits may directly interact with representations of one's body as disabled in AHP.

Furthermore, using a predictive processing framework, it has been proposed that AHP is best explained as a dissociation between current sensations *from the body* (coded egocentrically and in a first-person perspective) and more abstract beliefs *about the body* (including those coded in third perspectives and even those coded allocentrically), so that the later beliefs can no longer be updated by egocentric/first-person prediction errors. Furthermore, this dissociation is thought to be caused by damage to the ventral branch of the right superior longitudinal fasciculus (and related grey matter lesions in frontoinsular and temporoparietal areas, Pacella et al., 2019), affecting the normal functions of certain intrinsic connectivity systems such as the salience system and, to some degree, also the default mode network. Typically, the salience system supports the optimisation of the contextual salience of different signals, which in turn determines the degree to which sensorimotor prediction errors in first-person experiences are explained away by more abstract beliefs or allow the updating of the latter (Fotopoulou, 2015; Fotopoulou & Besharati, 2023). Interestingly, the interplay between salience and the default mode systems has also been implicated in the relationship between self and social cognition (Chiong et al., 2013; Kanske et al., 2015; Menon & Uddin, 2010; Schurz et al., 2014). This hypothesis was supported by robust neuroanatomical findings about the dissociation of ventral frontoparietal networks in AHP (Pacella et al., 2019). Such frontoparietal disconnections (Pacella et al., 2019; replicated and extended by Kletenik et al., 2023), particularly affecting the functions of the salience network, are thought to disrupt the integration between first-person and social perspectives on the self, leading to any prediction errors in the first person or the 'here-and-now' of experience, being unable to update more general, abstract, or social (e.g. third-person, allocentric, or counterfactual; see Fotopoulou & Besharati, 2023; Kirsch et al., 2021 for discussions on these terms) beliefs about the self. In simple terms, even if anosognosic patients can sense or feel their body being paralysed under specific clinical or experimental conditions, they quickly infer that they cannot be paralysed more generally, and they will explain away any related first person observations, as their most abstract view of themselves is of one that can move (Kirsch et al., 2021), or most pertinently to the present study, one that 'everyone regards as being able to move' (a third-person and allocentric perspective).

Notwithstanding the increasing empirical indications that led to the formulation of the above theoretical hypothesis, it has only been tested as far as spatially and temporally counterfactual beliefs are at stake (e.g. Kirsch et al., 2021) and not in relation to social cognition. Moreover, the previous studies on social cognition in AHP have used generic social cognition materials (i.e. stories containing everyday interactions between two people), and hence any observations regarding impaired social cognition abilities could not be directly linked to the content of anosognosic beliefs. In order to test whether anosognosic beliefs are directly related to an inability to take the perspective of a paralysed individual and make related inferences about their mental states, the experimental materials used need to be *paralysis*-specific.

Accordingly, in the present study, we adapted a set of previously validated ToM stories (Besharati et al., 2016; Hynes et al., 2006) to create content that was related to post-stroke paralysis and required participants to infer the mental states of agents in each story using either self-referent or other-referent perspective-taking. Accordingly, as illustrated in Figure 1, self-referent perspective-taking involved the first- or second-person perspective and egocentric (i.e. self *related* to the other) questions were asked.

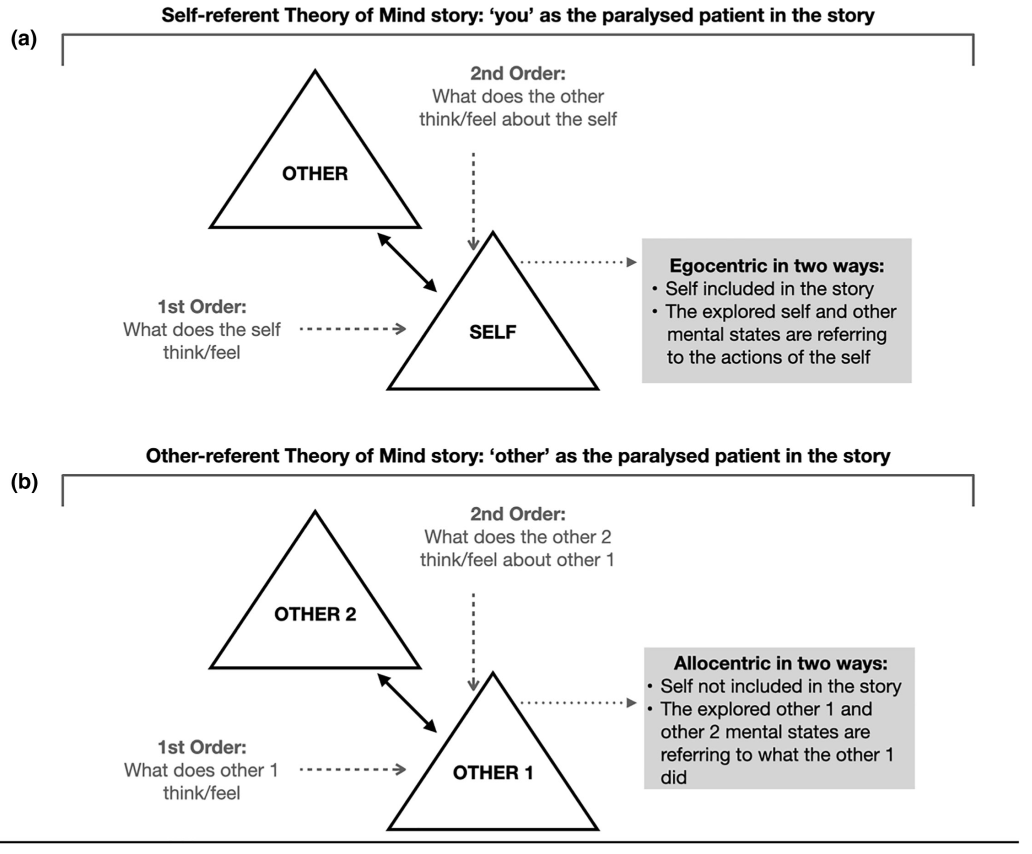

FIGURE 1 Figure representing self-referent and other-referent paralysis-related Theory of Mind stories. (a) Self-referent ToM stories depicted two agents (self and other) in the narrative and centred on 'you' (the self) as the person with the left-sided paralysis in the story. The dotted arrows represent the 1st order and 2nd order levels. Questions are expressed in the second person and are egocentric [the self as related to the other]. (b) Other-referent ToM stories depicted two agents (other 1 and other 2) in the narrative, with the other 1 character having left-sided paralysis. The dotted arrows represent the first-order and second-order levels. Questions are expressed in the third person and are allocentric [the other is unrelated to the self].

Whereas other-referent perspective-taking in the task involved third-person perspective-taking and allocentric (i.e. the other *unrelated* to the self) questions were asked. The complexity and complementarity between these terms are recognised in the social cognition literature (see Frith & De Vignemont, 2005), and we have provided further conceptual clarity on how these terms relate to bodily self-awareness in another paper (see Besharati et al., 2022) and as illustrated in this paper in Figure 1. Using these paralysis-related stories, we tested patients with a right hemisphere stroke who either had ($n = 19$) or did not have ($n = 19$) AHP. To explore the neuroanatomical components of our hypotheses and particularly to test if there is a disconnection between areas required for salience modulation and abstract social cognition inferences, we used an advanced structural neuroimaging technique (BCBtoolkit; Foulon et al., 2018). This lesion mapping method creates white matter disconnection maps from patient lesion data that allow for an analysis of both focal grey matter associations with behavioural data as well as identifying disconnections from white matter tracts. This connectivity technique has been used in previous neuropsychological studies (Bertagnoli et al., 2022; Moro et al., 2023; Pacella et al., 2019) to examine the relationship between brain disconnections and behaviour.

