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Discourse Impairments Following Right Hemisphere Brain Damage: A Critical Review

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Abstract

Right hemisphere brain damage (RHD) rarely causes aphasia marked by clear and widespread failures of comprehension or extreme difficulty producing fluent speech. Nonetheless, subtle language comprehension deficits can occur following unilateral RHD. In this article, we review the empirical record on discourse function following right hemisphere damage, as well as relevant work on non-brain damaged individuals that focuses on right hemisphere function. The review is divided into four sections that focus on discourse processing, inferencing, humor, and non-literal language. While the exact role that the right hemisphere plays in language processing, and the exact way that the two cerebral hemispheres coordinate their linguistic processes are still open to debate, our review suggests that the right hemisphere plays a critical role in managing inferred or implied information by maintaining relevant information and/or suppressing irrelevant information. Deficits in one or both of these mechanisms may account for discourse deficits following RHD.

While damage to the left cerebral hemisphere (LH) often causes significant impairment to language function at all levels, right hemisphere damage (RHD) seems to leave fundamental word and sentence processing operations more or less unaffected (for example, see Klepousniotou and Baum 2005a; c.f. Tompkins et al. 2007). This is readily illustrated by the fact that trauma to ‘traditional’ language areas in the left hemisphere often results in aphasic symptoms, while damage to the homologous structures in the right hemisphere (RH) rarely does. Consider, for example, that only 180 cases of aphasia resulting from RHD (crossed aphasia) have been reported since 1975 (Marien et al. 2004). This does not mean that insult to the RH has no effect on language comprehension and/or production; however, unlike left hemisphere damage (LHD), the linguistic deficits that may result from damage to the RH tend to be subtle in their presentation, emerging primarily in cognitively sophisticated settings such as narrative comprehension and conversation. This is unsurprising given that RH involvement seems to increase with the complexity of linguistic stimuli, being the least activated at the level of the word, and maximally activated at the level of narrative discourse (Xu et al. 2005; for other neuroimaging studies of healthy individuals showing RH activity during discourse processing, see Huettner et al. 1989; Lechevalier et al. 1989; Nichelli et al.

1995; St. George et al. 1999; Robertson et al. 2000; Braun et al. 2001; Kuperberg et al. 2006).

Discourse processing deficits following unilateral RHD may be broadly characterized as falling into two overlapping areas: impaired sensitivity to the macrostructure of discourse, including disorganized topic coherence and management; and diminished ability to successfully negotiate the inferential processes necessary to maintain discourse coherence and facilitate comprehension. These processes may also underpin interpretation of figurative and non-literal language, and a special role in comprehending such language is frequently attributed to the RH. The effects of RHD on each of these areas are considered in turn.

Right Hemisphere Damage and Discourse Macrostructure

The successful comprehension of written or spoken discourse requires comprehenders to construct a mental ‘model’ reflecting their understanding of the situation described in the discourse (Johnson-Laird 1983; McKoon and Ratcliff 1990, 1992; Graesser et al. 1994). This model is maintained in an active fashion, being updated and revised as new information becomes available. Construction and maintenance of this discourse model entails not only online comprehension of the linguistic structures being processed, but also the application of pragmatic knowledge from long-term memory regarding the characteristics and capacities of the entities being described in the discourse (Kintsch 1988; Graesser et al. 1994). An effective discourse model is built upon a coherent microstructure (e.g., successful syntactic and semantic analysis of incoming information) and macrostructure (e.g., the use of thematic and topical knowledge to organize sentences into a unified whole). While the LH seems to maintain a discourse model containing microstructural information, the RH does not (Long and Baynes 2002; Long et al. 2005; c.f. Prat et al. 2007). Patients with unilateral RHD rarely exhibit the microstructural deficiencies associated with unilateral LHD. For example, while LHD patients have no difficulty selecting a pictorial representation of the sentence ‘The butcher weighed the meat’, they often have difficulty selecting the correct pictorial representation of sentences, such as, ‘The fireman weighed the policeman’ (Byng 1988). The latter sentence requires use of microstructural information about syntax to determine that the policeman is the object of fireman’s (the agent’s) action, and not vice versa. RHD patients, in contrast, have no such difficulty. However, a large body of experimental evidence suggests that RHD patients may experience difficulty when macrostructural considerations are required to successfully comprehend discourse.

