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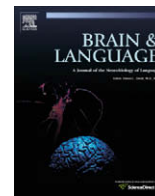
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## Theory of Mind in adults with right hemisphere damage: What's the story?

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## ABSTRACT

Why do people with right hemisphere damage (RHD) have difficulty with pragmatics and communication? One hypothesis has been that pragmatic impairment in RHD is the result of an underlying impairment in Theory of Mind (ToM): the ability to infer the mental states of others. In previous studies evaluating ToM abilities in people with RHD, researchers have used judgment tasks based on story or still cartoon stimuli. However, ToM is likely to draw on kinetic information as well, and these tasks ignore this aspect. The aim of this study was to assess ToM abilities in people with RHD using participants' evaluations of animated films with moving geometric shapes. Participants were presented with eight films of animated triangles. Four of the films represented the triangles as intentional agents with mental states, while the other four represented the triangles as simply inanimate, though moving, objects. Films were evaluated by both button-press response and by oral descriptions. Analysis of the transcriptions revealed that participants with RHD had a reduced ability to discriminate between the film categories, and a bias toward reduced mental-state ascription in the ToM condition.

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## 1. Introduction

The importance of the left cerebral hemisphere in supporting language has been known since the 1800s, and there has been a massive amount of research on this topic. The past few decades, however, have seen a growing awareness that the right hemisphere may also make important contributions to our ability to use language, particularly in the context of daily social interactions (Myers, 1999; Tompkins, 1995).

People with right hemisphere damage (RHD) can show a variety of language-related impairments, which tend to lie at least partially within the realm of pragmatics (Cummings, 2007). This can include impairment on tasks tapping humor comprehension (Bihrlé, Brownell, Powelson, & Gardner, 1986; Brownell, Michel, Powelson, & Gardner, 1983; Winner, Brownell, Happe, Blum, & Pincus, 1998), indirect requests (Brownell & Stringfellow, 1999; Foldi, 1987; Hirst, LeDoux, & Stein, 1984; Stemmer, Giroux, & Joannette, 1994; Weylman, Brownell, Roman, & Gardner, 1989), and narrative (Brownell, Potter, Bihrlé, & Gardner, 1986; Schneiderman, Mura-sugi, & Saddy, 1992; Wapner, Hamby, & Gardner, 1981).

It has been suggested that an underlying deficit in Theory of Mind (ToM) may be the cause of these pragmatic impairments (Brownell, Griffin, Winner, Friedman, & Happé, 2000; Griffin et al., 2006; Happé, Brownell, & Winner, 1999; Martin & McDonald, 2003; Winner et al., 1998). Briefly, ToM refers to the ability to infer the mental states of others. According to this account, successful communication rests on the ability to make inferences about the mental states of one's interlocutor. The idea that impairments in humor, indirect requests, and narrative comprehension might be related to difficulty in attributing mental states finds theoretical support in Sperber and Wilson's (1986) Relevance Theory, which proposes a central role for the attribution of and understanding of mental states in all communication. The relationship between mental-state attribution and comprehension of non-literal language has also been demonstrated experimentally in people with autism (Happé, 1993).

To date, empirical support for a deficit in ToM in people with RHD has been suggestive, but inconclusive (Weed, 2008), perhaps due to the type of experimental task used to measure social cognition. Tasks often require making judgments about the mental states of characters in single-frame cartoons, or in short stories. This type of task has been criticized, however, most prominently by Tompkins, who points out that these tasks usually require making meta-linguistic judgments about hypothetical situations, and may not accurately measure the underlying cognitive processes

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in question (Tompkins, Scharp, Fassbinder, Meigh, & Armstrong, 2006, 2008).

A more direct means of assessing participants' ability to impute mental states may be to measure their capacity to intuitively anthropomorphize. The spontaneous use of anthropomorphic language when describing animated objects moving and interacting in a purposeful way is a robust and well-known effect (see Rimé, Boulanger, Laubin, Richir, & Stroobants, 1985 for a review). However, to our knowledge, animated geometric-shape stimuli have not yet been used to measure social cognition in people with damage to the right hemisphere. Body movements are an important reflection of an agent's intentions, and the importance of this kinetic information in mental-state attribution cannot be assessed using stories or line drawings.