Accordingly, we tested the following hypotheses and predictions: First, we predicted (hypothesis 1a; H1a) that anosognosic patients would perform worse overall in inferring mental states in the disability-related, ToM stories (i.e. irrespective of whether the stories were self or other referent) than hemiplegic controls. We further predicted that such differences would be associated with white matter disconnections, particularly in ventral frontoparietal pathways (H1b). Furthermore, to investigate if any overall group differences found in ToM (H1a) were present in each individual AHP patient and represented a differential deficit, individual patient analyses were utilised to look at mental impairments in paralysis-related ToM stories on a case-by-case basis in AHP patients compared to the HP control group.

Secondly, we considered whether these group differences would vary based on whether the stories were self-referent versus other-referent (H2; i.e. we expected a significant interaction effect, Group x Reference). Our remaining 'sub-predictions' for hypothesis 2 were exploratory in nature, and we were interested in exploring three possible, alterative patterns of results as regards the follow-up tests of this significant interaction (H2a-c). First (H2a), these patients may have an allocentric inference deficit per se, irrespective of the motor disability-related content of the stories. They would perform worse when having to make allocentric rather than egocentric inferences (i.e. in other versus self-referent stories) in comparison to controls, as they did in previous studies, and they would show corresponding lesions in the posterior parts of the mentalising network (see below and Besharati et al., 2016; Fotopoulou & Besharati, 2023 for related findings and discussion). Alternatively (H2b), if however, these patients struggle to link self-beliefs with motor disability, they may perform worse in self-referent, first-/second-person perspective-taking (e.g. Imagine you are paralysed and …) than in other referent, third person stories (e.g. Imagine Lukanyo is paralysed…) in comparison to controls. Such differences in performance would be linked to disconnections due to white matter damage (see below), particularly in ventral frontoparietal pathways. Finally, a third alternative is that (H2c), the two difficulties may coexist and hence either cancel themselves out (no Group x Reference interaction, with the AHP group performing worse than the control group in both self-referent and in other-referent stories). Moreover, in this case, despite the potential lack of a significant interaction at the behavioural level, differences in each condition may be associated with different patterns of lesions, in accordance with the above hypotheses.

GENERAL METHODS AND RESULTS

Patients

Thirty-eight right-handed adult neurological patients with right-hemisphere lesions participated in the study (19 females, mean age = 65.47, SD = 16.25 years; age range: 33–97). Patients were recruited from consecutive admissions to three acute stroke wards in the United Kingdom and one rehabilitation clinic in Italy, using the following inclusion criteria: (i) imaging confirmed right-hemisphere damage; (ii) contralateral hemiplegia (as confirmed by the Medical Research Council – MRC – motor scale; using a cut-off score of 1); (iii) <4 months from symptom onset. The exclusion criteria are: (i) previous neurological or psychiatric history; (ii) <7 years of education; (iii) medication with significant cognitive or mood side effects and (iv) language impairment that prevented the completion of study assessments.

Patients were divided into two groups based on their classification of anosognosia using two awareness assessments: the Berti et al. (1996) structured interview and the Feinberg (2000) scale. The Berti et al. structured interview consists of questions related to the patients' motor ability and awareness (e.g. 'Can you move your left arm?') and 'confrontation' questions (e.g. 'Please touch my hand with your left hand. Have you done it?'). The interview is scored on a 3-point scale, with scores >1 indicating AHP. The Berti et al. interview was used to classify patients into the AHP and HP groups. The Feinberg scale was used as a secondary measure of awareness, which indicated the severity of the unawareness symptoms. The scale consists of 10 questions related to the patient's motor paralysis (e.g. 'Please try and move your left arm for me. Did you move it?'). Responses were scored by the examiner for each item (0 = no awareness, .5 = partial unawareness, and 1 = complete unawareness), and summed to produce a total 'Feinberg awareness score' (0 = no awareness, 10 = complete unawareness). Using the Berti et al. classification, 19 patients were classified as having AHP (11 females; mean age = 66.68, SD = 16.89 years; age range: 33–86) and 19 patients were classified as hemiplegic (HP) controls (8 females; mean age = 64.26, SD = 15.95 years; age range: 41–87). The anosognosia classification was further confirmed by the Feinberg (2000) scores and later used for the correlational analysis. Informed written consent was obtained, and the study was approved by the two local ethics committees in Italy (CEP, Verona) and the United Kingdom (local NHS ethical committee), respectively, and carried out in accordance with the guidelines of the Declaration of Helsinki.

Neurological and neuropsychological testing and results

In addition to the above anosognosia assessments, the neurological and neuropsychological profiles of the patients were formally assessed using the following measures: Motor strength was tested using the MRC scale (using a cut-off score of 1; Guarantors of Brain, 1986). For proprioception, the patients (eyes closed) were asked to report small, vertical, controlled movements applied to three upper limb joints (middle finger, wrist and elbow) at three time intervals (correct = 1; incorrect = 0; Vocat et al., 2010). Somatosensory sensations and visual fields were assessed by means of the 'confrontation' technique (Bisiach et al., 1986). For cognitive functions, premorbid intelligence was assessed using the Wechsler Test of Adult Reading (WTAR; Wechsler, 2001). Orientation in time, space and person was tested using the MMSE (Folstein et al., 1975). General cognitive functioning and long-term verbal recall were tested using the Montreal Cognitive Assessment (MoCA; Nasreddine et al., 2005). Working memory was also controlled using the digit span task (forward and backword) from the Wechsler Adult Intelligence Scale III (Wechsler, 1997). The Cognitive Estimates Test (Shallice & Evans, 1978) was used to assess reasoning abilities, and the six subtests (see Table 1) of the Frontal Assessment Battery (FAB; Dubois et al., 2000) were used to assess executive functions. Three subtests (see Table 1) of the Behavioural Inattention Test (BIT; Wilson et al., 1987) were used to assess visuospatial neglect. Personal neglect was assessed using the 'one item test' (Bisiach et al., 1986) and the 'comb/razor' test (Mcintosh et al., 2000). Finally, the Hospital Depression and Anxiety Scale (HADS; Zigmond & Snaith, 1983) was used to measure mood.

For the analysis of neurological and neuropsychological tests, non-parametric Mann–Whitney *U* tests were used (owing to the non-normal data distribution) to analyse the difference between the two patient groups, with the alpha significance level set to $a = .01$, to account for multiple comparisons. Analysis was conducted in SPSS version 28 (IBM Corp., 2021).

A summary of the neuropsychological and neurological profiles of the patients is provided in Table 1. No significant difference was observed for age, years of education, pre-morbid IQ, long-term memory recall and general cognitive functioning between groups (all p's $> .35$). As expected, there was a significant difference in awareness between the AHP and HP patients (Berti interview: $Z = -5.55$, $p < .001$, $r = .9$; Feinberg scale: $Z = -5.16$, $p < .001$, $r = .84$), with both groups presenting with contralateral hemiplegia as confirmed by the MRC motor scale. The groups did not differ in their time of symptom onset, assessment interval, orientation or working memory (all p's $> .37$). Both groups were also within the normal range (range: 0–7 normal, 8–10 borderline) for the general Hospital Anxiety and Depression Scale, with no significant difference between groups. AHP patients performed significantly worse on tests of proprioception compared with HP patients ($Z = -3.17$, $p < .001$, $r = .51$) and personal neglect ($Z = -2.56$, $p = .01$, $r = .42$). Both patient groups presented with similar visual and sensory deficits. There was no significant difference in using the corrected alpha ($a = .01$; all p's $> .02$) for tests of visual-spatial neglect. Both patient groups performed outside the normal range on the Cognitive Estimates Test, suggesting possible deficits in abstract reasoning; however, there was no statistical difference between groups (AHP vs. HP; $Z = -.22$, $p = .84$). There was a significant difference between patient groups for the overall FAB score ($Z = -2.56$, $p = .01$, $r = .39$) and a significant difference between groups on the go-no-go subtest ($Z = -3.16$, $p = .001$, $r = .51$).