A key component of a discourse’s macrostructure is its overarching message or theme. Individual sentences within a passage or conversation may be syntactically well-constructed and semantically congruent on their own, but may be inconsistent with the overall meaning of the discourse, and thus disrupt comprehension. In healthy subjects, the absence of such organizing information has resulted in increased RH activity, ostensibly as the RH attempts to establish a macrostructure (St. George et al. 1999). Such subjects have also shown greater RH activation when monitoring stories for thematic information (Nichelli et al. 1995). Therefore, an inability to detect or employ thematic information could contribute substantially to degraded discourse comprehension. Noting that Wapner et al. (1981) reported that patients with RHD had difficulty maintaining thematic consistency in speech,

Delis et al. (1983) examined RHD patients' ability to organize discourse. They employed a task wherein each sentence of a series of six-sentence paragraphs was written on separate cards. All participants began the task by receiving the first sentence of the paragraph, which contained its general theme; the remaining cards were randomized and subsequently presented together. In spite of the availability of thematic information, RHD patients performed significantly more poorly than healthy control (non-brain damaged, NBD) participants at arranging the sentences into coherent paragraphs, suggesting that they were unable to use available macrostructural information to sequence the narratives. However, this result is not unambiguous. Rather than a lack of sensitivity to thematic information, the results could be due to a disruption of some kind of organizational processing unique to the RH.¹ To address this ambiguity, Schneiderman et al. (1992) used the same paradigm, but manipulated the presence or absence of a theme as an independent variable. Their results indicate that both NBD and LHD participants were able to employ thematic information to successfully arrange sentences into coherent paragraphs, as illustrated by their relatively higher success rates when themes were provided relative to when they were not. In contrast, the presence or absence of thematic information did not seem to affect RHD patients' performance, suggesting that they did not recognize that the thematic information was important in structuring the stories.

Hough (1990) refined our understanding of RHD patients' thematic perception by demonstrating that RHD patients are, in fact, able to identify main ideas – but may be impaired in their ability to use them to create an organizing macrostructure. Hough presented thematic information either early or late in an auditory narrative. NBD and LHD groups proved able to employ thematic information regardless of when it was presented; RHD patients showed performance decrements when thematic information was delayed. LHD patients also exhibited impairment relative to the NBD controls. Hough echoes Delis et al. (1983) by suggesting that LHD patients' impaired performance may be the result of the linguistic demands of the task (verbalizing or verbally identifying a theme), inasmuch as the time of theme presentation did not modulate their performance. Hough's results (congruent with Schneiderman et al. 1992) also suggest that RHD patients are able to recognize themes, but may be unable to successfully capitalize on their unifying facility. These results are consistent with other research suggesting that RHD patients comprehend main ideas as efficiently as NBD controls (Brookshire and Nicholas 1984; Wegner et al. 1984).

Additional studies have contributed to the hypothesis that RHD may result in difficulty using macrostructural information in discourse comprehension. Rehak et al. (1992) further explored RHD patients' sensitivity to organizational factors in an experiment that manipulated discourse structure. Stories were constructed that either adhered to canonical story patterns (wherein a main idea or theme is followed by events that build to a climax) or followed a non-canonical pattern (building to a surprising ending). The latter type of story would necessarily require a revision of the macrostructure in order to accommodate the unexpected resolution, while the canonical structures would require no such process. While

¹A reviewer correctly pointed out that the lack of an LHD group in this study also leaves the results open to the interpretation that 'brain damage (not RHD) disrupts normal language processing'. This is true, and makes the subsequent, better-controlled studies all the more important for critically evaluating this early research.

