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Distinguishing intentions from desires: Contributions of the frontal and parietal lobes

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ABSTRACT

The ability to represent desires and intentions as two distinct mental states was investigated in patients with parietal ($N = 8$) and frontal ($N = 6$) lesions and in age-matched controls ($N = 7$). A task was used where the satisfaction of the desire and the fulfilment of the intention did not co-vary and were manipulated in a 2×2 set. In two experiments we show that lesions to the frontal lobe may impair the ability to deal with desires when their outcome is not congruent with that of the intention, and that parietal damage – especially if it encompasses the left temporo-parietal junction – may cause severe difficulties in the processing of both desires and intentions. The implications of the results for the neuropsychological and the developmental literature are discussed.

1. Introduction

The ability to reason in terms of desires and intentions and to discriminate between these two mental states is crucial in order to interpret and to predict human behaviour. The visible outcomes of desires and intentions often overlap, since agents tend to engage in intentional actions in order to accomplish specific desires (e.g., it is the desire to eat Chinese food that drives me to my local Chinese takeaway), and usually either the intention and the desire are both fulfilled (e.g., I go to the takeaway and get Chinese food), or they are both frustrated (e.g., I am unable to reach the takeaway and I do not get the Chinese food). However, both practically and conceptually, desires and intentions are rather distinct. In fact, it is possible for the intention to be fulfilled even though the desire is unsatisfied (e.g., I get to the takeaway and find out it is closed), as well as for the desire to be satisfied albeit the intention is unfulfilled (e.g., I am unable to reach the takeaway but I meet a friend who was just bringing me Chinese food). Hence intentions and desires may be separate in the cognitive mechanisms that implement them, but they may run together to determine behaviour.

A full understanding of intentions requires the ability to distinguish them from desires, when observing a given behaviour. Whereas the developmental literature has fully acknowledged distinctions in the development of the ability of using desires and intentions, our understanding of the relations between desires and intentions in adults is far from complete. This is potentially important because it means that most of the current literature on the processing of intentions in adults may in fact fall short of demonstrating a necessary role for intentions, and may instead reflect the operation of desire. It follows that conclusions about the functional and neural basis of understanding intentions must be viewed with considerable caution. The present study explores for the first time the functional and anatomical structure of the processing of desire and intention in adults, by testing patients with acquired brain damage to the frontal and the parietal lobes in a task designed to tease apart desire and intention attribution within the same action.

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1.1. Intention processing in adults

Malle and Knobe (1997, 2001) contend that, whilst desire and intention share some important features (e.g., they both express a pro attitude toward a represented state of affairs in the world), adults quite easily distinguish between them by using three criteria: the type of content of the pro attitude (with desires potentially having any type of content and intentions always representing an action content), the role that the attitude plays in the agent's reasoning (typically, desires stand at the very beginning of the process while intentions are at the output), and the agent's degree of commitment to a particular course of action.

As for the mechanisms responsible for this type of processing, a key suggestion comes from the work of Povinelli and colleagues. They proposed that intention understanding relies on two functionally and anatomically distinct systems. One system is shared with non-human primates and involves the detection of the structural regularities associated with intentional behaviour, whereas the other system is specific to humans and entails an individual mentally representing and reflecting on intentions and other mental states (Povinelli, 2001; Povinelli & Preuss, 1995). If this is the case, it should be this higher-level system that distinguishes intentions from desires.

There is increasing evidence that a universally shared and relatively encapsulated mechanism might subserve humans' ability to discern intentions from visual motion information and to discriminate between intentional and unintentional actions (Barrett, Todd, Miller, & Blythe, 2005; Blakemore & Decety, 2001; Malle & Knobe, 1997). The neural underpinnings of this basic intention reading skill appear to be located within the parietal and the frontal lobes. In particular, the left intraparietal cortex has been involved in the perception of biological motion (Battelli, Cavanagh, & Thornton, 2003; Grèzes et al., 2001), in the comprehension of pantomimes (Hermsdörfer, Terlinden, Mühlau, Goldenberg, & Wohlschläger, 2007; Moll et al., 2000) and in the observation of goal-directed actions (Buccino et al., 2001; Hamilton & Grafton, 2006). Within the frontal lobes, increased activity in the ventral premotor cortex has been linked to the processing of both transitive and intransitive actions (Buccino et al., 2001; Lui et al., 2008) and to the interpretation of action based on contextual cues (Iacoboni et al., 2005).

This relatively low-level system certainly makes it possible to recognize, within the behavioural stream, the spatiotemporal regularities that characterize intentional action. However, it is unlikely to be sufficient to process the semantic and logical attributes of the unobservable mental states that drive those same actions, because this operation requires a conceptual representation of their motivational, causal and epistemic components (Moses, 2001). The existing imaging and neuropsychological evidence shows that the frontal and the parietal lobes play an important role also in higher level mental state processing. In particular, the prefrontal cortex and the temporo-parietal junction have been implicated in belief reasoning (Apperly, Samson, Chiavarino, & Humphreys, 2004; Grèzes, Frith, & Passingham, 2004), in the discrimination between pretend and real actions (Chiavarino, Apperly, & Humphreys, 2009; German, Niehaus, Roarty, Giesbrecht, & Miller, 2004), and in the high-level representation of behaviour (Sirigu et al., 1996; Zalla, Pradat-Diehl, & Sirigu, 2003).

On the bases of these findings, a recent review by Van Overwalle and Baetens (2009) proposed that humans rely on two largely independent systems in their understanding of behaviour: the mirror system, encompassing the anterior intraparietal sulcus and the premotor cortex, is concerned with the processing of temporary goals and intentions at a perceptual level of representation, while the mentalizing system, including the temporo-parietal junction and the medial prefrontal cortex, is dedicated to the understanding of norms and intentionality at a more abstract level. Thus, there is a growing consensus among researchers from different perspectives suggesting that the same observed behaviour might be processed at different levels of complexity by distinct functional processes and differentiable neural networks within the frontal and parietal lobes (Keysers & Gazzola, 2007; Pacherie, 2000). However, there have been few attempts to contrast these levels and to specify the role of distinct frontal and parietal circuits within the same task. In one such case, De Lange and co-workers found higher activation in the inferior frontal gyrus in response to the observation of unusual intentions (e.g., a woman bringing a cup to her ear); however, if subjects were explicitly instructed to pay attention to the intention (vs. to the means) of the action, increased brain activity was detected in a wider network encompassing frontal as well as posterior areas (De Lange, Spronk, Willems, Toni, & Bekkering, 2008).