TABLE 1 Groups' demographic characteristics and neuropsychological profile.

	AHP		HP		Mann–Whitney *U*	
	Median[a]	**IQR**	**Median**	**IQR**	*Z*	*p*
N	19	—	19	—	—	—
Age (years)	73	22	62	26	−.64	.53
Education (years)	11.5	4.25	12	4	−.73	.48
Days from onset	9	11	9	19	−.5	.63
Anosognosia for hemiplegia						
Feinberg awareness scale (max 10)	6	3.25	0	.63	−5.16	**<.001**[b]
Motricity and sensory functions						
MRC left upper limb (max 5)	0	0	0	0	−.04	1
MRC left lower limb (max 5)	0	1	0	2	−.47	.65
Somatosensory (max 6)	3	2	2	4	−.83	.41
Proprioception (max 9)	4	3.5	7	1	−3.7	**<.001**
Visual fields (max 6)	4	2	4	4	−.5	.6
General cognitive functions						
Premorbid IQ-WTAR (max 50)	40	17.5	36	13.25	−.38	.73
Orientation (MMSE, max 3)	3	0	3	0	−.52	.67
MOCA (max 30)	24.23	7.8	24	8.13	−.33	.77
Memory						
MOCA memory (max 5)	4	2	5	2	−1.35	.19
Digit span forwards (WAIS, max *n*. repeated)	6	1.25	6	3.25	−.11	.91
Digit span backwards (WAIS, max *n*. repeated)	3	2	4	2	−.93	.37
Executive functions						
Cognitive estimates (max 30)	8.5	8.8	9	7.5	−.22	.84
FAB total score (max 18)	10.5	3.5	14.5	5.75	−2.56	**.01**
Similarities (max 3)	2	1.5	2	1	−1.63	.12
Lexical Fluency (max 3)	2	1	2	2	−1.97	.05
Motor Series (max 3)	2	1	2	3	−.59	.53
Conflict Instructions (max 3)	2	1.5	3	2	−2.16	.03
Go no Go (max 3)	.00	1.5	3	2	−3.16	**.001**
Prehension Behaviour (max 3)	2	1	3	0	−1.63	.1
Unilateral spatial neglect						
Star cancellation (BIT, max 54)	40	20.25	14.25	33.25	−2.04	.04
Line bisection (BIT, max 9)	0	2	2	1	−2.37	.02
Copy (BIT, max 3)	0	1	1	2.5	−2.15	.03
Comb/razor test bias (% bias)	−.45	−.32	−.06	.38	−2.56	**.01**
Comb/razor test left (*n*. of strokes)	2	1	5	4.25	−2.57	**.01**
Comb/razor test right (*n*. of strokes)	10	6	8.5	6.25	−.53	.6
Comb/razor test ambiguous (*n*. of strokes)	4	3	6	4.62	−.21	.84
Bisiach one item test (max 3)	1	1.5	1	1	−.7	.5
Mood						
HADS Depression scale (max 21)	6	6	7	4.4	−1.62	.11
HADS Anxiety scale (max 21)	8	7	6.5	10.8	−.39	.72

Abbreviations: % bias, left – right strokes/(left + ambiguous + right strokes); AHP, anosognosia for hemiplegia group; Bisiach one item test (Bisiach et al., 1986); BIT, Behavioural Inattention Test (Wilson et al., 1987); Comb/razor, Comb and Razor test (Mcintosh et al., 2000); FAB, Frontal Assessment Battery (Dubois et al., 2000); HADS, Hospital Anxiety and Depression scale (Zigmond & Snaith, 1983); HP, hemiplegic group; IQR, inter-quartile range; MMSE, Mini-mental state examination (Folstein et al., 1975); MOCA, The Montreal Cognitive Assessment (Nasreddine et al., 2005); MRC, Medical Research Council (Guarantors of Brain, 1986); *n*, number; Visual fields and somatosensory, customary 'confrontation' technique (Bisiach et al., 1986).

[a]Scores below tests' cut-off points or more than 1 standard deviation below average mean.

[b]Items marked in bold indicate a significant difference between groups ($p \leq .01$).

Experimental methods: Paralysis-related ToM stories

Design

Paralysis-related ToM stories were adapted based on previous story-based tests (Besharati et al., 2016; Hynes et al., 2006), which required participants to understand the mental states (e.g. beliefs, intentions or emotions) of different people in the stories. The experimental design included one between subject factor, groups (AHP and HP patients), and two within subject factors, reference (self-referent vs. other-referent; see below for detailed description) and order (1st order and 2nd order; see below for detailed description). Reference was manipulated, changing the reference of the story to the self (e.g. 'You are in the hospital recovering from a recent stroke'.) or to another agent (e.g. 'Jim is in the hospital recovering from a recent stroke'.). Order was manipulated by altering the questions the participants were required to answer to involve the characters mental state (1st order) or the character's belief about the mental state of another agent (2nd order). This order manipulation was used as it allows further ToM questions to be asked, increasing in difficulty but not changing the nature of the reference, perspective-taking or centricity of each condition, which is the focus of the present study. This design allowed for a 2 × 2 × 2 design on the main dependent variable of ToM accuracy (see below), allowing us to address our main prediction regarding overall group effects in paralysis-related ToM stories as well as our exploratory questions regarding any Group × Reference interaction.

Materials

Paralysis-related ToM stories were created by adapting classical ToM stories used by Hynes et al. (2006) and Besharati et al. (2016). Sixteen stories were created: 12 target stories and four control stories (used to exclude differences in more basic comprehension and reasoning abilities) of carefully matched characteristics (i.e. word length; Flesch reading ease; Flesch-Kincaid grade level test; number of characters in the story; and hospital scenario). All stories consisted of at least two characters, took place in a hospital setting and were followed first by an open ToM question and then by three multiple-choice responses (as in Besharati et al., 2016; Hynes et al., 2006). The content of the 12 paralysis-related ToM stories always consisted of the character having had a stroke and losing left-sided motor functions. The control stories were similar to the ToM stories and involved social situations in medical settings, but the questions required inferential reasoning and semantic knowledge rather than perspective-taking and did not have paralysis-related content or second-order questions. Eight of the stories (six ToM and two control) were framed in the self-referent perspective, requiring 2nd-person perspective-taking (e.g. 'You have had a stroke…'), while the other eight were framed in the other-referent perspective, requiring 3rd-person perspective-taking (e.g. 'Peter has just had a stroke…').

Examples of the control, self-referent and other-referent paralysis-related ToM stories are as follows, together with examples of spontaneous responses from AHP and HP patients:

Control Story: Kate is very frail and ill. One day Kate slips on her icy doorstep and falls on her side. The next day Kate's leg feels very stiff and she can barely walk. Kate makes her way to the emergency room, where she is immediately sent for an X-ray.

Why did they take an X-ray?

a. They always take an X-ray.
b. They were checking to see if Kate had a tumour.
c. Kate may have a broken bone.

Examples of spontaneous responses: *'To find out if she has any broken bones'. (HP patient); 'To find out if something is broken' (AHP patient).*

Self-referent paralysis related ToM story: You are in the hospital, recovering from a recent stroke. You are very hungry and are looking forward to lunch. You can use your right hand, but you are still unable to use your left. The nurse delivers your lunch at 12 o'clock. You ask the nurse to cut your food.

Why do you ask the nurse to cut your food?

a. You think the nurse has nothing to do.
b. You cannot use both hands to eat.
c. You are feeling lazy.