Frith and Happé have developed a set of short, animated sequences involving moving geometric shapes (Abell, Happé, & Frith, 2000; Castelli, Happe, Frith, & Frith, 2000). Based on the classic experimental stimulus used by Heider and Simmel (1944), these new stimuli consist of several animations in three categories: ToM (animations intended to evoke spontaneous anthropomorphizing), Random (animations in which the geometric shapes moved in a self-propelled fashion, but were not intended to evoke an anthropomorphic reading) and Goal-Directed (a middle category, intended to evoke a description of intention, but not explicit reference to mental states). All stimuli featured the same two triangles, one small and one large, as the protagonists. For example, in one of the ToM animations, the small triangle appears to tease the large triangle by knocking on a door, and then hiding when the large triangle pokes its head out and looks around. In contrast, a typical animation from the Random category has the two triangles moving mechanically back and forth across the screen, or bouncing aimlessly like billiard balls. The triangles have no other features that would suggest an anthropomorphic reading, such as eyes or faces; it is the human-like movement alone that promotes an anthropomorphic reading of the ToM films and differentiates them from the other films (Scholl & Tremoulet, 2000). Samples of the stimuli can be seen at <http://sites.google.com/site/utafrih/research>.

Frith and colleagues have validated these animations with a healthy population and used them to investigate ToM in children with autism (Abell et al., 2000), in a woman with medial frontal brain damage (Bird, Castelli, Malik, Frith, & Husain, 2004), and in healthy participants in a brain-imaging experiment (Castelli et al., 2000). Other groups have used the animations to evaluate ToM abilities in women with Turner syndrome (Lawrence et al., 2007), in relation to fetal testosterone levels (Knickmeyer, Baron-Cohen, Raggatt, Taylor, & Hackett, 2006), high-IQ children with autism (Campbell et al., 2006), alexithymia (Moriguchi et al., 2007), and schizophrenia (Russell, Reynaud, Herba, Morris, & Corcoran, 2006). The aim of this study was to use these same animated stimuli as a new means of assessing ToM in people with RHD.

## 2. Methods

### 2.1. Materials

Eight animations were selected from the animations used by Abell et al. (2000): the four 'Random' animations and the four 'ToM' animations from the original experiment. We did not use the middle category ('Goal-Directed') for this experiment; pre-testing indicated that these were more ambiguous, and we assumed that the two extremes would give the clearest results, while reducing the amount of time we required patients to attend to the task. Two of the unused animations were used in the practice session. A detailed description of the stimulus materials, their development,

and validation can be found in Abell et al. (2000). The stimulus animations were presented using the software extension Cogent 2000 (Wellcome Department of Imaging Neuroscience, University College London, London, UK; <http://www.fil.ion.ucl.ac.uk>) for MATLAB (Mathworks Inc., Sherborn, MA, USA), and oral descriptions of the animations were recorded using an Olympus digital voice recorder.

### 2.2. Testing procedures

All participants were tested in a quiet room. Prior to testing, the participants in the RHD group were given a clinical evaluation for hemispatial neglect. In addition, the participants were shown a picture on the computer screen, and were asked to describe what they saw in each of the four corners. All participants were able to satisfactorily describe the entire picture. Participants were instructed to view each film and then judge, by means of button-press, whether or not the film suggested a story to them, following which they were asked to describe the film they had just seen aloud. Participants completed two practice trials with the experimenter present, to insure they had understood the instructions. The experimenter then left the room while the participant completed the rest of the test alone.

The animations were presented in a randomized order on a computer screen. Following each animation, the participant was presented with the on-screen question "Synes du der var en historie?" (do you think/feel there was a story?). The wording of this test question was designed to encourage participants to rely on their intuitions about the films, rather than to make a more calculated judgment. Participants responded to this question by button-press. Following the button-press response, an on-screen instruction appeared asking participants to describe the animation they had just seen. Both the button-press and oral description tasks were self-paced.

### 2.3. Coding procedures

The oral descriptions were transcribed and coded by the primary investigator and two independent coders. The independent coders were both graduate students at the University of Aarhus, and were native speakers of Danish. Prior to coding, the individual transcriptions were randomly mixed together, so that the coders had no information about the identity of the speaker, or to which group the speaker belonged.

### 2.4. Coding for ToM

Transcripts were first categorized according to the procedure described by Abell et al. (2000), adapted to Danish. Each film description was categorized as either (1) a description of action, with no ascription of either intentional or mental states to the triangles, (2) a description in which the speaker appeared to ascribe intentions to the triangles, but made no reference to specific mental states, or (3) a description in which specific mental states are ascribed to the triangles. Although we did not use the Goal-Directed category from the original set of animations, we felt it was important to maintain the intentional language coding category, as this would allow for a more fine-grained analysis of the participants' descriptions.

