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RESEARCH ARTICLE

The relations between joint action and theory of mind: a neuropsychological analysis

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Abstract We examined the relations between joint action and Theory of Mind (ToM) in neurological patients with impairments in ToM, in control patients (who passed ToM tasks) and non-lesioned controls. In two experiments, joint action was assessed in a "social Simon" procedure where spatial compatibility effects were tested under two-alternative forced-choice and under go/nogo conditions, which participants performed in isolation or alongside another participant (the joint action condition). In Experiment 1, patients with impaired ToM showed evidence of increased spatial compatibility effects under standard (two-alternative forced-choice) conditions but, unlike the control participants, these effects disappeared in the joint action condition. In Experiment 2, the ToM patients were asked to pay particular attention to their co-actor. With these instructions, ToM patients with lesions of posterior parietal cortex now showed a sustained spatial compatibility effect in the joint action condition, while ToM patients with lesions primarily involving frontal regions showed an initial effect of spatial compatibility that decreased across trials. The data suggest common processes involved in ToM processing and joint action effects, related to either the ability to attend to appropriate social cues (affected in posterior parietal patients) or the ability to recruit sufficient resources to code another's actions (affected in frontal patients).

Keywords Joint action · Theory of mind · Neuropsychology

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Introduction

In many everyday tasks, people have to interact together in order to achieve a common goal—ranging from the co-ordination of action between members of a dance ensemble to one individual passing an object to another. These joint actions need to be based on representations of the common goal and of the other's actions in relation to that goal. The cognitive processes that underlie these joint actions are just beginning to be understood. In the present study, we ask whether the co-representation of joint action is modulated by the more general ability to code the beliefs of another person, measured through performance on "Theory of Mind" tests.

Sebanz et al. (2003, 2005a) developed a novel experimental paradigm to examine joint action effects. They used a version of the Simon task, in which participants make a spatially based response (keypress with the left or right hand) to the identity of a stimulus that also signaled a left or right spatial location (the stimulus was a hand pointing to the left or right, and participants responded according to the color of a ring on one finger). Under two-alternative choice forced-choice conditions, a spatial compatibility effect was established (cf. Simon 1969). This effect was eliminated when participants performed a go/nogo version of the task in which they only responded to one attribute of the stimulus, making a single keypress response. However, the spatial compatibility effect was restored when two participants performed the task, each making a go/nogo response to a single aspect of the display (the "social Simon" task). This result indicates that, when two individuals jointly perform a task, there is representation of the combined actions, which (e.g.) makes salient the spatial stimulus–response relations present across both actors.

Subsequent to this initial demonstration, effects of joint action have been demonstrated on a number of other paradigms. For example, inhibition of return effects (Welsh et al. 2005, 2007), negative priming effects (Frischen et al. 2009), and the effects on attention of information in working memory (He et al., this vol.; He et al. sub.) have all been shown to be modulated by joint action. Thus, when two are participants, each conducting a search task, attention allocation by one participant is biased by where the other participant has previously attended and by what the information the other participant must hold in memory. Interestingly, these joint action effects are observed when participants believe that they interact with another human being, but not when interactions are with a non-human agent (Tsai and Brass 2007), indicating that there is modulation of the effects by beliefs about the other person.

The ability to represent the beliefs, desires, and intensions of other people is known as Theory of Mind (ToM) (Premack and Woodruff 1978). Though initially studied primarily in a developmental context (Apperly et al. 2005), there is growing work assessing the functional and neural organization of ToM processes in adults. At a neural level, fMRI research has emphasized the involvement of an extensive fronto-parieto-temporal network including the medial prefrontal cortex, the temporo-parietal junction and the temporal poles (for reviews see Frith and Frith 2003; Saxe et al. 2004). These correlatory results are supported by neuropsychological studies showing deficits after damage to these brain regions (Apperly et al. 2004; Lough et al. 2001, 2005; Rowe et al. 2001; Stone et al. 1998; Samson et al. 2004) (but see Bird et al. 2004, for evidence against medial prefrontal involvement). The consequences of impairments in ToM processing for other social tasks have rarely been explored, however. One attempt to do this was made by Sebanz et al. (2005b). They examined joint action in autistic individuals using the "social Simon" procedure—impairments in ToM having been noted within autistic spectrum disorder (ASD) (Frith and Frith 2003). Interestingly, Sebanz et al. found that joint action effects were present, with a spatial compatibility effect emerging when two participants responded under go/nogo response conditions. These results suggest that joint action may be based upon residual social processing abilities that remain in ASD and when ToM abilities are impaired. However, the precise relations between joint action and ToM in this study are not clear. For example, all but one of the individuals tested by Sebanz et al. passed either first- or second-order ToM tasks (reflecting both an individual's knowledge of another's beliefs, and the knowledge inferred by an individual about the beliefs/intensions of another person about a third party). Though the ASD individuals were worse at ToM tasks than controls, their ToM abilities may still have been sufficient to support the joint action effect. In the present study, we attempted to examine the relations between ToM and joint action more directly by examining joint action effects in patients with acquired disorders of ToM processing who failed even first-order ToM tasks. Do deficits in ToM in such cases lead to insensitivity to joint action, when two individuals participate in a common experiment?

Recent neuropsychological studies suggest that different aspects of ToM can be fractionated in patients with contrasting brain lesions. For example, Apperly et al. (2004) reported data from patients with either frontal lesions or with lesions affecting the posterior parietal cortex (PPC) and temporo-parietal junction (TPJ). Both sets of patients failed on forms of "false belief" task. However, while the PPC/TPJ patients passed control tests which matched ToM tasks for working memory demands but without requiring inferences about another person's beliefs, the frontal patients failed on both tasks. Apperly et al. proposed that, following frontal lesions, patients may fail on ToM tasks because they lack sufficient processing resources to support the ability to infer another's beliefs/intentions. In contrast, damage to the PPC/TPJ may selectively affect processes that are necessary to making ToM inferences—such as the ability to take another's perspective or to taking note of key social cues that indicate another person's cognitive state—while conceptual knowledge about other people's beliefs may be preserved. Consistent with this argument, Samson et al. (2007) reported the case of a PPC/TPJ patient who had spared semantic knowledge about other's beliefs but who made errors on belief reasoning tasks by using a simplified mentalizing strategy—"what the person thinks is what the person sees." In addition, Samson et al. noted that their PPC/TPJ patient failed on ToM processing on early trials in their study but succeeded on later trials. Apparently, such patients remain able to represent the beliefs/intentions of other people, but may only do this when (perhaps through practice) they take account of appropriate cues. These data suggest that it might be possible to distinguish patients with different problems in ToM processing. Here, we examined if these different problems might impact on the representation of joint action. For example, patients capable of representing other perspectives may be sensitive to joint action when their attention is drawn to a partner's behavior; in contrast, patients lacking resources to represent other people's perspectives may remain insensitive to joint action even when the partner's behavior is highlighted. At a neuroanatomical level, this contrast may correspond to patients with, respectively, PPC/TPJ and frontal lobe lesions.