Examples of spontaneous responses: *'This is actually what has happened to me. You need to use both hands to cut'. (HP patient); 'Because I just do not want to. Why are you asking me such silly questions?' (AHP patient).*

Other-referent paralysis-related ToM story: Amanda has just had a stroke and is recovering in the hospital. Amanda is left-handed, but her left arm and hand are very weak, and she cannot use them. Amanda is bored in the hospital. The nurse, David, does not know that Amanda is left-handed and remembers that Amanda has many friends who have sent her cards. He suggests she write one of them a letter and gives Amanda a pen and some paper. Amanda gives back the paper and pen.

Why does Amanda not write a letter?

a. Amanda does not like the nurse and wants to upset him.
b. Amanda cannot write because she is left-handed.
c. Amanda is busy and has no time to write.

Examples of spontaneous responses: *'Because the stroke affected her ability to write'. (HP patient); 'Because she does feel like it'. (AHP patient).*

Drawing on the framework presented in Besharati et al. (2022), the set of self-referent ToM stories yields questions to the participants that could be answered in egocentric ways, as they involve the patient (the self) in relation to another character (other 1, as in Figure 1). The set of other-referent ToM stories yielded questions to the participants that could be answered in allocentric ways as they considered two agents that were unrelated to themselves. Half of the ToM stories were followed by a first order question (i.e. what do you/the other think/feel about…?), while the other half extended the original story and was followed by a second-order question (what does a second character think you/the other feel about….?). All conditions were matched to include an equal number of ToM stories that included content that implied that the character was either aware or unaware of motor disabilities.

Procedure and scoring

All stories and questions were read out loud to the participants in a slow pace, neutral tone. The same scoring methods used in Besharati et al. (2016) were utilised in this experiment. The participants were first required to make a spontaneous response, which the examiner wrote down verbatim. Subsequently, the experimenter read the multiple-choice options, and participants had to indicate their choice verbally, which all patients were able to do. Multiple-choice answers were scored as 1 = correct and 0 = incorrect. Spontaneous answers were scored as 1 = correct, .5 = partially correct/inadequate and 0 = incorrect. For each question, a composite score was calculated using both the multiple-choice answers and the spontaneous answer (minimum score = 0, maximum score = 2). Two raters scored the spontaneous answers independently. An interclass correlation coefficient of .92 indicated good agreement between raters. Divergent scores (<2% of stories) were discussed and jointly agreed on. Total scores were converted into percentages and used in the statistical analyses.

In the patient groups, testing was conducted in two successive sessions to avoid fatigue. The order of the presentation of the two sets (self-referent and other-referent) was counterbalanced. Each set began and ended with a control story. The administration of the control story consisted of a two-stage process consisting of a comprehension check and the story response. First, to check for comprehension, following each control story, all participants were asked to rate how well they understood the story. A 5-point Likert-type scale was used (i.e. 'Using this scale from one to five, how well did you understand the story? One being the lowest score, where you understood very little, and 5 being the highest score, where you understood the whole story'). Second, the control question was read out loud to the patient, followed by the multiple-choice options. Although some patients might have shown unawareness of any comprehension difficulties, the correct responses to the control stories were used as a second marker for story comprehension. The task was piloted on four neurological patients (two AHP and two HP) to test for comprehension of stories and questions, possible attentional biases in the patient group and other testing considerations. The results confirmed the suitability of the stories and questions, but minor corrections were made to the readability of the specific stories.

Statistical analysis

Group-level behavioural analyses were conducted in SPSS version 28 (IBM Corp., 2021). Raw scores from the behavioural task were converted into percentages for further analysis and to assist with graphical representation of the results. Non-parametric tests were used (owing to the non-normal distribution of the data), applying Bonferroni corrections where appropriate. We performed a serious of planned, a priori comparisons that were based on our main hypothesis (H1a) and our exploratory hypotheses (H2a–c) as detailed above. To test if AHP patients would perform worse overall than HP controls in perspective-taking of a paralysed agent in the ToM stories and infer their mental states (H1a), we examined the main effects for the Group factor (AHP vs. Controls) by looking at the overall perspective-taking scores for AHP patients compared to HP controls. In looking at our exploratory analyses (H2a–c), to explore potential differences in performance between groups in self-referent versus other-referent paralysis-related stories, we examined the interaction between the Group and Reference (self-referent vs. other-referent). Given the use of non-parametric tests, we did this by first calculating the difference between the self and other referent condition and looking at the effect of Group, and then using pair-wise comparisons to examine within group differences in self and other reference for the AHP group and HP controls. Pairwise comparisons were again used to look at group differences in the self and other referent conditions. Means and SE's (error bars) are used in the figures for convention and illustration purposes.

Additionally, to investigate if any group differences in overall perspective-taking (combining self and other referent perspective-taking; H1a) were found in each individual AHP patient looking at the scores on a case-by-case basis, individual-level analyses were conducted using modified *t*-tests (Singlims_ES; Crawford et al., 2010; Crawford & Garthwaite, 2002). The interval estimate of the effect size was also obtained using Bayesian methods. Secondly, further individual-level analyses were conducted to examine if any group differences between self-referent and other-referent perspective-taking in paralysis-related ToM stories were present in each individual AHP patient and represented a differential deficit (i.e. classical dissociation). Accordingly, a modified *t*-test (Revised Standardised Difference Test, RSDT; Crawford et al., 2010) was used to analyse on a case-by-case basis the differential deficits of AHP patients compared to HP controls for the self-referent and other-referent conditions as conducted in previous studies (Besharati et al., 2016, 2022; Moro et al., 2011). The interval estimate of the effect size was also obtained using Bayesian methods.

Furthermore, we examined the relationship between overall perspective-taking in the paralysis-related ToM stories and anosognosia using the Feinberg awareness scores in the AHP group. We also looked at the pattern of correlations between the overall perspective-taking score in both groups for all neuropsychological tests that showed statistical significance between groups using the adjusted alpha ($a = .01$), specifically: proprioception; personal neglect; the FAB; and the go-no-go subtest of the FAB. Non-parametric Spearman's rho was used for all correlational analyses

EXPERIMENTAL RESULTS

Control condition, comprehension rating sand manipulation check

All participants performed close to the ceiling level for control stories that assessed basic comprehension and reasoning, with AHP patients passing 92.7% and HP patients passing 96.9% of questions, respectively. There was no significant difference between groups ($Z = -1.63$, $p = .10$, $r = .26$; please see Figure S1). All participants reported comprehension ratings between four and five (maximum score = 5 indicating full comprehension).

To check if our manipulation of Order was effective, we also ran a confirmatory analysis. We expected the Order condition to increase the difficulty of the paralysis-related ToM questions and confirmed that this main effect of Order was significant (Wilcoxon signed rank test: $Z = -4.54$, $p < .001$, $r = .74$), with performance being overall higher in 1st Order questions (median = 75) compared to second-order questions (median = 47.92).

Group analyses

Our main prediction was that anosognosic patients would perform worse in the overall perspective of taking hemiplegic controls when trying to take the perspective of a paralysed agent in the ToM story and infer their mental states. A Mann–Whitney *U* test confirmed that there was a significant main effect of Group ($Z = -4.80$, $p < .001$, $r = .78$), with the AHP group (median = 46.87) performing significantly worse in the paralysis-related ToM stories overall (i.e. across both self- and-other referent stories and both orders) compared to the HP group (median = 78.12; see Figure 2).

To answer our second and more exploratory question regarding the nature of deficits observed in AHP patients (as detailed at the end of the introduction), we examined the interaction between Group and Reference. First, we calculated the difference between self and other referent conditions and analysed the effect of Group on this difference using a Mann–Whitney *U* test, finding a significant interaction ($Z = -3.01$, $p = .002$, $r = .49$). Subsequent Bonferroni corrections (four comparisons; $a = .0125$) pairwise comparisons were then performed, first using the Wilcoxon signed rank test to examine within-group differences, showing that the AHP patients performed significantly better in the other-referent stories (median = 52.08) compared with the self-referent stories (median = 33.33; $Z = -2.85$, $p = .003$, $r = .46$). By contrast, in the HP group, there was no significant difference between self-referent (median = 77) and other-referent perspective-taking (median = 77.03; $Z = -.48$, $p = .65$, $r = .08$).