Following Abell et al. (2000), descriptions such as "the red one tried to knock the blue one over" were categorized as ascribing *intentions* but not *mental states*. Verbs such as "to try" were not sufficient to categorize a description as a mental state description. However, a description such as "... it was a shy person on his way in, who knocked on the door but is a little bashful..." were categorized as mental state descriptions. In this example, the key

word is “bashful”, as this makes an explicit reference to the internal mental states of the character.

### 2.5. Coding for attribution of intentions

Using the mental-state coding rules, adapted from Abell et al. (2000), neither the control group nor the RHD group made many references to mental states at all. On closer examination, however, it seemed that both groups used many expressions that implied mental-state attribution, although the mental states were not mentioned *explicitly*. As an example, consider the following: “The red had caught the blue and put it in jail and guarded the entrance, and then the little one runs away at the end and the red goes out after it”. In this description, taken from our data, there were no words that explicitly ascribed a mental state to the triangles. Nonetheless, several of the phrases, such as “put it in jail and guarded the entrance” and “the little one runs away” certainly seem to *imply* that the speaker is attributing mental states to the triangles. Putting the blue triangle in jail and guarding the entrance implies that the red triangle *desires* that the blue triangle remain imprisoned, and “the little one runs away” implies that the little triangle *wants* to escape but is *aware* that the red one wants to keep it imprisoned. We therefore performed a second coding procedure, in which coders counted instances of expressions suggesting attribution of intentions to the triangles. Each transcription was first divided into linguistically meaningful phrases, consisting of a subject, a verb, and an object, to the degree that this was possible given the spontaneous spoken material. The coders underlined each whole phrase that they felt implied an ascription of intentions by the speaker to the triangles, and the number of underlined phrases was divided by the total number of phrases in each transcription to give an index of intention-ascription that was independent of the total number of words spoken in each description.

### 2.6. Participants

Participants with RHD ( $N = 11$ , 8 male, median age 65 years) with their first clinical stroke (Table 1) were recruited from the body of patients admitted to the Hammel Neurorehabilitation and Research Center in Hammel, Denmark. Only participants with right hemisphere cortical lesions were included. All participants were right handed. Lesions were located by CT or MRI-scans and ischemic lesions were classified in accordance with the Bamford classification system (Bamford, Sandercock, Dennis, Burn, & Warlow, 1991). An overall index of disability was estimated using the functional independence measure (FIM), an 18-item, 7-level scale that rates the ability of persons with disabilities to perform independently in self-care, sphincter control, transfers, locomotion,

communication and social cognition (Ottenbacher, Hsu, Granger, & Fiedler, 1996). A total score is obtained by summing the scores across all 18 items; scores range from 18 (maximally dependent) to 126 (maximally independent). All participants gave written informed consent to participate in the study. The local ethical committee reviewed and approved the study, and the experiment was conducted according to the standards set by the Declaration of Helsinki. The non brain-damaged (NBD) control group ( $N = 10$ , 4 male, median age 65 years) was matched as closely as possible for years of education. The control participants reported that they were not using any medication that affected their cognitive function, nor had they incurred any form of brain damage. All participants were native speakers of Danish.

## 3. Results

### 3.1. Button-press task

The RHD group performed at about chance level in the button-press task, making more errors (NBD:  $M = 2.14$ ,  $SD = 1.86$ ; RHD:  $M = 3.82$ ,  $SD = 0.75$ ) than the NBD group ( $t(7) = 1.9$ ,  $p < 0.05$ , one-tailed). An error was defined as categorizing an animation from the Random Action condition as a story, or categorizing an animation from the ToM condition as a non-story.

### 3.2. Coding for theory of mind

Inter-rater reliability for the first, categorical coding procedure was satisfactory (mean pairwise Cohen's kappa = 0.488). Both the RHD group and the NBD group used relatively little language that could be categorized as ascribing specific mental states to the triangles. There were no substantial differences between the groups in the total number of description types used for any one category; both groups used roughly equal amounts of Action, Intention, and Theory of Mind descriptions. There was a difference, however, in the way the groups differentiated their language (Fig. 1).