1.2. Distinguishing intentions from desires

Research on adults has rarely been concerned with the distinction between intentions and desires, and in those instances it mostly aimed at describing, from the perspective of folk psychology, the criteria we use to differentiate these two mental states (Malle & Knobe, 1997, 2001). Developmental studies, in contrast, have been very sensitive to this issue and have equally investigated the mechanisms responsible for young children's interpretation of behaviour in terms of desires and intentions, and the later processes that grant them the capacity to distinguish these two concepts. The present work conceptually and methodologically draws from this literature, which we will therefore briefly review.

Goal attribution appears very early in infancy. Three-month-old infants already show some degree of sensitivity to the inter-relatedness of movement patterns, as revealed by their ability to discriminate between random and social (e.g., chase) two-figure dynamic displays (Rochat, Morgan, & Carpenter, 1997) and by the time they are a year old, infants can interpret identical behaviours as goal-directed or not depending on the causal context (Phillips & Wellman, 2005), draw inferences on the presence of states of affairs (e.g., goals or obstacles) that they have not actually seen (Csibra, Biro, Koos, & Gergely, 2003), and understand the relation between an actor and the object of his gaze, therefore going beyond manual actions (Woodward, 2003). As for desire understanding, Repacholi and Gopnik (1997) reported that 18-month-old infants (but not 14-month-olds), after witnessing the experimenter express a positive affect toward a certain food and a negative affect toward another food, chose to give her the food toward which she expressed the positive affect, even if they themselves preferred the other food. These results suggest that infants this age have already acquired some ability to reason about other people's desires, and over the next 2–3 years, these abilities become progressively more integrated with an understanding of actions, outcomes, emotions and beliefs (e.g., Leslie, Friedman, & German, 2004; Wellman, Phillips, & Rodriguez, 2000; Wellman & Woolley, 1990; Wimmer & Perner, 1983).

However, desiring something and believing that it is possible to achieve what is desired are not sufficient conditions for an action to be performed: the agent must also have the intention to execute that action in a particular way (Searle, 1983). Intention understanding has been proposed to start evolving from the concept of agency (Shultz, 1991), by extending the notion that people can act to the notion that they deliberately plan and try to act guided by an internal mental state (Flavell, 1999). By 3 years of age, children are able to distinguish intentional actions from unintended ones, such as reflexes or mistakes (Shultz, Wells, & Sarda, 1980). However, it is not until a few years later that children acquire the deeper understanding of intention which is required, for example, to theorize about it (Thommen, Dumas, Erskine, & Reymond, 1998) or to decide that an intentional mental content necessarily underpins pretend behaviour (Lillard, 1998).

Evidence has shown that children acquire the ability to distinguish between desire and intention by age four or five, that is at the same time as they consolidate their understanding of intention (Feinfield, Lee, Flavell, Green, & Flavell, 1999; Phillips, Baron-Cohen, & Rutter, 1998; Schult, 2002). The studies by Phillips et al. (1998) and by Schult (2002) were particularly suited to examine the way children distinguish between desire and intention because they both used a methodology based on the link of intention and desire in a means-end relation and on the non-covariance between the two mental states. In this way, they separated the satisfaction of the desire from the fulfilment of the intention and prevented the possibility that responses could be based on a simple matching strategy. Phillips et al. (1998) engaged children in a game where they could win prizes (desire) by shooting down with an electronic pistol a series of cans (intention), some of which contained a prize while the others were empty. First the children were asked to declare at which can they were aiming, then to shoot at it, and finally they could check the content of the can they had hit to check for a prize. At the end of each trial, children were asked again at which can they originally aimed. Unbeknownst to the children, the experimenter controlled which can fell down at each trial, so that sometimes it would be the one at which the child really aimed while other times it would be a different can. The results showed that 5-year-olds performed above chance in all the conditions, but 4-year-olds, when they hit the can they declared they were aiming at but found out that it was empty (desire-unsatisfied/intention-fulfilled condition), tended to say that they meant to shoot a different can. The authors allowed the possibility that this could depend upon the pragmatics of the situation (e.g., children might have thought that the experimenter would have let them open another can in search for a prize) rather than upon an inability to distinguish between intentions and desires, because in the other discrepant condition (desire-satisfied/intention-unfulfilled) even the 4-year-old children were accurate in saying that they did not mean to shoot the can that fell down. Schult (2002, Study 1) avoided this problem of interpretation by using a task which did not personally involve the children themselves. Instead, children were read stories, illustrated with line drawings, where a character planned to do something (intention) in order to achieve an outcome (desire). As before, the fulfilment of the intention and the satisfaction of the desire were manipulated in a 2×2 set. In this task, 4-year-olds had difficulties in both discrepant conditions (desire-satisfied/intention-unfulfilled, desire-unsatisfied/intention-fulfilled), and even 5-year-olds showed confusion on the desire-satisfied/intention-unfulfilled stories. Importantly, not all the faulty responses in the discrepant conditions were due to a desire-outcome matching strategy, but mostly it seemed that children were genuinely confused about whether or not the intention had been fulfilled (Schult, 2002).

These results suggest the following. Even if infants at 9 months of age have expectations based on the intentions and goals of an agent (Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Woodward, 1998), it is not until the capacity to think of mental states as representations mediating actions in the world (what Perner (1991) called metarepresentation) has developed, around 5 years of age, that a full understanding of intentions is observed. It is then that children can confidently differentiate intentions from desires (Phillips et al., 1998; Schult, 2002; Thommen et al., 1998). The present study is the first to examine how this relatively late-developing ability might be impaired as a result of brain injury in adults.

A paradigm similar to the studies by Phillips et al. (1998) and Schult (2002) was used, but it was modified in order to minimize the verbal requirements of the task while still avoiding the personal involvement of the participants in the game. The first aim was to verify patients' general ability in dealing with desires and intentions when the two mental states were connected in a means-end relation within the same action. The second aim was to observe if more errors would be made in those cases where intention and desire were discrepant.

2. Experiment 1

Healthy and brain-damaged participants were shown pictures of a game where a man wanted to find a red or a green ball which was hidden in one of eight boxes. In order to get the ball (*desire*), the man had to first choose the box he thought contained the ball and then try to hit it by throwing a ball (*intention*). This design lead to four conditions: desire-satisfied/intention-fulfilled, desire-unsatisfied/intention-unfulfilled, desire-satisfied/intention-unfulfilled, desire-unsatisfied/intention-fulfilled. Note that in the first two conditions the desire and the intention of the man are congruent, while in the last two conditions the desire and the intention are discrepant. Participants were then asked about the desire and the intention of the man. Only by distinguishing desires and intentions was it possible to answer these questions correctly in all four conditions.