We also looked at the between-group differences in self-referent and other-referent conditions in a separate set of pairwise comparisons using a Mann–Whitney *U* test ($a = .0125$). There was a large, significant group difference in self-referent perspective-taking ($Z = -4.92$, $p < .001$, $r = .8$) with AHP patients performing worse (median = 33.33) compared to HP controls (median = 77.08). Other-referent perspective-taking was also significantly different between groups ($Z = -3.12$, $p = .001$, $r = .5$), with the AHP patients performing worse (median = 52.08) than hemiplegic controls (median = 77.08).

Individual-level analysis

Important individual differences in performance can exist within groups when looking at differences in motor awareness (Besharati et al., 2022; D'Imperio et al., 2017; Marcel et al., 2004; Pacella et al., 2022) between experimental conditions or ToM tasks (Besharati et al., 2016). These individual differences can be masked by group-level analysis. Therefore, in addition to the above group analysis, for our main prediction, we further investigated if overall perspective-taking deficits (i.e. self-referent and other-referent paralysis-related stories together; H1a) were found in each individual AHP patient looking at scores on a case-by-case basis, compared to the HP control group using

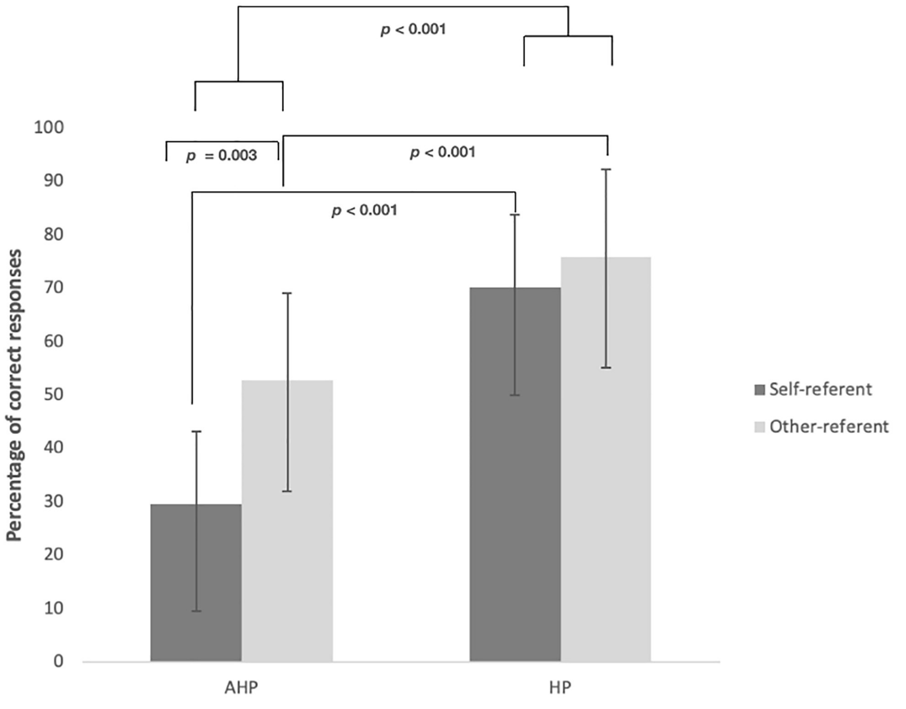

FIGURE 2 Percentage of correct responses for Theory of Mind (ToM) paralysis-related stories across groups. Means and standard errors for the self-referent (dark grey bars) and other-referent (light grey bars) conditions in the anosognosia and HP control groups. The significant main effect of Group ($p < .001$) is represented, with AHP patients performing significantly worse in overall perspective-taking when trying to take the perspective of a paralysed agent in the ToM story and infer their mental states. The significant within-group comparison ($p < .001$) is shown, with AHP patients performing worse in self-referent perspective-taking in paralysis-related ToM stories, showing that they make errors in linking self-beliefs with their motor disability. Significant between-group differences in self-referent and other-referent conditions are also shown, with AHP patients performing significantly worse than HP controls in both other-referent ($p < .001$) and self-referent perspective-taking ($p < .001$) when inferring the mental state of a paralysed agent in the ToM story.

singleims_ES (Crawford et al., 2010; Crawford & Garthwaite, 2002). Results showed that all but two AHP patients (89.5%) had significantly worse performance in overall perspective-taking (combining both self- and-other referent conditions), compared to the HP control group, when taking the perspective of a paralysed agent and inferring their mental states in the adapted ToM stories (all p's < .03; see Table S1 for full results). In only two AHP patients, no statistically significant difference was found (p's > .1) in overall perspective-taking in the paralysis-related ToM stories compared to HP controls.

Furthermore, additional individual-level analysis was conducted using RSDT (Crawford et al., 2010) to examine significant differences between self-referent and other-referent perspective-taking in paralysis-related ToM stories in each individual AHP patient compared to the HP control group, representing a differential deficit. Results using the RSDT showed that 13 (68%) AHP patients showed significantly better performance in other-referent conditions in the paralysis-related ToM stories (see Table S2 for full results). Of the six remaining AHP patients, no statistically significant difference was found between the self-referent and other-referent paralysis-related ToM stories. Therefore, the results of the individual statistical analysis were aligned with the above group-level analysis, showing better performance from other-referent perspective-taking using paralysis-related ToM stories.

Correlational analysis between neuropsychological and experimental results

Clinical unawareness and perspective-taking on paralysis-related ToM stories

In the AHP group, there was a significant negative correlation ($r_s = -.43$, $p = .04$) between the overall perceptive taking score in the paralysis-related ToM stories and patients' degree of motor unawareness as measured by the Feinberg scale. These results suggest that the more unaware the patients were (i.e. the higher the Feinberg scores), the worse their performance on overall perspective-tasking in the task and the greater the difficulty in taking on the perspective of a paralysed agent in the ToM task.

Neuropsychological differences and perspective-taking on paralysis-related ToM stories

Strong, significant correlations were found between overall perspective-taking in the paralysis-related ToM stories and proprioception ($r_s = .59$, $p < .001$), as well as for personal neglect ($r_s = .005$, $p = .005$). These results suggest that the greater the impairment in information specific to body representation (i.e. proprioception and personal neglect), the greater the errors in mentalising specific to paralysis-related content represented in the stories. Significant correlations were also found between overall perspective-taking in the paralysis-related stories and measures of executive function, specifically the overall FAB score ($r_s = .53$, $p = .003$) and a strong significant correlation with the go-no-go sub-test ($r_s = .78$, $p < .001$) of the FAB. Therefore, the greater the impairment in executive function, particularly inhibition or set-shifting as measured in the go-no-go subtest, the worse the patient's performance in perspective-taking abilities in the task, as we further discuss below.

LESION MAPPING METHODS

Lesion drawing

Routinely acquired clinical scans (22 CT and 12 MRI) were only available for 34 patients in the total sample. Neuroimaging analysis was therefore run with 34 patients, respectively. Scans were obtained for the 34 patients within the first week of symptom onset. Structural data were converted into software-readable formats for further processing. Accordingly, all images were pre-processed for visualisation using the dcm2nii programme.