The three description types were first assessed together in a MANOVA. There was a significant main effect for condition ( $F(2, 37) = 4.849$ ,  $p < 0.05$ ) and a significant group by condition interaction ( $F(2, 37) = 3.796$ ,  $p < 0.05$ ). There was no significant main effect for group ( $F(2, 37) = .57$ ,  $p = 0.57$ ). A separate ANOVA was then performed on each of the three description types. For action descriptions, there was a significant main effect of condition ( $F(1, 19) = 8.014$ ,  $p < 0.05$ ), and a significant condition by group interaction ( $F(1, 19) = 7.140$ ,  $p < 0.05$ ). For ToM descriptions, there was a significant main effect of condition ( $F(1, 19) = 13.209$ ,  $p < 0.05$ ), and a significant condition by group interaction ( $F(1, 19) = 5.999$ ,  $p < 0.05$ ). For descriptions coded as descriptions

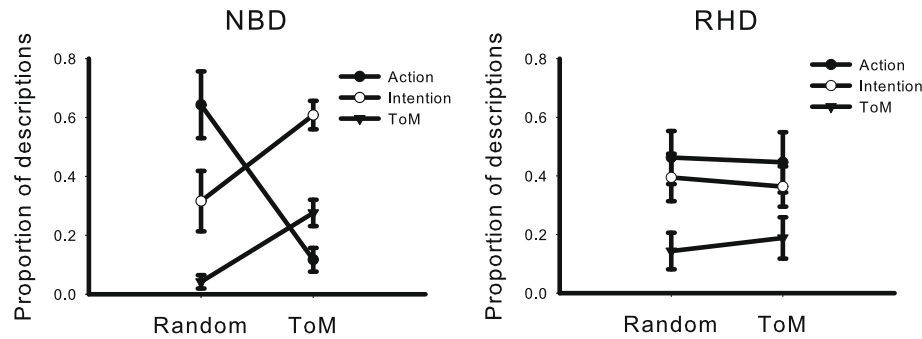
**Table 1**  
Description of participants with right hemisphere lesion.

Participant	Diagnosis	Location <sup>a</sup>	Gender	Age	FIM <sup>b</sup>	Months since stroke
1	Hemorrhage/infarction	Frontal <sup>a</sup> TACI	Male	71	110	3
2	Hemorrhage	Frontal	Female	67	116	4
3	Infarction	TACI	Male	63	<sup>c</sup>	5
4	Hemorrhage/infarction	Frontal + TACI	Female	46	34	7
5	Infarction	PACI	Male	61	93	3
6	Infarction	TACI	Male	57	121	2
7	Hemorrhage	Frontal <sup>a</sup> PACI	Female	52	104	3
8	Hemorrhage	Temporo-parietal	Male	73	103	1
9	Infarction	PACI	Male	155	57	2
10	Hemorrhage	Fronto-parieto-temporal	Male	159		1
11	Infarction	TACI	Male	63	116	3

<sup>a</sup> Bamford classification (TACI = total anterior circulation infarct, PACI = partial anterior circulation infarct).

<sup>b</sup> Functional independence measure, range (18–126).

<sup>c</sup> Missing value.

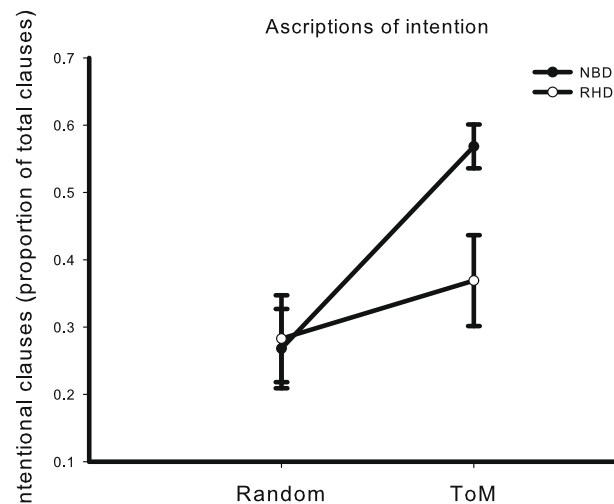


**Fig. 1.** Proportions of description types for the two film categories (Random Action and ToM). Proportions reflect averages across all coders. Error bars represent standard error of the mean.

of interaction without reference to specific mental states, the NBD group used nearly twice as many of these descriptions in the ToM condition as in the Random Action condition (ToM:  $M = 0.6$ , Random Action:  $M = 0.31$ ), while the RHD group did not differentiate greatly between the categories (ToM:  $M = 0.36$ , Random Action:  $M = 0.39$ ). However, this condition by group interaction failed to reach significance in the mixed-model ANOVA ( $F(1, 19) = 3.001$ ,  $p = 0.09$ ) (Fig. 1).