2.1. Methods

2.1.1. Participants

Eight patients with parietal lesions (five with left- and three with right-sided damage; mean age 64.5 years, range 51–72 years), six patients with frontal lobe lesions (three with left- and three with right-sided damage; mean age 55.8 years, range 32–74 years), and seven age-matched healthy controls (mean age 60.4, range 54–75 years) took part in this study. Details for each patient can be found in Table 1.

2.1.2. Apparatus

Participants were shown a series of pictures describing a game where a man had to find a ball hidden in one of eight boxes. Half of the boxes contained a green ball, and the other half contained a red ball. In half of the trials the man had to look for the red ball, while in the other half he had to look for the green ball. In either case, he did not know in which box the ball that he wanted was hidden and he could look into one box only in order to find it. Furthermore, he could not simply take the box he had chosen and look inside it, but he had to try and hit it by throwing a ball, making it fall. He had to open whatever box he hit, whether it was the one he intended to hit or not. Each trial was made up of six pictures: (1) the man indicated with a marker the box he had chosen to look into in search of his target ball; (2) the man threw a ball against the chosen box trying to hit it; (3) the picture depicted which of the eight boxes was actually hit; (4) the man took the fallen box; (5) the man looked inside the box and showed a pleased or displeased facial expression; (6) the man, with a neutral expression, showed the content of the box so that the participant could see it (see Fig. 1 for an example). Half of the time the man hit the box he indicated (intention fulfilled), while in the other half he hit a different box (intention unfulfilled). Half of the time he found the ball he wished (desire satisfied), while in the other half he found the other ball (desire unsatisfied). There were 32 congruent trials and 32 incongruent trials, for a total of 64 trials per participant. There were 16 trials for each of four conditions: desire-satisfied/intention-fulfilled (*d-s/i-f*, e.g., the man hit the box he marked and it contained the desired ball), desire-unsatisfied/intention-unfulfilled (*d-u/i-u*, e.g., the man missed the box he marked and the one he hit instead contained the wrong ball), desire-satisfied/intention-unfulfilled (*d-s/i-u*, e.g., the man missed the box he marked but the one he erroneously hit contained the desired ball), desire-unsatisfied/intention-fulfilled (*d-u/i-f*, e.g., the man hit the box he marked but it contained the wrong ball). Participants were asked the following two target questions: "Which ball did the man want?" (desire question) and: "Did the man intend to hit the box that fell down?" (intention question). Two control questions were asked, in order to ensure that participants had access to the information they needed to answer correctly to the intention question: "Which box did the man say he was going to hit?" (starting-state question), "Which box did the man really hit?" (final-state question).

2.1.3. Procedure

For each trial, participants watched the series of six pictures appear one at a time on a computer screen according to the following sequence: picture 1 appeared at the top left of the screen, followed by picture 2 at the top right of the screen; then picture 2 disappeared and picture 3 appeared at the same location, followed by picture 4 at the bottom left of the screen; then picture 4 disappeared and picture 5 appeared at the same location, followed by picture 6. Pictures progressed following key presses by the experimenter, in order to make sure that patients were paying attention to each stimulus. Once they had appeared, the crucial four pictures (pictures 1, 3, 5, 6) stayed on view throughout and remained on display whilst participants were asked the four questions, which also appeared at the very bottom of the screen. The two target questions (desire, intention) were always asked before the two control questions (starting-state, final-state), and the order in which each question appeared within the pair was counterbalanced. This was done in order to avoid any interference that the control questions might have on the target questions. Two practice tasks were given to the participants before the main task. In the desire practice task, participants watched a series of pictures where the man took one of the eight boxes, looked inside it showing a positive or negative affect, and then showed the content of the box. They were then asked: "Which ball did the man want?". In the intention practice task, participants watched a series of pictures where the man indicated one of the eight boxes, tried to hit it, and then the box that fell down was shown. They were then asked: "Did the man intend to hit the box that fell down?". Two correct responses in a row were required in order to proceed to the main task. In this way we made sure that patients could understand the target questions and possessed the basic emotion processing abilities needed to infer the man's desire. Patients did not receive feedback about the accuracy of their responses.

2.1.4. Performance evaluation

There were no significant differences between the two congruent conditions (*d-s/i-f* and *d-u/i-u*), nor between the two discrepant conditions (*d-s/i-u* and *d-u/i-f*) (all $t < 1.7$, all $p > .099$; see Appendix A for individual patients' scores in each condition); hence, in the subsequent analyses trials were categorized just as *congruent* or *discrepant*. In the group analyses, the proportion of correct responses out of the number of trials was counted. The items for which there was a correct response to the intention question but an incorrect response on either one of the control questions (starting-state, final-state) were excluded from the calculation. Data were analyzed with the Analysis of Variance (ANOVA) and LSD post hoc tests were used to investigate the significant effects. Because in both patient groups a high variability was observed in the data, individual patient analyses were also performed. In the patient analyses, to score above chance on a particular question

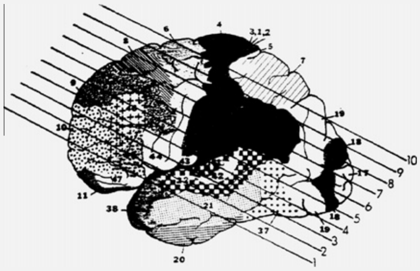
Table 1
Details of the patients who took part in Experiments 1 and 2. Lesions have been drawn onto standard slices from Gado, Hanaway, and Frank (1979). The bottom figure shows the 10 slices used. Only slices 3–8 are depicted here. The left of each slide represents the left hemisphere.

Patient	Sex/age	Main lesion site – frontal	Etiology	Years post-onset	Lesion reconstruction from MRI scan
GA	M/51	Bilateral medial and anterior temporal lobes, extending into the left medial frontal region	Herpes simplex encephalitis	11	
PH	M/32	Left medial and superior temporal gyri, left inferior and middle frontal gyri	Stroke	4	
PW	M/74	Right inferior and middle frontal gyri, right superior temporal gyrus	Stroke	2	
SP	M/52	Left medial frontal region, bilateral medial and anterior temporal lobes	Herpes simplex encephalitis	5	
TT	M/67	Right dorsolateral frontal region including the middle frontal gyrus	Stroke	5	
WBA	M/59	Right inferior and middle frontal gyri, right superior temporal gyrus	Stroke	2	
Patient	Sex/age	Main lesion site – parietal	Etiology	Years post-onset	Lesion reconstruction from MRI scan
AS	M/70	Right posterior and inferior parietal cortex including the angular gyrus	Stroke	2	
BA	M/59	Right posterior and inferior parietal cortex including the angular gyrus	Stroke	9	
DB	M/69	Left angular gyrus, superior and middle temporal gyri	Stroke	7	
FL	M/68	Left intraparietal sulcus, bilateral occipital gyrus, lenticular nuclei	Carbon monoxide poisoning	8	
MH	M/51	Left angular and supramarginal gyri, lentiform nucleus	Anoxia	8	

(continued on next page)

Table 1 (*continued*)

Patient	Sex/age	Main lesion site – parietal	Etiology	Years post-onset	Lesion reconstruction from MRI scan
PF	F/56	Left angular and supramarginal gyri, superior temporal gyrus	Stroke	6	
RH	M/71	Left angular and supramarginal gyri, superior temporal gyrus	Stroke	6	
WW	M/72	Right posterior and inferior parietal cortex including the angular gyrus	Stroke	3	



participants needed to give 12 or more out of a possible 16 correct responses (12/16 correct has a one-tailed probability of 0.038 by binomial test).