(http://www.mccauslandcenter.sc.edu/mricro/mricron/dcm2nii.html). Visual inspection of the obtained files was performed in fslview (http://fsl.fmrib.ox.ac.uk/fsl/fslview/) to identify possible equipment-induced or patient-induced (e.g. movement) artefacts. To facilitate comparison between the clinical data and a standard space template, the native structural scan of each patient was manually reoriented to the origin of the template using SPM (Statistical Parametric Mapping, http://www.fil.ion.ucl.ac.uk/spm/). For each patient, the structural scan was examined, and anatomical landmarks were identified to acknowledge the lesion location. Lesions were then manually drawn from available scans onto axial slices of the standard template provided within MRIcron (http://www.mccauslandcenter.sc.edu/mricro/mricron/). The corresponding binary mask was created for each lesion. An anatomist, who was blinded to the clinical information, groupings and study hypotheses, reviewed the reconstructions for accuracy and suggested corrections where necessary. The lesion volume was extracted using FSL (FMRIB Software Library, http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/). Overall lesion volume was comparable between groups (AHP: mean = 10.48 cm^3, SD = 13.31; HP: mean = 6.19 cm^3, SD = 3.84; $t = -1.13$, $p = .27$).

Disconnection maps

Disconnection maps were computed with the 'disconnectome map' tool of the BCBToolkit software (Foulon et al., 2018). The tool identifies white matter tracts passing through each patient's lesions by means of the registration of lesions on the diffusion-weighted imaging dataset of 10 health controls from the dataset of a previous study (Thiebaut De Schotten et al., 2017). A percentage overlap map was then produced for each patient that considers the inter-variability of tractography in a dataset of healthy controls. Voxels in the disconnectome maps generated for each lesion show the probability of white matter disconnection from 0% to 100% (Thiebaut de Schotten et al., 2015). These disconnection probabilities for each patient have been used for the statistical analysis explained below.

Statistical analysis for lesion sites and tract disconnection

As a first step, to identify lesion and disconnection voxels associated with the patients': (1) overall, (2) self-referent and (3) other-referent perspective-taking deficits in the experimental task, six regression analyses (i.e. for grey and white matter disconnections for each of the three conditions) were conducted via the 'randomise' tool (Winkler et al., 2014), which falls under the FSL package. The patients' lesions were used as the dependent variable and the patients' behavioural performance as the independent variable. The lesion volume was included as a nuisance variable in both analyses to control for the over-representation of large lesions at the expense of smaller incidents (Thiebaut de Schotten et al., 2020). Lesion analysis was conducted on all 34 patients and analysed as continuous data, regardless of classification into groups. The threshold-free Cluster Enhancement option was applied to boost cluster-like structures of voxels, and results that survived 5000 permutations of testing were controlled for family-wise error rate ($p > .95$). As a second step, similar to our behaviour results, overall perspective-taking (hypothesis 1), as well as self-referent perspective and other-referent perspective (hypotheses 2a-c) were used to identify associations with experimental results with lesion and disconnection voxels using the same six regression analyses conducted and the same method reported above.

LESION MAPPING RESULTS

Lesion and disconnection associations with overall perspective-taking on paralysis-related ToM stories

In looking at our main hypothesis, we first examined the lesions and dissociations associated with overall performance in the paralysis-related ToM stories across patients. Using a corrected p-value (.05) threshold, the results of the lesion analysis for grey matter structures and white matter disconnection associated with this performance were not significant. However, as in previous studies (Besharati et al., 2022; Jenkinson et al., 2020), due to the small sample size, we set an exploratory t-statistic threshold to 3.4 (.001 uncorrected p, *TFCE not applied*). Exploratory regression analysis on grey matter structures for deficits in overall perspective-taking in disability-related ToM stories, found involvement of the right cortical structure in the angular gyrus and right subcortical associations with the striatum.

Lesion and disconnection associations with self-referent perspective-taking on paralysis-related ToM stories

For our exploratory study hypotheses (hypotheses 2a–c), we also examined separately how patients performed in self-referent and in other-referent inference. Starting with the former, the results of the exploratory regression analysis computed on grey matter structures for deficits in self-referent perspective-taking for the paralysis-related ToM stories (Figure 3b–d) suggested the involvement of the right premotor cortex and thalamus. The second regression analysis on white matter disconnection (Figure 3a) suggested a significant contribution of the corpus callosum to the self-referent perspective-taking deficits in the experimental task.

Lesion and disconnection associations with other-referent perspective-taking on paralysis-related ToM stories

The exploratory regression analysis conducted on the lesion sites for deficits in other-referent perspective-taking for the paralysis-related ToM stories (Figure 4a–c) put forward the involvement of the right supra-marginal gyri, angular gyri and premotor cortex. The second regression analysis on matter disconnection (Figure 4d,e) suggested a contribution of parieto-frontal networks, specifically the superior longitudinal fasciculus II (SLF) and, to a less extent, the anterior arcuate, as well as frontal-occipital networks with identified involvement of SLF I.

Since non-significant results emerged from the regression analyses, no further post-hoc analysis could be conducted to statistically investigate the difference in contributions from grey matter structures and the disconnection of white matter tracts in relation to self- and-other referent perspective-taking in the experimental task.

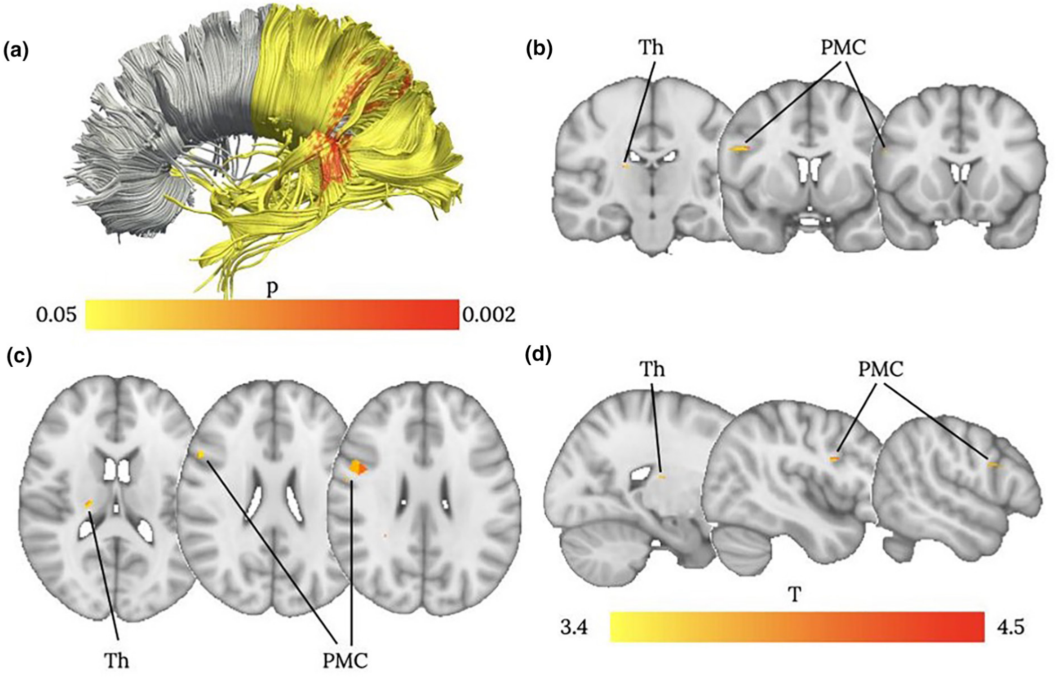

FIGURE 3 Grey matter and white matter areas associated with self-referent perspective-taking deficit. (a) Reconstruction of the corpus callosum. The posterior part of the body and the splenium are highlighted by the results colour code, thresholded at $p > .05$. (b) Coronal, (c) axial, (d) sagittal view of the grey-matter lesion analysis results thresholded at $t = 2.75$. Colour bars represent the p-value for the significant disconnection result and the uncorrected t-statistics for the grey matter results. PMC, premotor cortex; Th, thalamus.