To assess these possibilities, we examined joint action in patients with PPC/TPJ and frontal lobe lesions, all of whom had failed on pretests assessing ToM abilities (see Apperly et al. 2004). We used a "social Simon" procedure in which participants had to respond to the word LEFT or RIGHT, which appeared either on the left or right of the screen. In Experiment 1, the patients performed this task alone using a two-alternative forced-choice response (standard Simon), alone using a go/nogo procedure (respond either to the word LEFT or the word RIGHT only) or with a confederate (the second author), each making a go/nogo response. The PPC/TPJ and frontal patients with an impaired ToM performed these tasks along with a group of non-lesioned, age-matched control participants, and a group of "control patients", with a variety of lesions, all of whom passed the passed the ToM tasks. We assessed if the patients with impaired ToM manifested a joint action effect when performing the Simon task with the confederate (cf. Sebanz et al. 2003). In Experiment 2, we examined only the ToM patients and assessed whether they could show a joint action effect of specifically instructed to pay attention to the confederate. Does the instruction to attend to the confederate lead to at least some patients forming a joint representation of the action task?

General method

Participants

In Experiment 1, there were six participants in each of the 4 groups: (1) ToM patients with PPC/TPJ lesions; (2) ToM patients with frontal lesions; (3) non-lesioned controls; and (4) non-ToM control patients. Table 1 gives the demographic details about the patients in groups (1), (2), and (4). The non-lesioned controls had a mean age of 67.5 years (range 58–75) and there were four men and two women. The lesions of the patients are depicted in Fig. 1. In Experiment 2 only the ToM patients took part. The different groups of patients did not differ in terms of measures of pre-morbid IQ or some basic neuropsychology tests (Table 1).

Prior to taking part in the experiment, the patients were each tested using a clinical assessment of ToM abilities (from the social Birmingham Cognitive Screen, BCoS-social) and using the "false belief" task reported by

Table 1 Demographic details of the patients plus scores on basic neuropsychological tests

Patient	Age/gender	Handedness/aetiology	Neuropsychological profile	NART	Brixton	Corsi	Digit span
PPC/TPJ ToM group							
JB	71/F	R, stroke	Left extinction, hemisplegia	105	20	3	5
PF	58/F	R, stroke	Mild simultanagnosia, left extinction	90	31	2	5
RH	73/M	R, stroke	Word finding problems, right extinction, mild right neglect	85	32	4	2
PJ	73/M	R, stroke	Word finding problems and right side extinction	80	20	3	2
TM	72/M	R, stroke	Left neglect and hemiplegia	110	45	3	6
MP	63/M	L, stroke	Left neglect and extinction, hemiplegia	105	21	3	5
Frontal ToM group							
GA	53/M	R, herpes simplex encephalitis	Amnesia, surface dyslexia, category-specific agnosia, dysexecutive problems	102	20	4	6
FK	39/M	R, anoxia	Visual agnosia due to impaired semantic access, dysexecutive problems	112	38	4	4
AS	72/M	R, stroke	Left extinction	102	26	5	5
DS	71/M	R, stroke	Non-fluent aphasia, dysexecutive problems	105	20	3	4
JW	72/M	R, stroke	Left extinction	110	25	4	4
PW	74/M	R, stroke	Dysexecutive problems	105	27	3	5
Lesioned controls							
WBA	60/M	R, stroke	Dysexecutive problems	115	26	3	5
MH1	54/M	R, anoxia	Optic ataxia, right extinction	104	34	2	4
MH2	72/M	R, stroke	Semantic deficits, alexia, right extinction	n/t	15	3	2
PH	35/M	R, stroke	Non-fluent aphasia, deep dyslexia, hemiplegia	80	21	2	2
MS	46/M	R, stroke	Category-specific agnosia, visual dyslexia	n/t	12	3	5
DT	70/M	R, stroke	Left extinction	90	12	4	5

The NART (Nelson and Willison 1991) is a reading test that provides a score related to pre-morbid IQ. Patients MH2 and MS were unable to read well enough for a score to be taken. The Brixton test measures non-verbal rule finding and control of perseverative responding (Burgess and Shallice 1997). The Corsi visuo-spatial test provides a measure of visuo-spatial short-term memory and the digit span provides an equivalent measure of verbal short-term memory. The three patient groups did not differ on any of these measures (highest $F(2, 15) = 3.37$, $P > 0.05$, for the Corsi span measure, where the frontal ToM group tended to perform best