### 3.3. Coding for attribution of intentions

Inter-rater reliability for the second coding procedure was good (average measures intraclass correlation = 0.679). The proportions of the total number of clauses coded as intentional language by the three coders for the individual descriptions were averaged together, resulting in a mean score for each item. These item means were then averaged, resulting in an overall proportion of intentional language for each participant for each condition (Fig. 2). These mean scores were tested with a mixed-model ANOVA. There was a significant main effect of condition ( $F(1, 19) = 22.7$ ,  $p < 0.001$ ) and a significant condition by group interaction ( $F(1, 19) = 6.96$ ,  $p < 0.05$ ). As Fig. 2 illustrates, the interaction effect was driven by a difference between groups in the ToM condition, and a separate  $t$ -test (two-tailed) performed solely on the data from the ToM condition supported this;  $t(19) = 2.57$ ,  $p < 0.05$  (see Table 2).



**Fig. 2.** Mean proportion of total number of clauses coded as indicating an ascription of intentions. Error bars represent standard error of the mean.

**Table 2**  
Individual results for RHD group.

Participant (RHD group)	Proportion of descriptions of ToM stimuli using action language (ToM as act)	Number of "no" answers to button-press question 'do you feel there was a story?'	Number of errors on button-press task (out of eight possible)
1	0	2	2
2	0	0	4
3	1	3	4
4	0.66	6	4
5	0.08	0	4
6	0.33	8	4
7	0.83	8	4
8	0.41	4	5
9	0.33	4	4
10	0.5	2	3
11	0.75	2	4

## 4. Discussion

We found that the RHD group displayed a reduced ability to discriminate between the stimulus categories, and a bias toward reduced ascription of mental states in the ToM condition. In the following, we discuss these findings, and relate them to current issues in the literature.

### 4.1. The two coding procedures

The coding procedure used by Abell et al. (2000) only allows for a description to be counted as a ToM "hit" when the description includes an explicit reference to a mental state, for instance, "to feel bashful." This is a fairly strict procedure, and it excludes a good number of descriptions that might otherwise seem to imply the ascription of mental states. However, we felt it important to include this procedure for two reasons. First, since this was the first time these stimuli had been used to investigate ToM in an RHD group, we felt it important to maintain a certain degree of continuity with previous studies using the same stimuli.

Our second reason for distinguishing between language that made explicit reference to mental states and language that merely referred to intentions was to avoid accidentally coding metaphoric or ambiguous phrases as instances of ToM. For instance, one might say something like "the road approached the city." Although the word "approach" might suggest a sort of intentional movement, the speaker of this sentence probably does not actually mean to ascribe a mental state to the road.

At the same time, there were passages of text, such as the one cited above with the triangle that "guarded the entrance", which seemed to imply that the speaker was attributing mental states



to the triangles, but which counted as ToM “misses” according to the first coding procedure. Since our interest was in trying to measure the participants’ ascriptions of mental states to the triangles, and not the linguistic form used to express the ascription, we performed the second coding procedure as well. This second procedure was based more heavily on the coders’ intuitions about the speakers’ ascriptions, rather than strictly on the linguistic form as in the first coding procedure. Although the coding procedures were slightly different, the main results were similar in both cases.

#### 4.2. *Reduced ability to discriminate*

The two film categories were distinguished solely by the motion of the triangles. Although the triangles moved and came in close contact with each other in both categories, only in the ToM animations did this movement strongly suggest an interaction between two sentient beings with intentions toward one another; the movement in the Random Action category was mechanical.

The RHD group was less able than the NBD group to accurately categorize the films by button-press. The question (“do you feel there was a story?”) was open-ended, and members of the NBD group did also categorize some of the Random Action animations as ToM. The RHD group, however, appeared to make their categorical decisions at random. As indicated by Fig. 1, the NBD group varied their language according to the stimulus condition, while the RHD group did not. As shown in Fig. 2, this was also true of the second coding procedure, in which the RHD group did not modulate their language in terms of the amount of “intentional” clauses used when describing the films. The NBD group, in contrast, increased the amount of ascriptions of intentions when viewing the ToM films significantly more than the RHD group. Together, these results suggest that the RHD group either had difficulty perceiving or, having perceived, difficulty making use of the kinetic information embedded in the films when making their categorical decisions or describing the films.