the RHD group was significantly impaired in their ability to identify stories' main themes, no performance differences emerged between canonical and non-canonical stories. While this might at first appear to be at odds with Hough's (1990) findings, recall that in this experiment the stories' themes did not change as a result of the structure; subjects were always able to use thematic information from an early point in the discourse. In this sense, the results are congruent with Hough's, and suggest that the RHD patients' impaired performance may be driven by factors related to, but not sourced in, the macrostructure. More recently, Ferstl et al. (2005) conducted a thorough study examining story comprehension in NBD, LHD, RHD, and traumatic brain injury (TBI) participants. The task employed in this study is notable for its contrast with those used in many of the studies reported above. Instead of reading or hearing a series of short passages, participants heard two long passages of approximately 650 words, which increased the need for effective use of discourse macrostructure in order to successfully comprehend the discourse. Performance was measured using yes/no questions to assess knowledge of both main ideas and less salient details from the passages. Results showed that, while all groups performed equally well on questions of explicit details and main ideas, the clinical groups performed more poorly on implicit questions – and exhibited a different pattern of impairment. RHD patients exhibited significantly better performance on explicitly stated information from the passages than the LHD and TBI groups, a result consistent with previous research suggesting that patients with RHD remain sensitive to main ideas and themes (Brookshire and Nicholas 1984; Wegner et al. 1984; Hough 1990). RHD participants also showed the greatest error rate in their answers to questions about implied details from the passages – details that, the authors note, are not dependent on information from the discourse that is necessarily macrostructure relevant. The TBI group showed comparable impairment for implicit and explicit details, while the LHD patients showed the opposite pattern, being more impaired on explicit than implicit details of the narratives.

While the preceding evidence makes a solid case that damage to the RH may have appreciable effects on discourse processing – and that these effects deviate from those deficits characteristic of LH damage – the question of the proper characterization of these RHD language deficits remains. The RH does not seem to possess any 'special' role in the sequencing of linguistic information, a finding that puts into sharper relief the fact that the LH does seem to play such a role (especially in syntactic processing, in and around Broca's Area, Grodzinsky 2000; and the basal ganglia, Friederici et al. 2003). Neither does the detection and extraction of thematic information seem to be the exclusive province of the RH, inasmuch as patients with RHD generally seem to perform comparably to LHD patients and NBD control participants in tasks requiring the identification of such information. Where damage to the RH seems to create problems is in the application of such thematic information to support comprehension – a finding clearly demonstrated in Rehak et al. (1992), wherein thematic information was available but apparently unused to aid in comprehending stories deviating from typical structures. Rehak raises the possibility that deficits in RHD patients' inferential processes may explain impaired ability to comprehend stories, most especially when 'surprise' endings are present – when a revision of previously drawn inferences about the story's macrostructure would be necessary. Ferstl et al. (2002) also posited inference deficits in their RHD participants, suggesting that executive

dysfunction in the RHD group resulted in failure to integrate information from test passages both with other discourse information and with information from the patients' own general world knowledge. There are other findings suggesting that patients with RH damage exhibit impaired ability to generate inferences (e.g., Brownell et al. 1986; Beeman 1993; c.f. McDonald and Wales 1986; Harden et al. 1995), while research with split-brain patients (e.g., Phelps and Gazzaniga 1992) suggests that the RH possesses minimal inferential ability, and may instead support LH-driven inferential processes by way of other cognitive mechanisms. The loss of the ability to negotiate the inferential processes necessary to build a coherent discourse representation, and to tie that representation to general world knowledge, may underlie a range of linguistic impairments associated with RHD (Myers 1991). After all, a 'macrostructure is essentially an inference about the "gist" of a narrative' (Myers 1993: 286). But what is meant by the term 'inference'?

Right Hemisphere Damage and Inferential Processes

Comprehenders make inferences when they assume or surmise information that is then incorporated into their discourse representation, even though that information is not explicitly stated in the text or conversation. There are many different types of inferences and some of these are drawn more automatically than others (Graesser et al. 1994; McKoon and Ratcliff 1992). Examples include bridging (or coherence) inferences: upon hearing the story '*Kenny rode his bike yesterday. He came home covered in scrapes and bruises,*' one might infer that Kenny fell off his bike. This inference connects the story's two sentences in a logical way and consequently enriches the discourse model of the narrative by offering a plausible direct cause for *Kenny was covered in scrapes and bruises*, and a not unreasonable consequence of *Kenny rode his bike*. In instrument inferences, comprehenders make assumptions about the tools or devices necessary to perform some task; for instance, people may infer that a spoon was used as the instrument for a stirring action in *Kenny stirred his coffee* even though a spoon is never explicitly mentioned, and is not even a logical necessity (Kenny could have used a fork). Elaborative inferences are those a comprehender may make about the details contained in a narrative: after reading *Kenny began playing the piano beautifully*, readers may note that pianos are heavy and have black and white keys, despite the seeming narrative inconsequence of such information. Elaborative inferences are typically inessential for comprehension. Another type of elaborative inference is predictive, wherein people make assumptions about what kinds of events are likely to appear next in a story. For example, in a story that begins *Kenny won the lottery*, comprehenders might predict that Kenny will quit his job (having also inferred that Kenny is old enough to participate in a lottery in the first place ... and that he has a job). Coherence and instrument inferences are thought to be drawn more or less automatically (Potts et al. 1988; Graesser et al. 1994; Kintsch 1998), while elaborative inferences may or may not be reliably drawn (Singer 1979, 1980; Potts et al. 1988; McKoon and Ratcliff 1992; St. George et al. 1997; see Graesser et al. 1994, for an extensive taxonomy of inferences).