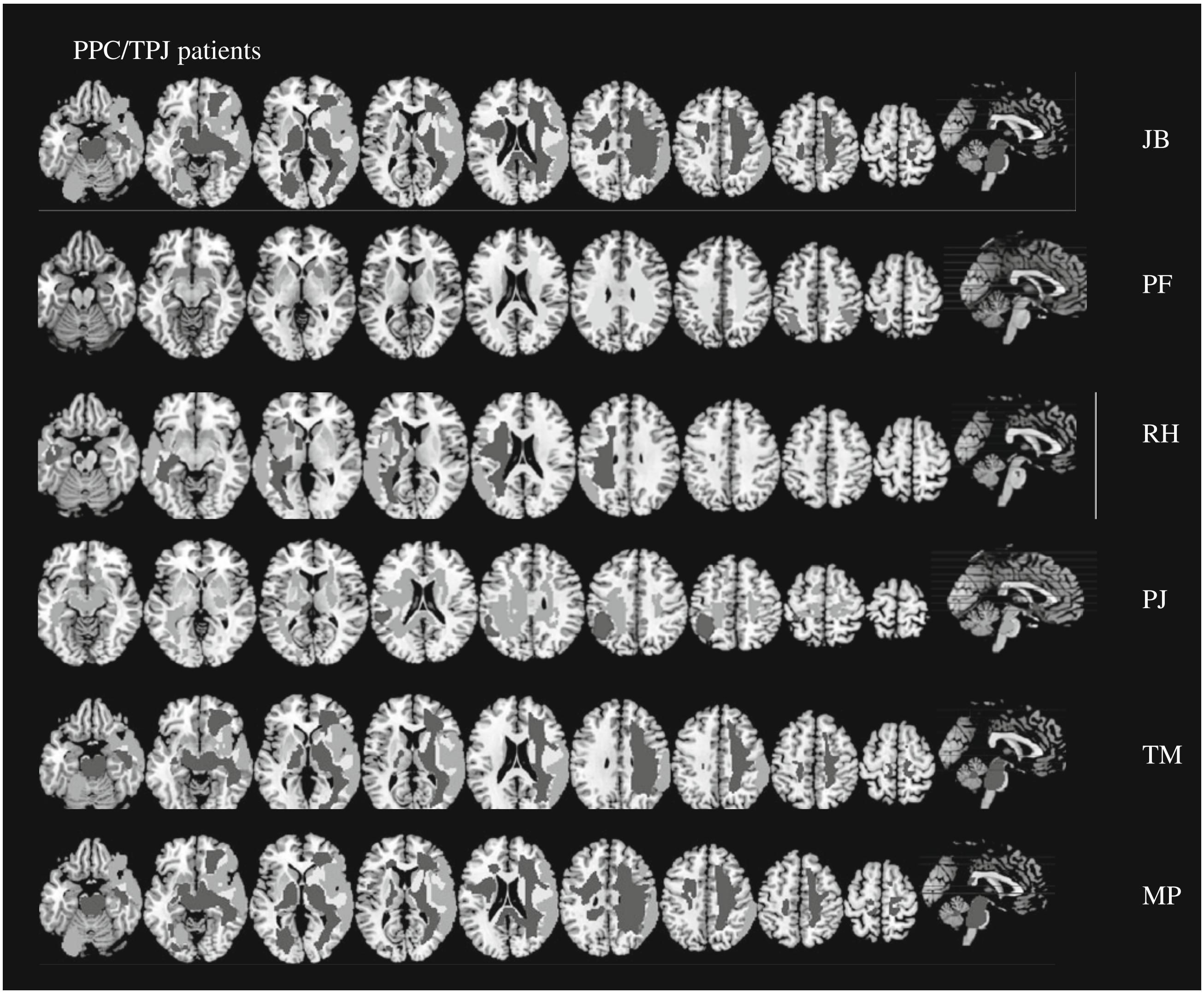


Fig. 1 Lesion transcriptions for the patients. The *figure* depicts T1 structural scans (taken at 3T, with a 1 mm isotropic resolution). Colored-in *light gray* areas and colored-in *dark* areas reflect, respectively, changes in gray and white matter in the patients relative to scans from 201 control participants aged 40+ with no history of brain lesion. The changes were detected using voxel-based morphological analysis in SPM5 (http://www.fil.ion.ucl.ac.uk/spm/software/SPM5), and they are overlaid here on a standard multi-slice template in MRIcron. The images were first segmented into gray matter, white matter, and cerebro-spinal fluid (*CSF*), and the resulting tissue classes images were normalized without modulation (i.e., to compensate for the effect of spatial normalization). Images were smoothed with a Gaussian kernel of 2 × 2 × 2 mm. The analyses are based on one sample *t*-tests with three covariates: healthy gray/white matter versus patient gray/white matter, age, and gender. All areas are FWE corrected with $P = 0.05$ and an extent threshold specifying that only significant blobs containing ≥100 voxels be included in the lesion

Apperly et al. (2004) and Samson et al. (2004). The clinical test required a judgement of false belief. The false belief task from Apperly et al. (2004) was adapted from Call and Tomasello (1999). This test was based on non-verbal videos designed to control for incidental processing demands. The task was to decide out which of two boxes contained a hidden object (non seen by the participant). A woman in the video was shown looking inside the boxes. On false belief trials, the woman left the room and in her absence, the locations of the two boxes were swapped. When the woman returned to the room, she offered the participant a clue about the location of the object by pointing to one of the two boxes. Given that the boxes swapped locations, this clue was wrong, but, provided the woman's false belief was taken into account, it could be used to infer the location of the object. This task generates a discrepant perspective between the participant and the woman as is standard in false belief tasks; however, since the participant does not know the location of the object, there is no conflict between the participant's self-knowledge and the inference