#### 4.3. *Complex motion perception*

Two of the RHD participants in the present study had incurred temporal-parietal damage, as confirmed by either MR or CT scan. Five others had lesions clinically diagnosed as a total anterior circulation infarct, which is likely to have affected large areas of the right hemisphere, including temporal and parietal areas. A number of studies have indicated that a temporal region, encompassing the posterior superior temporal sulcus (pSTS) and the adjacent posterior superior temporal gyrus (pSTG), plays a crucial role in the perception of complex motion, including intentional and biological motion.

Although both the left and right pSTS/pSTG seem to be involved in biological motion perception, there is some evidence that the right pSTS may be of particular importance. Saxe, in particular, has argued for a special role for the right temporal sulcus in biological motion and social cognition (Saxe, 2006; Saxe & Wexler, 2005; Saxe, Xiao, Kovacs, Perrett, & Kanwisher, 2004), and Grossman et al. (2000) found the right STS to be more active than the left during biological motion perception. Saygin (2007), however, reports impairments among both RHD and LHD (left-hemisphere damage) participants in a biological motion task.

Closely related to the perception of biological motion is the perception of animacy. In two PET studies using the same animated stimuli that we used in the present study, Castelli et al. (2000) and Castelli, Frith, Happe, and Frith (2002) have found activation around pSTS related to perception of the triangles as intentional agents. Schultz, Imamizu, Kawato, and Frith (2004) and Schultz, Friston, O’Doherty, Wolpert, and Frith (2005) report from fMRI studies using similar animated geometric shapes, in which anima-

tions representing intentional actions elicited increased activation in pSTS and pSTG. Although the stimuli used in these studies were not, strictly speaking, biological motion stimuli of the point-light sort, they suggested animacy, and elicited activation in the same areas often implicated in point-light studies of biological motion (Blake & Shiffrar, 2006).

Taken together, these studies are strong evidence for the importance of the pSTS and pSTG, areas likely to be affected in many of the RHD participants in the present study, in the perception of both biological and animate, intentional motion. This would account for the RHD participants’ reduced ability to discriminate between the stimulus conditions. If participants from the RHD group were impaired in their ability to perceive animacy and intentionality because of damage to pSTS or pSTG, this information, which is critical for both the categorization and description tasks, would be unavailable to them. An impairment in perception of animacy could also explain the bias toward reduced mentalizing in the ToM condition seen in the RHD group. Perception of biological motion, animacy, and intention are thought to be key elements in an extensive brain network responsible for social cognition (Frith, 2007). Ascribing intentions and mental states to the animated triangles relies on the ability to extrapolate beliefs, desires, and goals from the kinetic information embedded in the animations. Without access to or with reduced access to the perception of biological/animate motion, participants would have difficulty describing what the triangles might be doing or thinking.

#### 4.4. *Damage to frontal systems*

Although an impairment in perception of animacy resulting from damage to the pSTS/pSTG region seems a likely explanation for our results, it is also the case that not all of our RHD participants had damage to this area. At least one of the participants had solely frontal damage, and several had frontal damage in addition to potential temporal and parietal damage. Might there then also be a frontal component to the impairments we observed?

Four of the participants from the RHD group (numbers 2, 5–7) stood out from the others, because they seemed to have a strong inclination to apply a single interpretive frame to all of the films. These four participants answered consistently either “yes” or “no” to the question “do you feel there was a story?” for all films. Furthermore, their verbal descriptions of these same films suggest that they interpreted the eight films as a single film in eight episodes, rather than eight separate films, each with their own storyline.

Although we had no tools to assess this point quantitatively, this appeared to be a tendency among many members of the RHD group. One seemed to see all eight films as installments in an extended battle of wills between the triangles, saying at one point: “. . . [the film] ends with the remaining triangle enjoying total hegemony over the area. We shall see. . . I do not think it will – I think there will be a continuation” and at another point, “. . . the fight ends with the red one driving the blue one out, but one is nonetheless certain that there will be a continuation – they are not finished with this business!” Another participant from the RHD group begins a description of a new film by saying, “We continue the story. . .” and a third begins a description by saying “This story is, in fact, the same. . .”. Other members of the RHD group seemed to adopt a “physical story” frame, narrating all of the films in terms of the physical movements of the triangles, and making little or no mention of intentional, emotional, or mental states.

This is compatible with much of the earlier research on RHD and right-hemisphere processes in general, such as Coulson’s idea that impaired frame-shifting may explain people with RHD’s reported difficulties with humor comprehension (Coulson & Sevens, 2007; Coulson & Williams, 2005), Tompkins’ idea that a suppression deficit may undermine people with RHD’s ability to

revise inferences (Tompkins, Baumgaertner, Lehman, & Fassbinder, 2000; Tompkins, Baumgaertner, Lehman, & Fossett, 1997; Tompkins, Lehman-Blake, Baumgaertner, & Fassbinder, 2001), as well as classic work on the integration of information in humor and narrative comprehension in people with RHD (Brownell et al., 1986; Wapner et al., 1981).