2.2. Results and discussion

2.2.1. Group analyses

For the control questions, an ANOVA with question (starting-state, final-state) and condition (congruent, incongruent) as within-subjects variables and group (control, frontal, parietal) as a between-subjects variable showed that there were no significant effects (all $F < 2.4$, all $p > .121$). However, a similar ANOVA on the two target questions (desire, intention) revealed a significant main effect of question ($F(1, 18) = 4.7$, $p = .044$), of condition ($F(1, 18) = 5.8$, $p = .027$) and of group ($F(2, 18) = 4.5$, $p = .026$), and a significant question∗condition∗group ($F(2, 18) = 4.0$, $p = .036$) interaction (Fig. 2). The effects of each question were analyzed separately.

For the desire question, there was a significant main effect of condition ($F(1, 18) = 4.6$, $p = .046$) and of group ($F(2, 18) = 4.3$, $p = .030$), and a significant condition∗group interaction ($F(2, 18) = 3.6$, $p = .049$). Overall, the control group performed better than both the frontal ($p = .050$) and the parietal ($p = .013$) groups (frontal group vs. parietal group, $p = .640$), and the congruent condition was in general easier than the discrepant condition.

Also for the intention question there was a significant effect of group ($F(2, 18) = 4.4$, $p = .028$; all other $F < 1.8$, all $p > .201$). However, this time the control group and the frontal group performed at the same level ($p = .874$), while the parietal group was significantly more impaired than both of them (control vs. parietal, $p = .016$, frontal vs. parietal, $p = .029$).

2.2.2. Individual analyses

Individual patients were grouped according to their pattern of performance in response to each of the four questions (desire, intention, starting-state, final-state) in each of the two conditions (congruent, incongruent) (Table 2).

All patients with right-sided lesions (frontal patients PW, TT and WBA, and parietal patients AS, BA and WW) performed above chance in all judgments. Among left-damaged patients, however, only patient PH showed the same normative pattern, while for the other patients errors in response to one or more questions were observed.

Three patients (frontal patients GA and SP and parietal patient MH) were impaired in response to the desire question in the discrepant condition, while performing above chance in all the other judgments. This profile might indicate a somewhat weak understanding of desires in those cases where they are inconsistent with the outcome of the actor's intentional actions. That is, when the actor hits a box different from the one he had chosen and this contains the ball he was looking for, these patients tend to report that the actor did not really wish to find that ball; similarly, when the actor hits the chosen box but this does

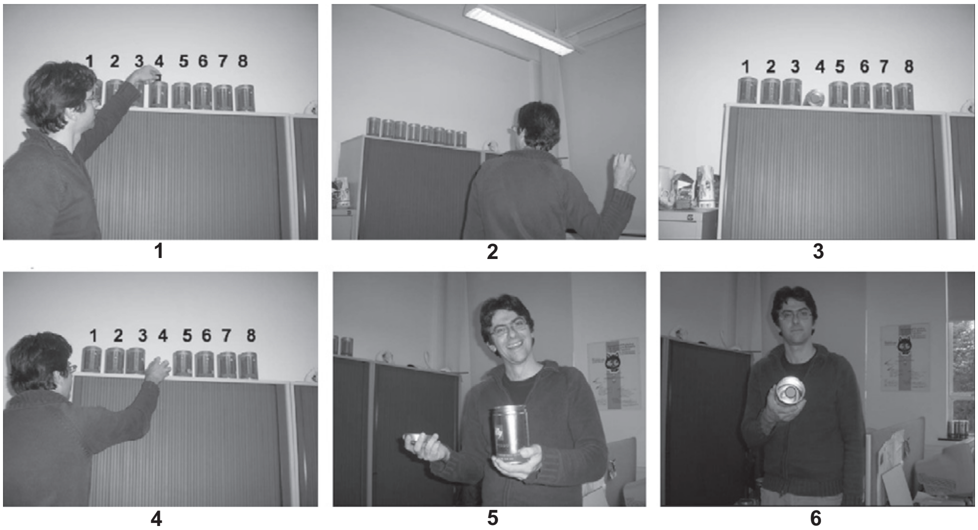


Fig. 1. Apparatus of Experiment 1. Example of a desire-satisfied/intention-fulfilled trial (pictures 1, 3, 5 and 6 remained on display while the questions were asked).

not contain the desired ball, they tend to say that he was in fact looking for the ball he found. The finding that these patients made errors in response to the desire question but performed above chance in the intention question is quite surprising in view of the developmental literature showing that desires are mastered well before intentions (Lillard, 1998; Repacholi & Gopnik, 1997; Thommen et al., 1998; Wellman et al., 2000). One possibility is that the task was set up in a way that responding to the desire question was quite demanding in terms of executive functions. This possibility was explored in Experiment 2. However, another option is that acquired brain damage might result in different impairments than those found in normally developing children, because desires and intentions at some point have been fully acquired. In addition, in the adult brain, the representation of desire and intention contents might be subserved by different brain regions. If this was the case, then damage to each of these regions might cause difficulties in the processing of one mental state but not the other.

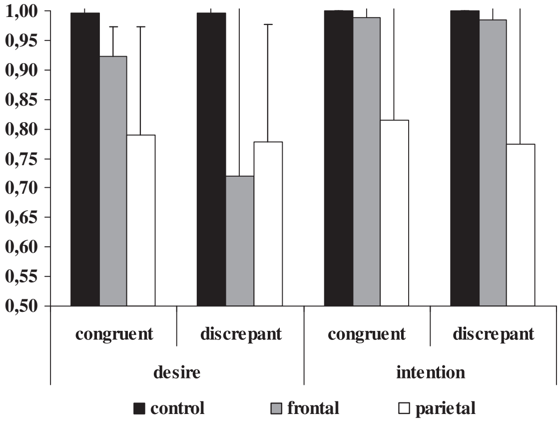


Fig. 2. Experiment 1 – group response patterns. Proportion of correct responses to the two target questions (desire, intention) in the congruent and discrepant conditions. Error bars represent standard deviations.