Any discussion of potential inferential impairment produced by RHD must first consider whether or not RHD patients show impaired sensitivity to critical contextual information. Such information is essential to the initiation of inferential processes, inasmuch as discourse context both circumscribes the type information likely to be automatically inferred to

produce coherence (would *Kenny fell off his bike* be the likely inference if the story's first sentence had been *Kenny annoyed the bully yesterday?*) and also influences the kinds of outcomes likely to be predicted (*After visiting his invalid mother at the nursing home, Kenny won the lottery*). Fraunfelder and Tyler (1987) dichotomized context into two types: structural, for example, the syntactic code implicit in a linguistic unit that defines proper parsing of incoming text/speech input, and non-structural, as in the meanings and associations between the words in a discourse separate from syntactic constructions. If RHD impairs appreciation of relevant contextual detail, RHD patients may exhibit difficulty employing contextual information to support comprehension.

Given the left hemisphere's well-established dominance for syntactic analysis, it may be that RHD affects the use of non-structural details more than structural details. Interestingly, RHD patients are often unimpaired in their use of available contextual information of both types. This was demonstrated by Leonard and colleagues in a cogent and systematic series of studies examining the use of context following RHD. Investigating structural contexts, they demonstrated that RHD patients respond more quickly to the correct referent of an ambiguous pronoun than to an incorrect alternative under a variety of conditions: in single sentence contexts (1997a); in target sentences preceded by disambiguating introductory sentences (1997a); and in sentence pairs requiring the use of general world knowledge (1997b). They have also shown that RHD patients are able to use non-structural semantic information contained in a discourse to facilitate word recognition (1998), even under conditions that should tax available processing resources (2001, using compressed speech; 2005, using a dual-task paradigm). Lehman-Blake and Lesniewicz (2005) created stories with contexts that either strongly or moderately suggested non-essential (in this study, predictive) inferences and found that RHD patients successfully generated these in both conditions, matching the performance of a control NBD group. Such findings are far from uniform, however; for example, Grindrod and Baum (2003) report a study of semantic priming wherein RHD seemed to disrupt facilitation of words related to supportive sentence contexts, at least under some stimulus presentation conditions.² Additionally, many of the studies cited above indicate at least some type of difficulty employing context to successfully build a discourse model (Rehak et al. 1992; Schneiderman et al. 1992; Ferstl et al. 2002).

This divergence of empirical findings is not altogether unexpected; in many cases, the types of information that constitute 'context' have not been rigorously controlled, resulting in broad variability in stimuli and experimental tasks. Comparisons across studies must be made carefully. And, as observed by Lehman and Tompkins (2000) and Ferstl et al. (2002), the same holds true for the literature on RHD patients' inferencing abilities. In part because models of discourse processing have only recently advanced to the point where they can be applied to studies of the neural bases of language function, much of the research concerning the effects of RHD on inferencing has paid little heed to the psycholinguistic inference literature. Consequently, most have not controlled for the types of inference(s) that may be generated, or for the probability that some kind of inference will be generated, in the

²This study did not evaluate the possible impact of RHD on inferencing, but is offered here to show that there is at least one recent study wherein an RHD test group was unable to employ contextual information.

processing of a given discourse. The selection of experimental tasks to assess inferential success or failure has been equally varied. However, in spite of this, it is clear that RHD patients, at the very least, often exhibit idiosyncratic patterns of performance when inferencing is probable and/or possible. Two hypotheses have been advanced that seek to link RHD and inferential impairment. The first of these holds that RHD prevents activation of information necessary to generate inferences. The second hypothesis trades upon the notion that discourse processing relies on a limited capacity system, and that successful language processing requires efficient management of the neural resources powering the system. According to this hypothesis, RHD results in disruption not of activation, but of suppression. Suppression is a cognitive process thought to eliminate activated but irrelevant information from comprehenders' text representations (e.g., Gernsbacher 1989, 1990; Gernsbacher and Faust 1991). Failure of suppressive processes is thought to impair correct construction of a discourse model.