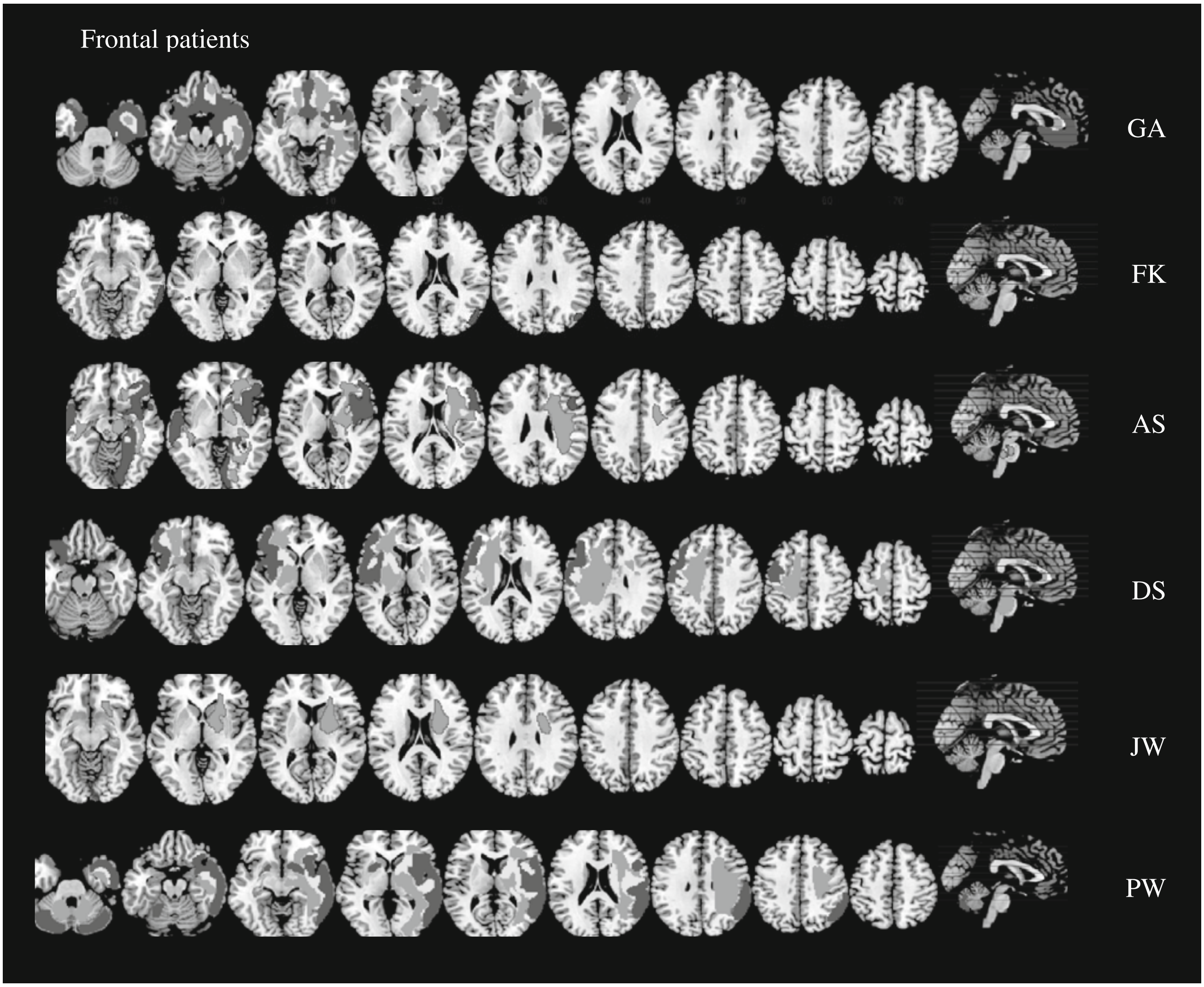


Fig. 1 continued

about the woman's belief, and hence any inference about the woman's belief should be less affected by any problems in inhibiting self-knowledge than is in the case in standard false belief tasks (where the participant has direct knowledge about the location of the hidden object). Apperly et al. (2004) reported that patients with both PPC/TPJ and frontal lesions were impaired on this task, though the frontal patients also failed on control conditions (not requiring inferences about the woman's beliefs), consistent with these patients lacking sufficient resources (e.g., working memory capacity) to perform the inferences. There were 12 false belief videos, and performance was taken as at chance or below if patients made 8 or fewer correct responses. The ToM patients either performed at chance on the ToM videos or below the control level on the clinical screen of ToM from the BCoS-social. The non-ToM patients were above chance and/or in the normal range on the clinical screen.

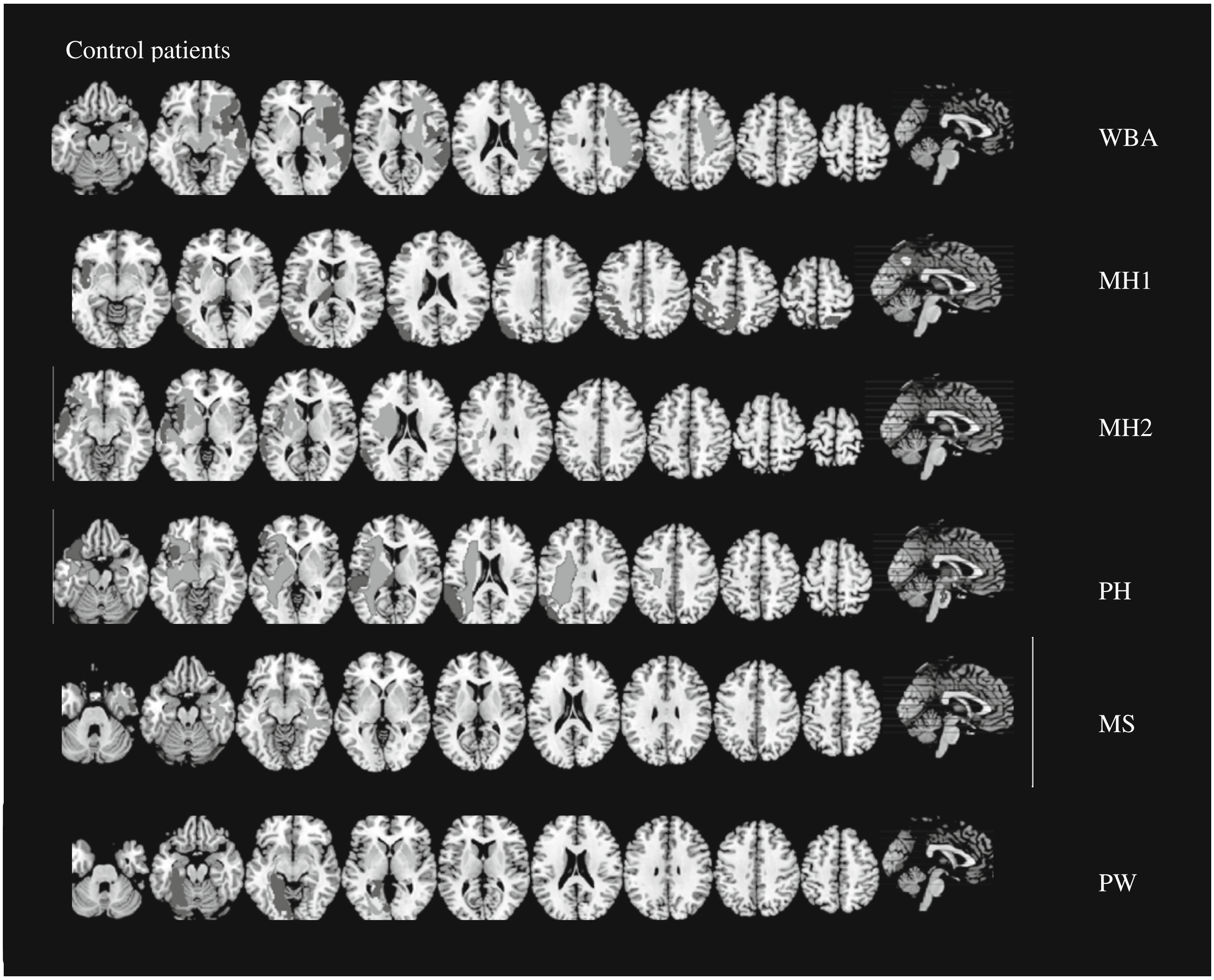
Apparatus

The stimuli were presented on a pc using eprime software (Psychological Software Tools, 2002). For all participants, single-handed responses were recorded using key presses (keys b and m).[1] The maximum number of patients within each group who made a left-handed response was 3 (the control patient group). We asked 3 of the normal control participants to respond with just their left hand and 3 responded with just their right hand (all were right handed).

Design and procedure

There was a 2 × 2 design in which the words LEFT and RIGHT (presented in capitals in Times Roman font 18)

[1] Note that some of the patients had a hemiplegia which made it impossible for them to make two handed responses.