The crucial finding, however, is that the remaining four patients (parietal patients DB, FL, PF and RH) were impaired in response to both the desire and the intention questions, in the congruent just as in the discrepant conditions. It is noteworthy that these patients – and these patients only – presented lesions to the left temporo-parietal junction. However, while patient RH performed above chance in response to the control questions, patients DB, FL and PF were impaired in response to the starting-state question as well (and patient FL was further impaired in response to the final-state question). Thus, while RH's pattern of performance suggests a genuine impairment in the processing of desires and intentions, the difficulties showed by the other three patients are also consistent with a difficulty in meeting the general task demands. Yet, another option is that, because the target questions were always asked before the control questions, these patients gave wrong starting-state responses so that they would be consistent with the (wrong) intention responses. Indeed, 80% of the times an error in the starting-state question was preceded by an error in the intention question: in these cases, patients mostly named the box that actually fell down instead of the box indicated by the man. In other words, they gave the same response as for the final-state question, which would justify the "yes" response they gave to the intention question. This explanation might particularly apply to the case of patients DB and PF, who made errors in the starting-state but not in the final-state questions.

3. Experiment 2

Two features of the task used in Experiment 1 might have been contributed unnecessarily to patients' errors.

Table 2
Experiment 1 – individual response patterns (maximum score = 32). Pattern of errors of all the patients in the congruent and the discrepant conditions in response to the desire, intention, starting-state and final-state questions (italic cells indicate chance performance in one or both of the congruent and discrepant conditions).

Patient	Lesion site	Desire		Intention		Starting-state		Final-state	
		Congr.	Discr.	Congr.	Discr.	Congr.	Discr.	Congr.	Discr.
GA	Frontal L	28	*9*	30	29	30	29	31	31
SP	Frontal L	28	*12*	32	32	29	32	30	32
PH	Frontal L	32	32	32	32	32	30	30	31
PW	Frontal R	31	29	32	32	32	32	32	32
TT	Frontal R	29	28	32	32	32	32	32	32
WBA	Frontal R	29	28	32	32	31	31	31	29
DB	Parietal L	*25*	*27*	*20*	*13*	*19*	*17*	31	32
FL	Parietal L	*16*	*13*	*16*	*15*	*19*	*24*	*15*	*13*
MH	Parietal L	28	*27*	29	30	29	31	31	31
PF	Parietal L	*18*	*22*	*27*	*27*	*25*	*27*	30	32
RH	Parietal L	*23*	*19*	*25*	*20*	30	29	32	31
AS	Parietal R	30	31	32	32	32	32	32	32
BA	Parietal R	32	30	32	32	32	32	32	32
WW	Parietal R	30	30	32	32	32	32	32	32

First of all, in Experiment 1 answering the desire question required participants to map the emotional reaction of the man (Fig. 1, picture 5) to the content of the box (picture 6), and to reason backwards from this information to the desire of the man. For example, if in picture 5 the man had a happy expression whilst looking inside the box he had hit and in picture 6 he showed that the same box contained a red ball, the participant had to infer that the happiness of the man had to do with finding the red ball and – thinking backwards – he could conclude that his initial desire was for the red ball. Difficulties in backwards reasoning could explain the errors made in the desire question by the patients with frontal and temporo-parietal lesions (as well as those of MH). In the new version of the task participants were shown in the very first picture what the desire of the man was and their task was to decide, after seeing his emotional reaction in the last picture, if the desire had been satisfied or not.

Secondly, as we already noted, because the target questions always preceded the control questions, it is possible that, when the patients with left temporo-parietal lesions gave a wrong answer to the intention question, they responded wrongly to the starting-state question as well so as to be consistent with their response to the intention question. In order to control for this factor, in Experiment 2 the target questions half of the time preceded the control questions and half of the time followed them.

3.1. Methods

3.1.1. Participants

The same patients who took part in Experiment 1 participated in this study (Table 1), together with a group of six age-matched healthy controls (two females, four males; mean age 59.2, range 53–77 years).

3.1.2. Apparatus

Participants were presented with the same game as in Experiment 1, but there were several differences in the pictures that were used. Each trial was made up of six pictures: (1) this showed a man with a thought bubble of the ball he was looking for (red or green); (2) the man indicated with a marker the box he had chosen to look into in search for his target ball; (3) the man threw a little ball against the chosen box trying to hit it; (4) this showed which of the eight boxes was actually hit; (5) the man took the fallen box; (6) the man looked inside the box and showed a pleased or displeased facial expression (see Fig. 3 for an example). As before, half of the time the man hit the box he indicated (intention fulfilled), while in the other half he hit a different box (intention unfulfilled). Half of the time he found the ball he wished and he looked happy (desire satisfied), while in the other half he found the other ball and looked unhappy (desire unsatisfied). However, this time participants did not need to infer the man's desire, because it was clearly shown in the very first picture. There were 24 congruent trials and 24 incongruent trials, for a total of 48 trials per participant. There were 12 trials for each of four conditions: desire-satisfied/intention-fulfilled (*d-s*/*i-f*), desire-unsatisfied/intention-unfulfilled (*d-u*/*i-u*), desire-satisfied/intention-unfulfilled (*d-s*/*i-u*), desire-unsatisfied/intention-fulfilled (*d-u*/*i-f*). Participants were asked the following four questions: "Did the man get the ball he wanted?" (desire target question), "Did the man intend to hit the box that fell down?" (intention target question), "Which box did the man say he was going to hit?" (starting-state control question), "Which box did the man really hit?" (final-state control question).

3.1.3. Procedure

For each trial, participants watched the series of six pictures appear one at a time on a computer screen according to the following sequence: picture 1 appeared at the top left of the screen, followed by picture 2 at the top right of the screen and by picture 3 at the bottom left of the screen; then picture 3 disappeared and picture 4 appeared at the same location, followed by picture 5 at the bottom right of the screen; picture 5 then disappeared and picture