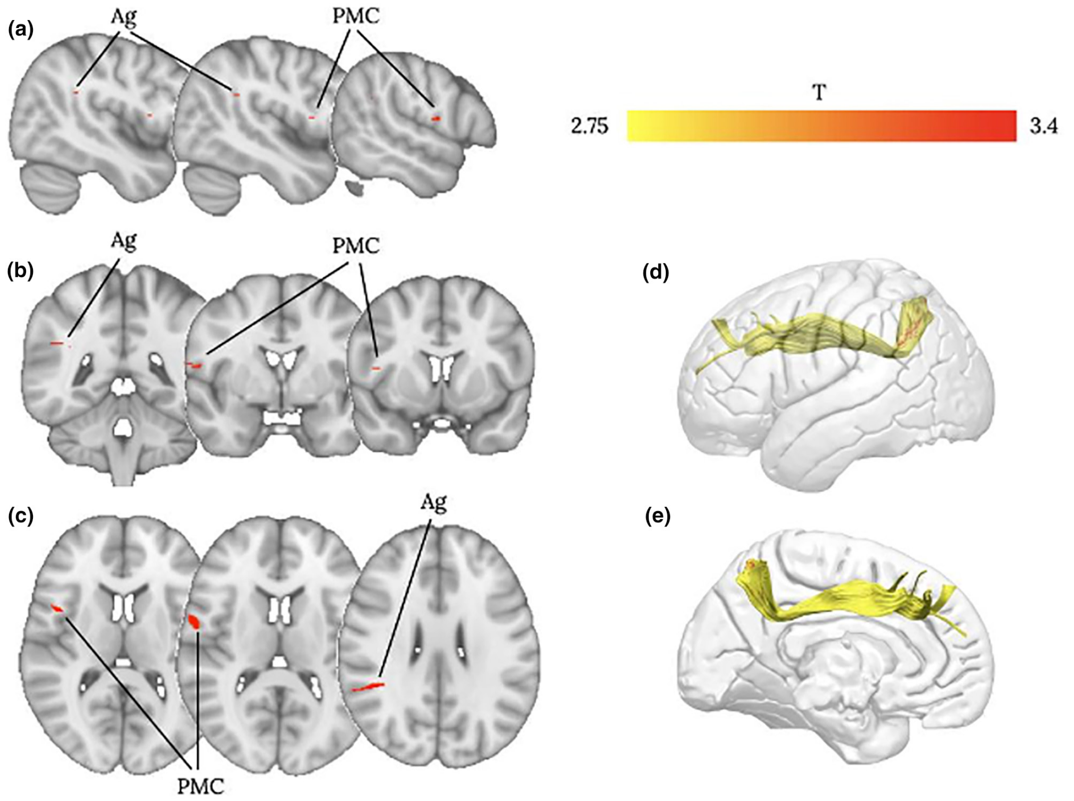

FIGURE 4 Grey matter and white matter areas associated with other-referent perspective-taking deficit. (a) Sagittal, (b) coronal, (c) axial views of the cortical lesion analysis results thresholded at $t = 2.75$. (d) and (e) represent the reconstruction of the second branch of the superior longitudinal fasciculus in the lateral and medial views, respectively. The colour bar represents the t-statistics thresholded at $t = 2.5$. Ag, angular gyrus; PMC, premotor cortex.

DISCUSSION

Previous studies have found a relationship between selective social cognitive deficits and the clinical characteristics of anosognosia. However, these studies drew on general social cognition material – related to typical, everyday scenarios and social interactions – and were not specific to content that is associated with anosognosic beliefs, such as the paralysis experienced by the patients. In comparison, other studies have drawn on paralysis-specific content in experimental studies of AHP, but these have not involved perspective-taking or social cognitive manipulations. Accordingly, in this paper, we combined these different research traditions of investigating reference (Besharati et al., 2022; Moro et al., 2011; Ramachandran & Rogers-Ramachandran, 1996), perspective-taking (Besharati et al., 2016; Marcel et al., 2004), and using deficit-related material (Fotopoulou et al., 2010; Nardone et al., 2008) in a novel way in order to examine how social cognitive deficits may interact with representations of the body as paralysed in AHP by using experimental material that was *paralysis* specific. To do this, we used a set of previously validated ToM stories that were adapted to have paralysis-related content to investigate differences between right-hemisphere-damaged patients with and without AHP. Group and individual-level analysis confirmed our main study hypothesis (H1a) and found that AHP patients performed worse than controls when trying to infer paralysis-related mental states.

We also expected this significant group difference to vary based on the mode of presentation of the paralysis-related ToM story as self-referent (i.e. 'you' – the patient – had a stroke) or other-referent (i.e. Samantha has had a stroke; H2) and this hypothesis was confirmed based on a significant Group x Reference interaction. To further explore the pattern of results of this interaction and three potential interpretations (alternative, exploratory hypotheses, H2a–c) we follow-up on this interaction with both within and between group analyses (correcting for multiple comparisons). Within group comparisons found that AHP patients performed significantly worse in the self-referent condition involving first/second perspective-taking rather than other-referent, third-person stories, showing that they make errors in linking self-beliefs with motor disabilities. The equivalent difference was not statistically significant in HP controls. However, between group differences in self-referent and other-referent conditions revealed that AHP patients performed significantly worse than HP controls in both self- and-other referent perspective-taking when inferring the mental state of a paralysed agent in the ToM story. Taken together, this pattern of results provides provisional support for our hypothesis H2c, suggesting that while AHP patients have deficits in overall mentalisation, including third-person, allostatic mentalisation in comparison to HP controls, they perform even worse when they need to link mental states about motor paralysis to the self. Impairments in generic, allocentric verbal reference have been shown in previous work with ToM stories that include generic content (Besharati et al., 2016). The present study further suggests that the relation between anosognosia and such impairments is not a mere clinical correlation, but rather that patients with AHP have particular difficulties applying social cognitive skills to paralysis-related content when this is associated with themselves. Although this study has several limitations (see below) and this specific hypothesis was exploratory and dependent on a complex pattern of results (see introduction), these findings add to fast accumulating evidence towards a disconnection hypothesis for anosognosia rather than discrete lesion causation (see also Fotopoulou, 2014; Pacella et al., 2019; Kirsch et al., 2021). Nevertheless, even though some evidence was found that supports the proposed disconnection hypothesis (see below), the concomitant cortical lesions and probably sub-cortical involvement prevent us from concluding that AHP is only a disconnection syndrome, but rather that white matter disconnections and damage, together with cortical and subcortical damage, contribute to the multifaceted presentation of the disorder.

Furthermore, this study also used advanced structural imaging methods (Foulon et al., 2018) to investigate the associated grey matter and white matter disconnections associated with social cognitive deficits. Lesion results were only significant at an exploratory level and should therefore be interpreted as tentative in nature. While there were no associations with the specific white matter disconnections predicted (i.e. the ventral branch of the SLF; H1b), other dissociations were noted (e.g. of the corpus collosum and the other two branches of the SLF), as discussed below. Specifically, difficulties in overall perspective-taking on paralysis-related ToM stories were associated with cortical lesions in the right angular gyrus and striatum. Similar anatomical associations have been found in other lesion mapping studies investigating the effect of self- and-other references on awareness (Besharati et al., 2022; Moro et al., 2011). A different pattern of results for self and other reference inferences was further observed, confirming the exploratory hypothesis (H2c), like our behavioural results. Specifically, difficulties in other-referent perspective-taking were associated with lesions in the right supra marginal gyri, angular gyri and premotor cortex, similar to those found in Besharati et al. (2016), as well as disconnections in more dorsal, attentional frontoparietal networks. Interestingly, self-reference inference was associated with white matter disconnections in the posterior body and splenium of the corpus collosum, as well as the involvement of the right premotor cortex and thalamus. These findings are supported by both earlier seminal work (Berti et al., 2005) and confirmed by more recent lesion mapping studies (e.g. Bolognini et al., 2016; Garbarini et al., 2019) that found the right premotor cortex to be a critical neural correlate for motor awareness. Therefore, this study provides preliminary indications for specific lesions to key areas and connections of the mentalising network associated with difficulties in generic social cognition in AHP, while the application of social cognition skills to the self was affected by dissociations between the hemispheres and lesions to a well-recognised are of sensorimotor planning, the premotor cortex. Future studies will need to target this complex pattern of findings on the interplay between sensorimotor, self and social cognition in order to confirm the present pattern of results.