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appeared equally often on the left and right sides of the screen. The words were centred 8 deg left or right of fixation, and each subtended a visual angle of 2 deg when viewed from 50 cm. The stimuli appeared 40 times at random in each condition, creating 160 trials. The task was to respond to the meaning of the words.

Experiment 1: standard Simon, single and joint go/nogo conditions

Method

There were three conditions: (i) standard Simon, (ii) single go/nogo, and (iii) joint go/nogo. In the standard Simon condition, participants performed the task alone and, respectively, made a left or right button press response to the words LEFT and RIGHT irrespective of the locations of the words on the screen. In the single go/nogo task, participants performed the task alone and made a forced-choice response to just one word (half responded to the word LEFT by pressing the key b, half responded to the word RIGHT by pressing the key m). In the joint go/nogo task, participants carried out the same go/nogo task as in the single go/nogo condition, but alongside a confederate (the second author) who responded to the alternative word. In the go/nogo conditions, half the participants within each group were assigned to respond to the word LEFT and half were assigned to respond to the word RIGHT. Participants responding to the word LEFT sat on the left of the confederate and participants responding to the word RIGFHT sat on the right of the confederate. The order of the three conditions was randomized across participants and they were performed on separate days.

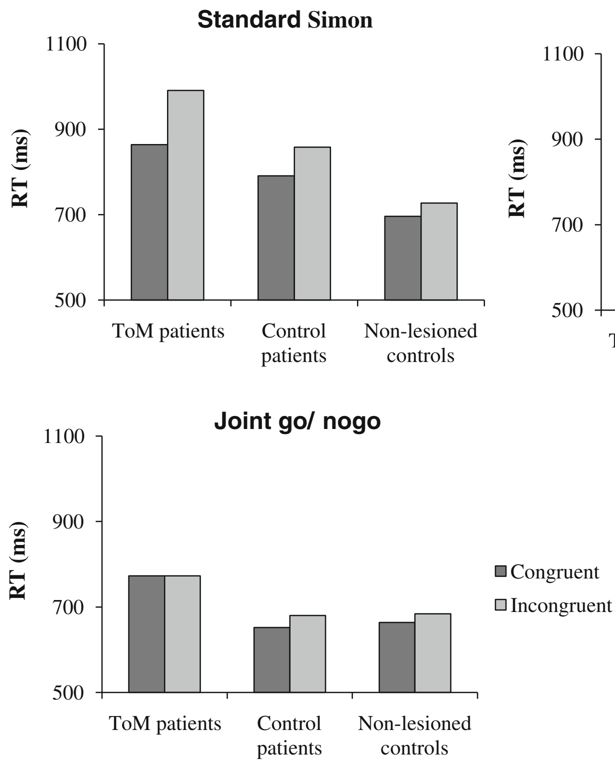

Fig. 2 Mean correct RTs in the standard Simon, single go/nogo and joint go/nogo tasks, for the ToM, control patients and non-lesioned control groups

Table 2 Mean error rates in experiments 1 and 2

	ToM: PPC/TPJ patients		ToM: frontal patients		Lesioned patient controls		Non-lesioned controls	
	Cong.	Incong.	Cong.	Incong.	Cong.	Incong.	Cong.	Incong.
Experiment 1								
Standard Simon	0.01	0.03	0.02	0.06	0.01	0.03	0.01	0.01
Single go/nogo	0.02	0.02	0.03	0.03	0.02	0.01	0.01	0.01
Joint go/nogo	0.01	0.01	0.03	0.02	0.01	0.02	0.00	0.02
Experiment 2								
Joint go/nogo	0.01	0.03	0.01	0.02				

Results

The mean correct RTs are presented in Fig. 2 and the errors in Table 2. The error rates were low for all groups and there were no signs of any speed-accuracy trade-offs. These data were not analyzed further.

Condition (i): standard Simon

We first assessed if the group of non-lesioned control participants and the control patients (who passed the ToM tasks) differed. The correct RTs were subjected to a mixed design ANOVA with the factors being congruence (word and location congruent or incongruent) and group (non-lesioned controls vs. patient controls). There was a reliable main effect of congruence ($F(1, 10) = 28.53$, $P < 0.001$) and group ($F(1, 10) = 6.11$, $P < 0.05$). The interaction was not reliable ($F(1, 10) = 3.73$, $P > 0.05$). For further analyses, the data from these two groups were pooled and the participants were considered as members of a single control group.

The control group was then compared with the ToM group (PPC/TPJ and frontal patients combined). There were reliable main effects of both congruence and group ($F(1, 22) = 89.13$ and 20.51, both $P < 0.001$), and a congruence × group interaction ($F(1, 22) = 18.79$,

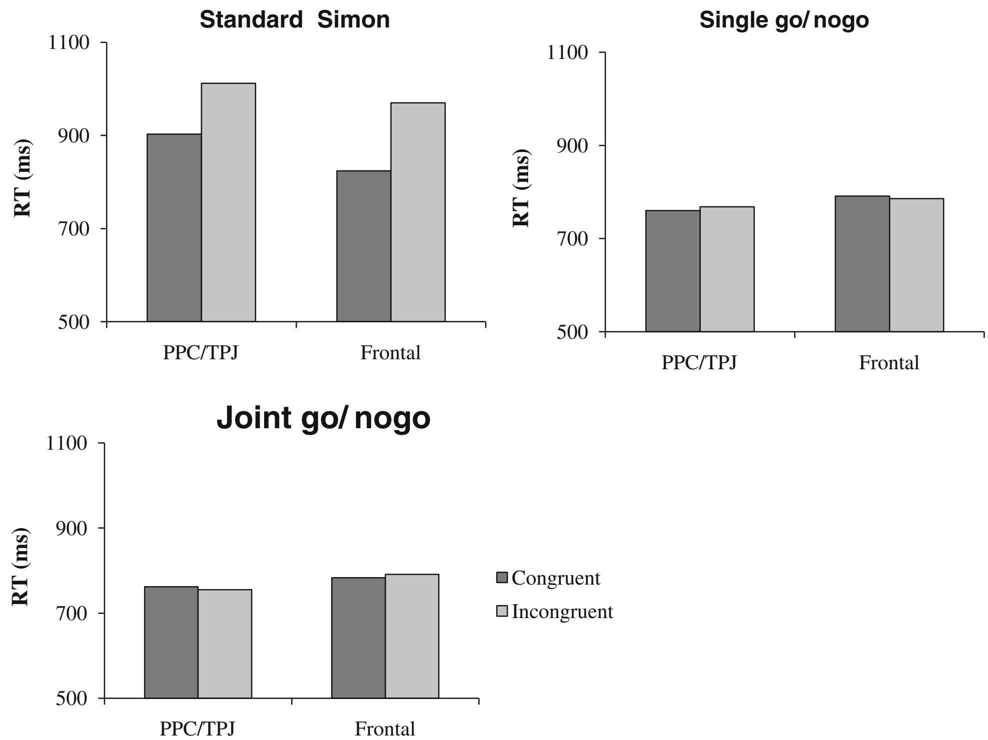

Fig. 3 Mean correct RTs in the standard Simon, single go/nogo and joint go/nogo tasks, for the sub-groups of PPC/TPJ and frontal ToM patients