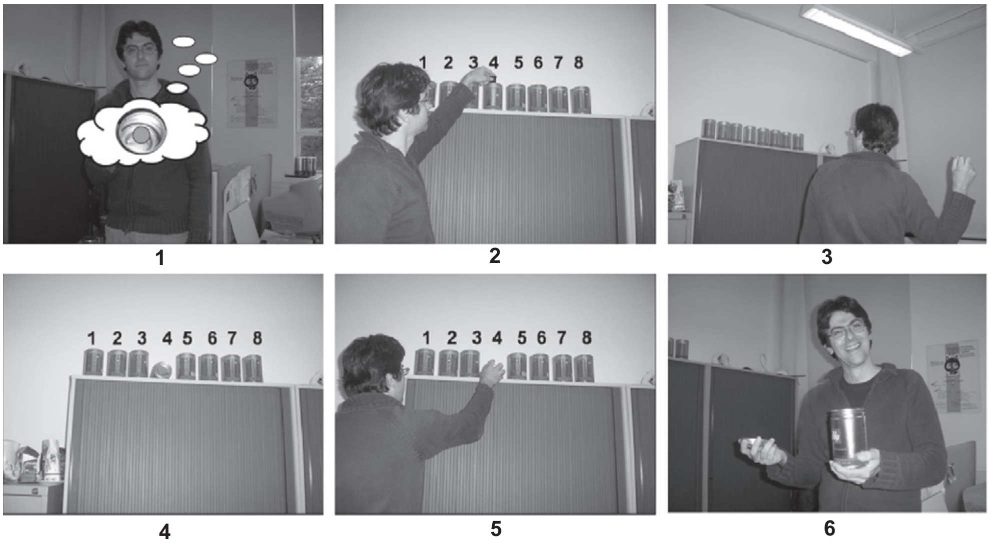


Fig. 3. Apparatus of Experiment 2. Example of a desire-satisfied/intention-fulfilled trial (pictures 1, 2, 4 and 6 remained on display while the questions were asked).

6 appeared at the same location. Pictures progressed following key presses by the experimenter, in order to make sure that patients were paying attention to each stimulus. Once they had appeared, the crucial four pictures (pictures 1, 2, 4, 6) stayed on view throughout and remained on display whilst participants were asked the four questions, which also appeared at the very bottom of the screen. The control questions (starting-state, final-state) were asked an equal number of times before and after the target questions (desire, intention), and the order in which each question appeared within the pair was counterbalanced. A desire practice task and an intention practice task were given to the participants before the main task, so that they could familiarize with the new features of the task (e.g., the thought bubble) and the new desire question. Two correct responses in a row were required in order to proceed to the main task. Patients did not receive feedback about the accuracy of their responses.

3.1.4. Performance evaluation

There were no significant differences between the two congruent conditions (*d-s*/*i-f* and *d-u*/*i-u*), nor between the two discrepant conditions (*d-s*/*i-u* and *d-u*/*i-f*) (all $t < 1.8$, all $p > .085$; see Appendix A for individual patients' scores in each condition); hence, in the subsequent analyses trials were categorized just as *congruent* or *discrepant*. In the group analyses, the proportion of correct responses out of the number of trials was counted. For the intention questions, the items for which there was a correct response to the intention question but an incorrect response on either one of the control questions (starting-state, final-state) were excluded from the calculation. Data were analyzed with the Analysis of Variance (ANOVA) and LSD post hoc tests were used to investigate the significant effects. Because in both patient groups a high variability was observed in the data, individual patient analyses were also performed. In the patient analyses, to score above chance on a particular question participants needed to give 10 or more out of a possible 12 correct responses (10/12 correct has a one-tailed probability of 0.019 by binomial test).

3.2. Results and discussion

3.2.1. Group analyses

For the control questions, an ANOVA with question (starting-state, final-state) and condition (congruent, incongruent) as within-subjects variables and group (control, frontal, parietal) as a between-subjects variable showed that there were no significant effects (all $F < 2.9$, all $p > .105$). However, a similar ANOVA on the two target questions (desire, intention) revealed a significant main effect of condition ($F(1, 17) = 8.6$, $p = .009$) and significant question∗condition ($F(1, 17) = 7.6$, $p = .014$) and question∗condition∗group ($F(2, 17) = 3.8$, $p = .042$) interactions (Fig. 4). Subsequently, the effects of each question were analyzed separately.

For the desire question there was a significant main effect of condition ($F(1, 17) = 8.8$, $p = .009$), with the congruent condition being overall easier than the discrepant condition. The main effect of group did not reach significance, even though both patient groups made numerically more errors than the control group ($F(2, 17) = 2.7$, $p = .099$).

For the intention question there was a significant effect of group ($F(2, 17) = 3.6$, $p = .048$; all other $F < 3.2$, all other $p > .091$), with the parietal group being again significantly more impaired than both the control ($p = .029$) and the frontal ($p = .044$) groups, who did not differ from each other ($p = .850$).

3.2.2. Individual analyses

Individual patients were grouped according to their pattern of performance in response to each of the four

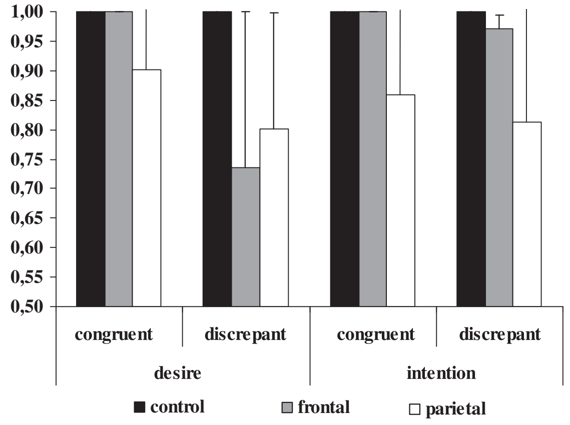


Fig. 4. Experiment 2 – group response patterns. Proportion of correct responses to the two target questions (desire, intention) in the congruent and discrepant conditions. Error bars represent standard deviations.

questions (desire, intention, starting-state, final-state) in each of the two conditions (congruent, incongruent) (Table 3).

Results looked very similar to those of Experiment 1. All the patients with right-sided lesions (with the exception of frontal patient TT, see below) performed above chance in all judgments, but only two patients with lesions to the left hemisphere (frontal patient PH and parietal patient MH) showed the same normative pattern. For the other patients, errors in response to one or more questions were observed.

Patients GA, SP and TT were impaired in the discrepant condition of the desire question, while responding above chance to all the other questions. The persistence of this performance profile despite the changes to the task format favours its interpretation in terms of a difficulty in desire processing when there is a contrast with the outcome of the actor's intentional action. Notably, these patients all had lesions to the frontal lobes.

As for the left temporo-parietal patients, while DB and FL again made mistakes in both conditions of the desire and the intention questions, and were further impaired answering to the control questions, patients PF and RH showed a more differentiated response pattern, with errors confined to the discrepant conditions of the desire and the intention question. We think the safer interpretation of DB and FL's profile is a difficulty in meeting the general task demands. However, PF and RH are more likely genuinely confused in discriminating between desires and intentions, and this impairment emerges every time the two mental states are not congruent.