The results of the neuropsychological assessments also revealed significant differences in the AHP group compared to the hemiplegic controls in deficits typically related to body representations, specifically proprioception and personal neglect. Both personal neglect and proprioception have consistently been documented in the literature as correlates of body representations (Longo et al., 2009), but also in more recent years with AHP itself (Moro et al., 2021; Orfei et al., 2007; Vocat et al., 2010). The relationship between executive functions and social cognition has also been long shown in the literature (see Wade et al., 2018 for review). The significant differences in selective executive functioning deficits between groups, together with the significant correlation with the FAB and the go-no-go subtest of the FAB, support this association between general ToM and executive functions. It also provides provisional neuropsychological evidence to support the association between ventral and dorsal attentional streams and mentalising functions to process self-referent and other-referent perspective-taking (Koster-Hale et al., 2017). However, it is important to highlight that AHP and HP patients were comparable across the majority of neuropsychological and neurological measures – including general cognitive functioning, working memory, mental flexibility, verbal fluency and orientation – demonstrating that AHP patients do not preform worse overall in cognitive tasks. This is also reflected in the performance and comparable scores in both groups in the physical-control stories of our experimental task. Double dissociations have also been found in the literature between executive function impairments and AHP (Bisiach et al., 1986) and can therefore not be indicative of a causal relationship. Nevertheless, the influence of factors such as personal neglect and proprioception, as well as executive function, on mentalisation tasks specific to beliefs about the body is an original finding that merits further investigation.

These results, however, need to be interpreted in the context of several study limitations. Although our study draws on a relatively large sample of AHP patients for experimental investigations of the phenomenon, a larger sample size may have allowed for covariation with neuropsychological test scores in both the behavioural and lesion mapping analyses. Nevertheless, lesion size was included as a covariate in the lesion analysis component of the study, despite the small sample restriction. It is also important to acknowledge that the anatomical implications for our study are limited, owing to the small sample size and inherent limitations of lesion mapping methods (de Haan & Karnath, 2018; Karnath et al., 2018) and the exploratory (i.e. uncorrected) nature of our lesion mapping results. Nevertheless, despite these lesion mapping limitations, the use of the advanced structural neuroimaging technique (BCBtoolkit; Foulon et al., 2018) as applied to our novel experimental task, provides initial support for the role of both cortical and white matter damage and disconnections, which underscores the value of the lesion mapping results in the current study. Furthermore, owing to the acute nature of AHP, quick and easy to administer, neuropsychological assessments conducted at the bedside needed to be utilised. However, when possible, future studies can attempt to use more comprehensive neuropsychological assessments, as to provide more rigorous data on related cognitive functions, such as proprioception, executive function and personal neglect, as well as verbal long-term memory. Although previously validated experimental material was used, constructing adequately comparable ToM stories and questions in each and across both conditions is arguably a further limitation of the study. Nevertheless, these are almost intrinsic limitations of experimental material looking at mentalising and ToM processes that do not always capture the complexity of the social world (Quesque & Rossetti, 2020). This is a reality in the field that is widely acknowledged and debated in the ToM and wider social cognition literature (Schaafsma et al., 2015). Therefore, this might impact the ecological validity of ToM stories, but not the experimental rigour of the design or the unique application to a rare group of neuropsychological patients, such as in AHP. Furthermore, the study also did not include a range of comparisons that would have been of theoretical interest to the literature on body awareness, body representation and social cognition, such as comparisons between generic ToM stories and paralysis-related ToM stories, the emotional valence in the ToM material (see Shah et al., 2017), and intricacies in the nosognosic and anosognosia content. Future studies could also consider expanding our ToM story set to include material related to other bodily deficits not related to their motor paralysis to determine the specificity of the effect. However, given the specificity of AHP in other domains, we predict that other, stroke-irrelevant material will not produce the same effect (also see Fotopoulou et al., 2010 for discussion). Lastly, this study only included right-hemisphere-damaged patients, as AHP typically occurs following right-hemisphere damage; therefore, we cannot speculate on the potential role of left-hemisphere lesions and disconnections. ToM and self-referent perspective-taking have also been associated with right-hemisphere functioning in several neuroimaging studies (Koster-Hale et al., 2017); however, other studies have also shown the involvement of bilateral or left dominance in self and social mental states (Northoff et al., 2006). Therefore, this remains an open issue and merits further investigation. Together, these provide for important new avenues to explore in designing new experimental studies on the social-emotional components of bodily self-awareness.

CONCLUSION

AHP, as a rare and prototypical disorder of self-awareness, offers nuanced insights into the integration of social cognitive components of bodily self-consciousness. This study has drawn on an integrated methodological approach using neuropsychological, experimental and lesion evidence to show the multi-layered nature of body awareness, which includes abstract, social perspectives and beliefs about the body.

AUTHOR CONTRIBUTIONS

Sahba Besharati: Conceptualization; investigation; funding acquisition; writing – original draft; methodology; visualization; formal analysis; project administration; data curation. **Paul M. Jenkinson:** Conceptualization; writing – review and editing; methodology; supervision; formal analysis; project administration. **Michael Kopelman:** Conceptualization; writing – review and editing; project administration; supervision. **Mark Solms:** Supervision; project administration; writing – review and editing; conceptualization. **Cristina Bulgarelli:** Project administration; writing – review and editing; investigation. **Valentina Pacella:** Formal analysis; investigation; writing – review and editing; methodology; visualization; conceptualization. **Valentina Moro:** Conceptualization; supervision; writing – review and editing; project administration; data curation. **Aikaterini Fotopoulou:** Funding acquisition; conceptualization; investigation; methodology; writing – review and editing; project administration; supervision; formal analysis.

ACKNOWLEDGEMENTS

We thank the patients and their relatives for their kindness and willingness to take part in the study, and we thank the staff at participating hospital sites (St. Thomas' Hospital, St. George's Hospital, King College Hospital and IRCSS Sacro Cuore Don Calabria) for their assistance with this study. We are also very grateful to Cristina Papadaki, Mimi Borrelli and Cristina Bulgarelli for help with patient recruitment and testing, as well as the Neuroscience Alliance (NEURAL) brainhack Bordeaux 2023 for contributions to the lesion mapping component of this study.

FUNDING INFORMATION

This work was funded by an European Research Council (ERC) Starting Investigator Award for the project 'The Bodily Self' N°313755 to A.F. SB, supported by a Commonwealth Scholarship, the Oppenheimer Memorial Trust, a Neuropsychology International Fellowship Award from the British Psychological Society in conjunction with the British Neuropsychological Society, the National Research Foundation (NRF) of South Africa (grant number 150745) and is a CIFAR Azrieli Global Scholar in the Brain, Mind and Consciousness Program. The study was also supported by MIUR Italy (PRIN Edit. 2017, Prot. 2017N7WCLP) for VM.

CONFLICT OF INTEREST STATEMENT

No conflicts of interest were reported.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Data S1.

How to cite this article: Besharati, S., Jenkinson, P. M., Kopelman, M., Solms, M., Bulgarelli, C., Pacella, V., Moro, V., & Fotopoulou, A. (2024). What I think she thinks about my paralysed body: Social inferences about disability-related content in anosognosia for hemiplegia. *Journal of Neuropsychology*, *00*, 1–22. https://doi.org/10.1111/jnp.12378