$P < 0.001$). The magnitude of the spatial congruency effect was greater for the ToM patients than the control group ($t(22) = 3.67$, $P < 0.001$).[2] To assess if this result was driven by either the PPC/TPJ or the frontal patients with ToM difficulties, we also evaluated if there were differences between the two sub-groups of ToM patients. There was a main effect of congruence ($F(1, 10) = 73.56$, $P < 0.001$) but neither the effect of group nor the condition $\times$ group interaction were significant ($F(1, 10) = 2.63$ and 1.62, both $P > 0.05$). The magnitude of the congruency effects were larger for both the PPC/TPJ and frontal sub-groups compared with the controls ($t(16) = 3.29$ and 4.21, both $P < 0.01$). The ToM patients showed larger effects of congruency than the control participants, and there were no differences between the PPC/TPJ and frontal sub-groups of ToM patients (Fig. 3).

Condition (ii): single go/nogo task

The data were analyzed in the same manner as the results for the standard Simon task. An initial comparison was made between the non-lesioned controls and the patient controls. There were no effects: main effects of congruence and group both $F < 1.0$; $F(1, 10) = 1.13$, $P > 0.05$ for then interaction). Accordingly, the results for the two control groups were pooled for the further analyses.

The comparison between the control group (non-lesioned and patient controls) versus the ToM patients revealed no effects (all $F < 1.0$). There were also no differences between the sub-groups of ToM patients (PPC/TPJ patients vs. frontals). Taking all the ToM patients as one group and the controls as another failed to reveal any effect of congruence and no congruence $\times$ group interaction (both $F < 1.0$), though the ToM patients were overall slower ($F(1, 22) = 27.81$, $P < 0.01$). In the single go/nogo task, there were no effects of congruence and no differences in congruency effects between the different groups (see also Fig. 3).

Condition (iii): joint go/nogo task

As before, we first assessed if there were differences between the patient controls and the non-lesioned controls. Across these two groups there was a main effect of congruence ($F(1, 10) = 47.94$, $P < 0.001$) but no effect of group ($F < 1.0$) and no interaction ($F(1, 10) = 1.56$, $P > 0.05$). The data from the two groups were subsequently pooled for further analyses.

The comparison between the controls and the ToM patients showed effects of congruence ($F(1, 22) = 15.76$, $P < 0.001$), group ($F(1, 22) = 22.43$, $P < 0.001$) and a

[2] There was a trend for the control patients to show a larger congruency effect than the non-lesioned controls (see Fig. 2). However, there was a larger congruency effect for the ToM patients even when compared with the patient control group alone ($t(16) = 2.44$, $P < 0.05$.

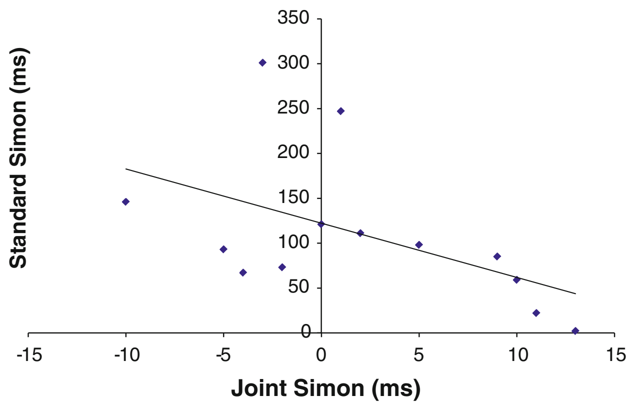

Fig. 4 Correlation between the magnitude of the standard spatial compatibility effect (incongruent—congruent RTs for the 2-alternative forced-choice task) and the spatial compatibility effect in the joint go/nogo condition (incongruent–congruent RTs)

reliable interaction ($F(1, 22) = 15.77$, $P < 0.001$). The magnitude of the congruency effect was larger for the control participants than the ToM patients ($t(22) = 3.97$, $P < 0.001$), and this held too for the comparison between just the patient controls and the ToM group ($t(16) = -3.48$, $P < 0.01$). A further comparison between the two sub-groups of ToM patients failed to reveal any differences. The main effects of congruence and group were not significant (both $F < 1.0$) and the interaction of group and congruence was not reliable ($F(1, 10) = 2.69$, $P > 0.05$; Fig. 3).

Correlations

To examine the relations between the congruency effects in the standard Simon condition and the joint go/nogo condition, we correlated the magnitude of the two congruency effects across the ToM patients. There was a reliable negative correlation (Person product moment, $r(24) = -4.39$, $P < 0.05$). Participants who showed a larger congruency effect in the standard Simon condition tended to have a lower congruency effect in the joint go/nogo condition (see Fig. 4).

Discussion

The data show clear contrasts in spatial compatibility effects both across the different versions of the Simon task (standard, single go/nogo, joint go/nogo) and across the different groups of participants. Under standard conditions (single participants, two-alternative forced-choice responses), all the groups showed a spatial compatibility effect, which was larger for the ToM patients than for the two control groups (lesioned patient controls and non-lesioned controls). The magnitude of the compatibility effects did not differ between the sub-groups of PPC/TPJ and frontal ToM patients. The control patients responded more slowly than the non-lesioned controls, and the control patients also tended to show larger effects of congruency. This last result likely reflects the general effect of sustaining a brain lesion on responding under relatively difficult alternative choice conditions. Neither the effects of spatial compatibility nor the effects of group were evident in the single go/nogo conditions. The data on spatial compatibility replicate prior work (Sebanz et al. 2003). More strikingly, differences between the groups emerged when go/nogo responding was carried out in the joint action condition, when complementary responses were made by a confederate. As previously reported (Sebanz et al. 2003, 2005b), an effect of spatial compatibility emerged for the control participants. This represents an effect of joint action and suggests (e.g.) that participants became aware of the spatial context of the responses when they acted jointly with the confederate. The result occurred with both lesioned and non-lesioned control groups. In contrast to the data from the controls, however, the ToM patients showed no evidence of a spatial congruency effect in the joint action condition. This was again true for both the PPC/TPJ and frontal ToM subgroups (Fig. 3). Thus, there was a double dissociation between the ToM patients presenting with a larger effect of spatial congruency under standard Simon conditions, and a smaller effect under joint action conditions. Consistent with this, there was a negative correlation across the ToM patients between the magnitudes of the standard and joint Simon effects—individuals who had large congruency effects under standard conditions tended to have smaller effects under joint action conditions (Fig. 4).