The modifications made to the task used in Experiment 1 eliminated the confounding factors that lead most patients to resort to the use of response strategies, and this in turn helped to uncover the presence of real difficulties in the processing of desires and intentions. Three of the patients with frontal lesions (GA, SP, TT) and all the patients with left temporo-parietal lesions (DB, FL, PF, RH) had some difficulties with the desire question. The left temporo-parietal patients had clear difficulties with the intention question as well. Of particular interest was the performance of RH and PF, who were markedly impaired in response to the desire and the intention questions only when the desire and the intention were discrepant.

One potentially confounding variable still remaining is that, in both experiments, participants were required to decide if the desire was satisfied or not based on the emotional reaction of the man to the ball he found in the box he hit. Therefore, if patients were impaired at processing emotions, they would not have been able to solve the task, and they could therefore have decided to base their responses on the outcome of the intention. However, their performance in the desire practice trials showed that they could match the emotional reaction to the outcome of the desire, and their comments during the tasks confirmed that this

Table 3
Experiment 2 – individual response patterns (maximum score = 24). Pattern of errors of all the patients in the congruent and the discrepant conditions in response to the desire, intention, starting-state and final-state questions (italic cells indicate chance performance in one or both of the congruent and discrepant conditions).

Patient	Lesion site	Desire		Intention		Starting-state		Final-state	
		Congr.	Discr.	Congr.	Discr.	Congr.	Discr.	Congr.	Discr.
GA	Frontal L	24	*8*	24	23	24	24	24	24
SP	Frontal L	24	*15*	24	23	24	24	24	24
PH	Frontal L	24	22	24	24	23	24	23	24
PW	Frontal R	24	23	23	22	23	24	23	23
TT	Frontal R	24	*14*	24	24	24	23	23	23
WBA	Frontal R	24	24	23	22	24	24	24	24
DB	Parietal L	*13*	*13*	*12*	*15*	*17*	*19*	*18*	*17*
FL	Parietal L	*18*	*19*	*9*	*12*	*13*	*17*	*14*	*18*
MH	Parietal L	24	22	22	22	23	24	22	23
PF	Parietal L	22	*16*	23	*19*	23	22	23	23
RH	Parietal L	24	*13*	24	*19*	24	23	24	24
AS	Parietal R	24	23	23	23	23	24	23	24
BA	Parietal R	24	24	24	24	24	24	24	24
WW	Parietal R	24	24	24	24	23	24	23	24

was the case (e.g., "I don't understand… he didn't get what he wanted but he is smiling…"). It seems safe, then, to attribute their impairment to a difficulty in processing desires, or better, in distinguishing between desires and intentions, since errors were made only in the discrepant conditions.

4. General discussion

The present study investigated for the first time the ability of patients with different brain lesions to represent desire and intention as two distinct mental states. The developmental literature has shown that children come to differentiate between desires and intentions relatively late (e.g., Phillips et al., 1998; Schult, 2002), but no previous study has explored how this ability can break down in adults with acquired brain damage.

In Experiment 1 participants were asked to watch a series of pictures depicting a game where a man tried to satisfy a desire (get a red or a green ball) by fulfilling an intention (hitting the box he thought contained the desired ball). Subsequently, they were asked questions to assess their understanding of the desire and of the intention of the man, together with two control questions. The desire and the intention could be congruent (both satisfied/fulfilled or both unsatisfied/unfulfilled) or discrepant (one satisfied/fulfilled and the other unsatisfied/unfulfilled). In Experiment 2 two possibly confounding factors were eliminated from the task, so as to avoid as much as possible that responses to the desire and the intention questions could be driven by response strategies, and to allow genuine difficulties in processing these two mental states to emerge.

There were two main results. First of all, damage to frontal areas might in some cases lead to difficulties in responding in a distinct way to questions about intentions and desires. More specifically, when the desire and the intention were discrepant, some frontal patients (patients GA and SP, and patient TT in Experiment 2) tended to make errors in the desire question, while responding correctly to the intention question (as well as to the control questions). Their good performance in response to the intention question, and to the desire question in the congruent conditions, argues against an interpretation of these patients' difficulty in terms of a conceptual deficit, such as a complete loss of knowledge of what desires and intentions are or of the notion that desire and intention can be different. Rather, their impairment appears to involve the ability to coordinate the notions of desire and intention when they conflict.

The fact that this difficulty affected desire inference more than intention inference is surprising in light of the developmental findings showing that desire processing is quite accurate well before children get to master the concept of intention (e.g., Repacholi & Gopnik, 1997; Thommen et al., 1998). Moreover, studies contrasting desires and intentions with tasks similar to the one used here found that children tended to make more mistakes in response to intention than to desire questions (e.g., Schult, 2002). One possibility is that, once the concepts of desire and intention have been fully acquired in the course of development, damage to frontal areas might weaken the ability to resolve conflict between desires and intentions when reason about desires but not when reasoning about intentions, resulting in a different pattern of performance than that found in children. Another option, is that there might not be a substantial dissimilarity between child and adult processing of desires and intentions, and that the difference in performance might be a consequence of subtle differences between the current task and the tasks used in developmental studies. Specifically, in our study the desired outcome was not particularly significant for the character (i.e. it consisted in getting a ball of a particular colour), nor did the failure to satisfy the desire have serious consequences (i.e. the character would get a ball of a different colour). In contrast, in the developmental studies the desired outcome was much more noteworthy for the participant (i.e. getting a prize) or for the story character (i.e. having a snack with one's favourite food). Thus, in the current study the frontal patients might have based their responses to the target questions predominantly on information relevant for intention because the information relative to the character's intention was more salient than the information relative to his desire in the context of the task. In either case, the interpretation would be that the difficulty of patients with frontal lesions was with the flexible co-ordination of information about intentions and desires, rather than with representing these concepts.

Another interesting finding of the present study was that damage to left parietal areas was consistently and specifically linked with more widespread difficulties in desire and intention processing than frontal lesions, as demonstrated by chance performance in response to both the desire and the intention questions. Individual patient analyses showed that, within the group of patients with left parietal lesions, some patients had problems in response to the control questions as well, but it noteworthy that two of them, patients PF and RH, were exclusively impaired in the discrepant conditions of the desire and the intention questions. This result suggests that, rather than having a problem in coordinating the notions of desire and intention, these patients may present a genuine conceptual difficulty in understanding the semantic and logical properties of intentions, which makes it very difficult to differentiate them from desires. This difference in performance between the frontal and the left parietal patients is consistent with the findings of Chiavarino et al. (2009), who showed that patients with parietal lesions were more impaired than frontal patients in the differentiation of pretend from real actions. In that study, however, right parietal patients were as impaired as left parietal patients, while in the current tasks all the right parietal patients performed at ceiling. An interesting possibility is that there might be a left hemisphere specialization for the processing of the most abstract features of intention, though this hypothesis needs further investigation by means of more closely matched tasks.