An ongoing debate in the literature has been the extent to which the discourse impairments observed in people with RHD are the result of damage to the right hemisphere in *general*, or whether it is more specifically *frontal* damage that causes discourse impairment (Channon et al., 2007; Cheang & Pell, 2006; Shamay-Tsoory, Tomer, & Aharon-Peretz, 2005; Shammi & Stuss, 1999). Results reported by Aron and others (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Aron, Robbins, & Poldrack, 2004) suggest a special role for the right inferior frontal cortex in the suppression of initially-activated scripts in favor of others. Although Shallice, Stuss, Picton, Alexander, and Gillingham (2008) do not ascribe the same importance in suppression to the right frontal cortex that Aron et al. (2003, 2004) do, they do see an important role for the right frontal cortex in *task-monitoring*, that is, deciding when it is time to switch from one task to the other. Both interpretations are consistent with the idea that patients with RHD have difficulty in using context, or in the case of the present study, visual kinetic cues, to choose the appropriate interpretation of a stimulus, be it linguistic or otherwise.

Although the evidence is not unequivocal, there is further evidence from lesion-overlap studies suggesting a role for the RH in linguistic tasks that might be assumed to involve suppression of dominant but incorrect meanings. A study by Channon et al. (2007) found that right frontal lesions were associated with impairment in selecting among alternatives when judging sarcasm. Shamay-Tsoory et al. (2005) also found that right frontal damage was associated with difficulty in comprehending sarcasm. However, they pinpoint ventral-medial areas, rather than inferior frontal areas, and interpret their results as related to emotional circuits, rather than inhibitory circuits.

Although the application of a single interpretive framework that we observed in our several of the participants from the RHD group resembled what one might expect from frontal damage, there was no obvious correlation between lesion location and persistence in applying the same story framework. Of the four RHD participants mentioned above, two had frontal damage, and two did not. In addition, the other RHD participants who seemed to exhibit this tendency did not have damage restricted to the frontal cortex. Thus, while our results may support a general RH involvement in frame-shifting, they lend no support to a decidedly frontal-executive interpretation.

#### 4.5. Reduced mental-state ascription

The RHD group was capable of attributing intentions to the triangles, but did so inappropriately. As a group, the participants with RHD used less language coded as indicating an explicit ascription of mental states. However, one individual from the RHD group showed the opposite pattern, tending to *over-ascribe* mental states. This participant described a film in which the triangles bounce back and forth across the screen in a rather aimless, ping-pong-like fashion in the following way:

Here we see the red and the blue triangle again, and they still have not become allied or connected with each other. They live in a peaceful coexistence, they have created a neutral area known as the blue square, in which there is an opening so that on the face of things they could enter the square, but none of them do it. They circle around it, both are clearly interested in the square but they do not step over the line and they do not

take anything where the other one would be able to say that they had taken something that was less- that is, that they had gotten more than that which they are apparently allotted by a sort of mutual agreement and that mutual agreement states that the square is a neutral area.

This is reminiscent of results reported by Champagne-Lavau and Joannette (2007), who found that participants with RHD tended to make significantly more errors in the interpretation of direct requests than did a control group. Champagne-Lavau and Joannette (2007) suggest that people with RHD may over-attribute intentions to the protagonists in a story task. Although one subject from the present study exhibited this behavior, the tendency of the group was to under-attribute mental states.

Our results support the results of previous studies reporting reduced performance on ToM tasks in people with RHD (Brownell et al., 2000; Griffin et al., 2006; Happé et al., 1999; Winner et al., 1998), and point to the need to investigate means of training ToM skills as a part of a post-stroke rehabilitation program (Lundgren, Brownell, Cayer-Meade, & Spitzer, 2007). Whether the performance of people with RHD on ToM tasks is due to a specific ToM deficit or whether performance on ToM tasks is reduced in people with RHD because of impairments in a variety of cognitive domains is still an open question, however, and cannot be answered with the results from the present study. However, our data indicate that impairment on ToM tasks can arise from damage to a variety of cortical areas in the RH, suggesting that more than one cognitive mechanism may affect performance on ToM tasks. Our study included RHD participants with both frontal and/or temporal-parietal damage. As we have seen, impaired perception of animacy and impaired frame-shifting abilities may both have influenced our results. Although both of these abilities are important for social cognition, neither of them is specific to social cognition. We therefore find it likely that the performance of participants with RHD on ToM tasks is not due to a domain-specific ToM impairment. Further research will be needed, however, to firmly establish this.