The data demonstrating that ToM patients failed to show a joint action effect seem at first sight to go against the results reported by Sebanz et al. (2005b), where autistic individuals manifested a joint action effect using a paradigm similar to that used here. However, as we have noted, the individuals tested by Sebanz mostly succeeded at ToM tasks, whereas the current patients all failed a first-order task with (to some degree) reduced processing demands (e.g., the requirement to inhibit self-knowledge). Hence, our results provide a stronger test of the relations between joint action and ToM, giving evidence that an impaired ToM does limit the ability to co-represent a joint action task. It may be that the requirement to represent a co-actor's thoughts is critical to generating a joint action effect, and this core process is disrupted in the ToM patients here. Alternatively, the ToM patients may lack specific component processes and/or sufficient resources to represent a co-actor, perhaps because all resources need to be devoted to the primary task if the patients are to operate successfully (cf. Apperly et al. 2004). This resource account fits with the negative correlation we observed between the congruency effects on standard Simon and joint action trials. If patients have impaired processing resources to support task performance, then they will tend to show a strong congruency effect in the standard Simon conditions, since they lack the capacity to deal efficiently with incongruent information. In addition, such patients will not have sufficient resources to encode the actions being undertaken by their co-actor in the joint action condition. The net result is that the patients do not manifest a spatial congruency effect in the joint action condition.

Although we observed differences between the ToM and control patients in terms of their sensitivity to joint action, the different patient sub-groups did not differ in terms of their general neuropsychological profile. Hence, if we do put forward a resource account of the lack of a joint action effect in the ToM patients, then we need to consider resources that might be specific to coding another person's beliefs (in ToM tasks) and the other person's actions (in the joint go/nogo task). One possibility here is the ability to represent more than your own perspective or actions, which may impose a particular load on social cognition.

These different accounts of the congruency data were assessed in more detail in Experiment 2. In this experiment, we only tested the ToM patients. However, in contrast to Experiment 1, we instructed them specifically to pay attention to what their co-actor was doing. Samson et al. (2005, 2007) suggested that patients may fail some ToM tasks because they fail to attend to important social cues that would enable normal ToM coding to take place. If this was critical for performance in Experiment 1, then the ToM patients may begin to manifest a joint action effect in the explicit instruction condition (Experiment 2). On the other hand, if the patients lack sufficient processing resources to take account of their co-actor, then they may still fail to show a joint action effect even when told to attend to their co-actor.

Experiment 2: explicit attention instructions

Experiment 2 examined the performance of the ToM patients from Experiment 1 on the joint action procedure (condition (iii), joint go/nogo task). In Experiment 1, no specific instructions were given to the patients. In Experiment 2, however, patients were told to pay attention to the actions that their co-actor performed. Would this lead to the patients generating a joint action effect, so that the spatial congruency of the words now affects performance?

Method

The Method was the same as for the joint action condition in Experiment 1. There were two main differences: (1) only the patients with ToM impairments were tested; and (2) the patients underwent more prolonged testing—completing 3 blocks of 160 trials each. The patients were assigned to the same word responses as in Experiment 1.

Results

The mean correct RTs are presented in Fig. 5 and the error rates in Table 2. As in Experiment 1, there were relatively few errors, there was no sign of a speed-accuracy trade-off, and the error data were not analyzed further.

The RT data were analyzed with congruency and block (1–3) as within-subjects factors and group as the between-subject factor (PC/TPJ vs. frontal patients). There were reliable main effects of block and congruency ($F(2, 20) = 55.90$ and $F(1, 10) = 77.38$, both $P < 0.001$, respectively). There were also interactions between congruency and group ($F(1, 10) = 17.67$, $P < 0.001$) and a 3-way interaction between congruency, group, and block ($F(2, 20) = 3.96$, $P < 0.05$).

The 3-way interaction was assessed by analyzing the data for the two patient sub-groups separately. For the PC/TPJ patients, there were reliable effects of congruency and block ($F(1, 10) = 59.26$ and $F(2, 10) = 20.99$, both $P < 0.001$). There was no interaction ($F < 1.0$). There was

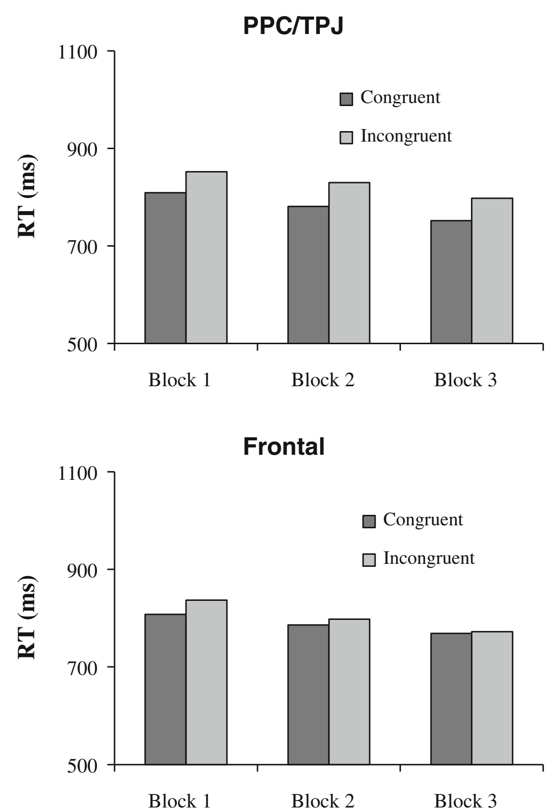

Fig. 5 Mean correct RTs in the joint go/nogo task for the ToM patients in experiment 2 (explicit attention instructions), with the data separated for the PPC/TPJ and frontal sub-groups

a reliable effect of congruency and faster RTs in the later blocks, while the congruency effect was maintained across the blocks.