Finally, it is worth noting that patients PF and RH, whose lesion within the left parietal lobe includes the temporo-parietal junction, have previously been shown to be selectively impaired in performing intentional/accidental judgments and in recognizing the intentional nature of pretence (Chiavarino et al., 2009), as well as in understanding false beliefs (Samson, Apperly, Chiavarino, & Humphreys, 2004). The tasks used in these studies all required participants to infer mental states from behaviour, lending support to the notion that the left temporo-parietal junction might play a fundamental role in the realization of social inferences from action observation, whether such inferences involve processing of the actor's intentions, desires or beliefs. This finding contributes to the debate on the role of the left temporo-parietal junction within the mentalizing system, hinting to its involvement in the representation of complex social mental states (i.e. Ciaramidaro et al., 2007), with frontal structures assisting in the co-ordination of these states in the service of particular judgements about what someone will do, think, want or intend.

To summarize, our findings illustrate the importance of differentiating intentions from desires. Moreover, the data suggest that this differentiation relies on (at least) two distinct mechanisms, one involved in the conceptual understanding of the semantic and logical properties of intentions, and critically dependent upon the parietal lobes; and the other responsible for coordinating the notions of desire and intention when they conflict, and critically dependent upon the frontal lobes. It is important to note that when intentions and desires are not in conflict – as in many everyday circumstances and in many existing studies of adults – an account that stresses the necessary role of high-level intentional processing is unnecessary. In these circumstances, it is sufficient to comprehend that a certain action expresses a pro attitude toward a represented state of affairs in the world, which is the fundamental feature that intentions share with desires. This basic understanding of desires and intentions appears to be acquired during childhood, it appears still to be available after frontal and parietal brain damage, and may indeed be the basis on which neurologically intact adults often process "intentions" in real life and in laboratory tasks. Nonetheless, this falls short of a full understanding, in which intentions and desires are clearly distinguished. The current research suggests that in adults this full understanding is cognitively demanding and dependent upon multiple functional and neural processes in the parietal and frontal lobes. Indeed this may help to explain why a full understanding of intentions is relatively late to develop in children, for not only must children be able to meet the cognitive demands of coordinating conflicting intention and desire states, but the neural systems that appear necessary for this understanding in adults are among the latest to mature (Giedd et al., 1999).

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Experiment 1 (maximum score = 16)

Patient/lesion	Desire				Intention				Starting-state				Final-state			
	d-s/i-f	*d-u/i-u*	*d-s/i-u*	*d-u/i-f*	*d-s/i-f*	*d-u/i-u*	*d-s/i-u*	*d-u/i-f*	*d-s/i-f*	*d-u/i-u*	*d-s/i-u*	*d-s/i-f*	*d-u/i-u*	*d-s/i-u*	*d-u/i-f*	*d-s/i-f*
GA/L-fr	16	12	6	3	14	16	16	13	15	15	14	15	16	15	15	16
SP/L-fr	14	14	3	9	16	16	16	16	16	13	16	16	14	16	16	16
PH/L-fr	16	16	16	16	16	16	16	16	16	16	14	16	14	16	15	16
PW/R-fr	15	16	13	16	16	16	16	16	16	16	16	16	16	16	16	16
TT/R-fr	13	16	14	14	16	16	16	16	16	16	16	16	16	16	16	16
WBA/R-fr	13	16	13	15	16	16	16	16	16	15	15	16	16	15	13	16
DB/L-par	16	9	16	11	16	4	1	12	16	3	1	16	16	15	16	16
FL/L-par	10	6	6	7	16	0	0	15	11	8	13	11	11	4	1	12
MH/L-par	12	16	11	16	13	16	16	14	13	16	15	16	16	15	15	16
PF/L-par	16	2	16	6	16	11	11	16	16	9	11	16	16	14	16	16
RH/L-par	14	9	13	6	16	9	4	16	14	16	14	15	16	16	15	16
AS/R-par	16	14	16	15	16	16	16	16	16	16	16	16	16	16	16	16
BA/R-par	16	16	15	15	16	16	16	16	16	16	16	16	16	16	16	16
WW/R-par	16	14	16	14	16	16	16	16	16	16	16	16	16	16	16	16

Experiment 2 (maximum score = 12)

Patient/lesion	Desire				Intention				Starting-state				Final-state			
	d-s/i-f	*d-u/i-u*	*d-s/i-u*	*d-u/i-f*	*d-s/i-f*	*d-u/i-u*	*d-s/i-u*	*d-u/i-f*	*d-s/i-f*	*d-u/i-u*	*d-s/i-u*	*d-u/i-f*	*d-u/i-u*	*d-s/i-u*	*d-u/i-f*	*d-s/i-f*
GA/L-fr	12	12	6	2	12	12	11	12	12	12	12	12	12	12	12	12
SP/L-fr	12	12	7	8	12	12	11	12	12	12	12	12	12	12	12	12
PH/L-fr	12	12	11	11	12	12	12	12	12	11	12	12	12	11	12	12
PW/R-fr	12	12	11	11	12	11	11	11	12	11	12	12	12	11	11	12
TT/R-fr	12	12	6	8	12	12	12	12	12	12	11	12	12	11	11	12
WBA/R-fr	12	12	12	12	12	11	11	11	12	12	12	12	12	12	12	12
DB/L-par	12	1	12	1	9	3	3	12	12	5	7	12	12	6	5	12
FL/L-par	10	8	11	8	3	6	3	9	5	8	9	8	5	9	8	10
MH/L-par	12	12	10	12	12	10	12	10	12	11	12	12	12	10	11	12
PF/L-par	12	10	9	7	12	11	10	9	12	11	10	12	12	11	11	12
RH/L-par	12	12	6	7	12	12	9	10	12	12	11	12	12	12	12	12
AS/R-par	12	12	11	12	12	11	12	11	11	12	12	12	11	12	12	12
BA/R-par	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12	12
WW/R-par	12	12	12	12	12	12	12	12	12	11	12	12	12	11	12	12

Appendix A

Number of patients' correct responses in the two congruent conditions (desire-satisfied/intention-fulfilled, *d-s/i-f*; desire-unsatisfied/intention-unfulfilled, *d-u/i-u*) and in the two incongruent conditions (desire-satisfied/intention-unfulfilled, *d-s/i-u*; desire-unsatisfied/intention fulfilled, *d-u/i-f*) for each question (desire, intention, starting-state, final-state) in Experiment 1 and in Experiment 2 (italic cells indicate chance performance). L-fr: left frontal; R-fr: right frontal; L-par: left parietal; R-par: right parietal.

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