#### 4.6. Problems and potential sources of error

Three factors present potential problems for the interpretation of the data presented here. First, because of the small sample size, and the normal variation among both the RHD and the NBD groups, we must be careful about making generalizations to the population level. Second, the open-ended nature of the task makes a quantitative analysis of the data challenging. This is a problem that has also plagued previous investigations of linguistic production in RHD (Heath & Blonder, 2005). One promising method of avoiding the issue of variability in open-ended self-reports is to employ eye-tracking methods, as recently shown by Klein, Zwickel, Prinz, and Frith (2008). Use of eye-tracking equipment would also allow the inclusion of an LHD group for comparison, which was impossible in the present study due to the general linguistic impairments among patients with LHD. Finally, the task, as we posed it, may have led participants in the both the control and the RHD groups to feel that they were expected to read stories into the films, when they might not naturally have done so otherwise. An interesting manipulation would be tell participants ahead of time whether or not a given film was or was not intended as a story, to see whether the participants in the present study were responding more to the films directly, or the experimental situation and the perceived need to make up a story for the films.

#### 4.7. Unanswered questions and future research

We have suggested that either of two separate cognitive systems may have affected the performance of the RHD group on

our task: a temporal-parietal system involved in the perception of biological motion, and a frontal system involved in task-monitoring or task-switching. In future studies, it will be useful to see whether performance on tasks specifically tapping these systems correlates with impairment on ToM tasks, including tasks using animated stimuli like the Frith–Happé triangles. It will also be useful to compare the same RHD participants on a wider range of ToM tasks, to see whether they are impaired on all, or only some of them. Finally, the inclusion of an LHD control group is an important next step; this could potentially be accomplished using eye-tracking methods.

## 5. Conclusions

Impaired communication is an important symptom often associated with right hemisphere damage. This can manifest itself in different ways, but a common theme is a reduced ability to function normally in social settings. Theory of Mind has been identified as a critical cognitive component in normal communication and social interactions. The aim of this study was to measure Theory of Mind abilities in RHD using animated stimuli. The RHD group showed a reduced ability to discriminate between the two stimulus categories, and a bias toward under-attribution of mental states when viewing the ToM animations, suggestion that they either had difficulty perceiving or using the kinetic information embedded in the animations, or both. We suggest that either an impairment in complex motion perception, or an impairment in higher-level frame-shifting may have affected the RHD group's performance on the task.

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## Appendix A. Instructions to coders

Our instructions to coders for the first coding procedure were adapted from Abell et al. (2000). Our data were collected and scored in Danish; we present here an English translation of the coding instructions.

### A.1. Intentions

Count each phrase in which an expression is used that suggests that the speaker is ascribing intentions to the triangles. Underline each phrase you include. The texts are divided with slashes – the phrases between the slashes count as one unit.

Ex.:

The triangles flew around on the screen/at one point the red one tried to get out of the square/after the blue one tried to open the door/but it gave up/.

In this example, the score would be 3.

### A.2. Description type

Read each description and decide whether it describes *Random Actions*, *intentional* actions, or whether the speaker ascribes specific *mental states* to the triangles.

Each description may only belong to one category. *Random Action* is the lowest category, and *mental state* the highest. Each

description always receives the highest possible category (*intentional* trumps *Random Action*, and *mental state* trumps *intentional*). NB: this time, you should rate the description as a whole: give one number per description, no matter how many or how few references to mental states there occur in the description.

Random Action = 1

Intentional = 2

Mental states = 3

Ex. 1

"They just flew around on the screen and I don't think there was a story" = Random Action (1).

NB: "I don't think" does not count as a mental state, because the speaker is referring to herself, not to the triangles.

Ex. 2

"One might almost think that the red tried to capture the blue one" = intentional (2).

NB: "tried to" is not enough by itself for the description to count as a 3.

NB: just as "I don't think" refers to the speaker and not the triangles, "one might almost think" does not refer to the triangles, and does not count as a mental-state ascription.

Ex. 3

"The red and the blue triangle wanted to make contact with each other" = mental-state ascription (3).

NB: the key phrase in this case is "wanted to": the triangles *wanted something* from each other.

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