For the frontal patients, there were again main effects of congruency and block ($F(1, 10) = 18.37$ and $F(2, 10) = 46.46$, both $P < 0.001$), but in this case there was a reliable congruency × block interaction ($F(12, 10) = 11.54$, $P < 0.01$). In the first block, the frontal patients showed a reliable congruency effect ($t(5) = 6.08$, $P < 0.01$). This effect was borderline for block 2 ($t(5) = 2.55$, $P = 0.051$) and not reliable for block 3 ($t < 1.0$).

Discussion

In contrast to Experiment 1, when there was no evidence for a spatial congruency effect for the ToM patients, Experiment 2 demonstrated that the patients could show a congruency effect when they were specifically instructed to attend to the co-actor. The results differed for the PPC/TPJ and frontal patients, however. The PPC/TPJ patients showed a congruency effect across the three trial blocks. This fits with the idea that these patients can process information about relevant others and can incorporate this information into their own task representation, but often fail to respond to the appropriate cues to do this (e.g., in Experiment 1), unless explicitly instructed (Experiment 2). The frontal patients showed a similar pattern, but, unlike the PPC/TPJ patients, the frontal patients were not able to sustain the coding of the other person across the trial blocks—the effects of congruency decreased across trials and were eliminated by block 3. These data are consistent with the frontal patients having insufficient processing resources to sustain the coding of their co-actor across the trials. Initially, the patients appear to attend to their co-actor and code the co-actor's response along with their own. The allocation of attention to the co-actor is resource-demanding, however, and as the trials proceed so the frontal patients appear to code their co-actor less, with the result that the joint action effect is eventually eliminated.

General discussion

We examined the effects of acquired brain lesions on the sensitivity of brain lesioned patients to joint action. We contrasted patients who failed a ToM task (Apperly et al. 2004; Samson et al. 2004) with non-lesioned and brain lesioned controls (the lesioned controls passed the ToM test). In Experiment 1, we found that the ToM patients tended to show larger effects of spatial congruency in a standard Simon task than the control participants (when two-alternative forced-choice responses were made). The effects of congruency in all groups were eradicated when participants made go/nogo responses. However, under conditions where a confederate responded to the alternative stimulus, in a contrasting spatial location to the participant, then the spatial congruency effect was re-established for the control participants (non-lesioned and lesioned controls alike) but not the ToM patients. This result provides a first link between ToM abilities and sensitivity to joint action. When directly tested (in Experiment 1), there was no difference between the PPC/TPJ and frontal patients with ToM deficits, and neither showed a congruency effect.

In Experiment 2, we re-tested the ToM patients, but in this case, we asked them to pay attention to the actions of the confederate. Under these conditions, effects of joint action began to emerge, even though individuals again made go/nogo responses as before. However, there were then differences in the performance of the PPC/TPJ and frontal patients. The PPC/TPJ patients showed consistent effects of joint action across 3 trial blocks. In contrast, the frontal patients initially showed reliable effects of joint action, but these effects decreased across the trial blocks and were not reliable in the third block. These results indicate that, although both the PPC/TPJ and frontal patients can fail on ToM tasks, they may do so for different reasons (see Apperly et al. 2004; Samson et al. 2005, 2007).

To explain the data with the parietal patients, we suggest that the basic ability to represent the mental state of another person can be reasonably preserved, but the patients can fail on ToM tasks because they fail to spontaneously pay attention to the cues that signal the other person's mental state. Under joint action conditions, a failure to attend to the other person's actions can result in a failure to develop a joint representation of the task. For example, the patients may fail to encode the spatial location of their co-actor or fail to note the responses that the co-actor is making, and this lack of awareness of their the relative locations and/or the relative responses being made may render the patient indifferent to the normal influence of the other person. Guagnano et al. (2010) presented evidence that the social Simon effect is stronger when individuals are spatially proximal rather than when they are more distant, and spatial coding of the relative positions and responses of each actor, within a common spatial representation, may be important for generating the effects. If the patients do not code this information, then a null effect of spatial congruence will emerge. However, if explicitly instructed to attend to the co-actor (e.g., to note the spatial location of their co-actor or the items being responded to), the PPC/TPJ patients have the capacity to develop a joint representation of the task and to show joint action effects.

In this study, the frontal patients also showed sensitivity to joint action when cued to attend to the confederate, but they failed to sustain this over time. One account for this is that the frontal patients had difficulty in marshaling enough processing resources to code both the actions of the confederate and to maintain their own actions. When the actions of the confederate were highlighted, the patients appeared able to code the other's actions for a short period, but perhaps because of the effort required for this, the coding of the other person's actions decreased over time, eliminating the joint action effect. Here, again the data suggest that the basic ability to develop joint representations is present in such patients, but the patients find this taxing because it involves a greater cognitive load relative to when they only have to code the stimulus–response rules for a single go/nogo response. Given that the patient sub-groups did not differ in other respects (Table 2), the apparent load effects here may be specific to coding another's person's actions.

Though our data point to there being a relationship between ToM and joint action, we should be cautious in making conclusions about the precise nature of this relationship. For example, we do not think our data point to the necessity of having "full" ToM abilities in order to show sensitivity to joint action, nor do the data indicate that the patients were able to achieve these full ToM abilities when cued to attend to the confederate—though this may be the case. We can propose either "basic representation" or a "full ToM" accounts of the data. According to the "basic representation" account, a joint action effect may be generated in the "social Simon" paradigm if individuals register that the co-actor is responding to the alternative stimulus and that both stimuli have a associated relationship to the spatial location of the required response—both the PPC/TPJ and frontal patients may be able to achieve this rudimentary representation of the other person's actions when cued to attend to the co-actor—though the two sub-groups of patients may fail to do this spontaneously for different reasons (in Experiment 1: a failure to code socially significant cues [PPC/TPJ patients] or a failure to marshal sufficient resources [frontal patients]) (see Guagnano et al. 2010, for an argument along these lines). On the other hand, a "full ToM account" would suggest that the ability to represent the intentions/goals of the other person, and then to incorporate these goals into their own representations of the task, are necessary to the joint action effect. This ability to represent the goals of the co-actor requires ToM capability. It may be that the ToM patients are able to code the intentions and goals of others when cued appropriately (i.e., both groups are then capable of achieving a full ToM representation). Further work is required to tease apart these possibilities—including assessing the effects of cueing patients to attend to socially informative cues in tasks designed to test increasingly higher-levels of representation of the actions and mental states of others. For now, the data indicate that acquired deficits in ToM can disrupt sensitivity to joint action, while patients with different lesions may lack a joint action effect for contrasting reasons.

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