Researchers such as Beeman (1993, 1998, 2005; Beeman and Chiarello 1998) have argued that RHD patients do not generate the coherence inferences that are routinely and automatically drawn by healthy comprehenders. Using fairly lengthy auditory passages (10 sentences, considerably longer than many studies of RHD patients' discourse processing), Beeman (1993) showed that NBD controls show priming for words related to bridging inferences suggested in the narratives. An RHD test population showed no such priming, leading Beeman to conclude that RHD prevented the activation of the semantic concepts essential to generating coherence inferences. Subsequent research (Beeman et al. 1994; Beeman 1998) with healthy participants examined patterns of semantic priming in the two cerebral hemispheres, and supports Beeman's theory that the LH engages in fine semantic coding (small, focused semantic fields related to the dominant meaning of input words) while the RH engages in relatively coarse semantic coding (larger semantic fields related to word meaning are activated, allowing more distantly related, convergent concepts to summate and activate). Beeman asserts that this difference in semantic processing allows the RH to provide semantic activation to disparate concepts, which are then used in inferential processing; RHD, therefore, disables such processes, and the inferences on which they depend. Furthermore, Beeman et al. (2000) have suggested that it is the LH that is most responsible for coherence inference-related priming (leading to their finding of coherence priming for related words presented to the LH but not the RH, which is congruent with the lack of coherence priming in the RH found in Beeman 1993). The RH, in contrast, is primarily responsible for predictive inferences (supported by the finding that predictive inference-related words were named more quickly when presented to the RH than the LH).

In contrast, researchers such as Tompkins and Lehman-Blake (Tompkins et al. 1994, 2000, 2001, 2002, 2004; Lehman-Blake and Tompkins 2000; Lehman-Blake and Tompkins 2001; Lehman and Lesniewicz 2005) maintain that RHD critically disables RH suppressive function, which they assert is a critical subcomponent process of successful inferencing, and furthermore, that these suppression deficits may be the result of RHD patients having fewer neural resources to support such cognitive processes. That is, contra the activation failure hypothesis, patients with RHD may activate a range of potential inferences, but are unable to suppress those that prove irrelevant to the discourse or inconsistent with macrostructural revisions. In a pair of studies, Tompkins and colleagues examined the effects of suppression

following RHD on resolving lexical (Tompkins et al. 2000) and inferential ambiguities (Tompkins et al. 2001). In both studies, suppression ability accounted for a relatively large proportion of the explained variance of the comprehension task for the RHD group: in the former, suppression accounted for 12.6% of the variance explained, and in the latter, 9.4%. Results such as these would support a compelling alternative to the activation failure account of RHD inferencing, if research bears out the activation of inferences in RHD populations. There is indeed such evidence: Lehman-Blake and Tompkins (2001) found that both normal and clinical populations reliably drew predictive inferences suggested by narrative-final sentences. (It is also interesting that RHD patients were able to draw predictive inferences, which are less likely to be drawn automatically than coherence inferences, as reliably as controls.) Providing additional support to a neural resource account of inferencing, a trend towards greater ability to maintain predictive inferences across time emerged for those adults with higher estimated working memory capacity, regardless of damage.

Additionally, Tompkins and colleagues have offered evidence that RHD patients not only activate inferences, but may activate multiple inferences (Tompkins et al. 2004). This study examined bridging inferences using both lexical decision and comprehension questions during the auditory presentation of five-sentence narratives. RHD participants exhibited faster lexical decision reaction times to inference-related words. Such coherence inferences were also drawn by RHD patients in an explicit recognition task (McDonald and Wales 1986); congruent with the suppression failure hypothesis, RHD patients in this study also performed more poorly than NBD controls at correctly rejecting false statements. However, the evidence for multiple activations is less clear. Tompkins et al. (2004) tested for alternative inferences (those that could be generated in addition to bridging inferences) and found evidence for these alternatives – but only in the more explicit accuracy data provided by the comprehension questions, and not in their lexical decision data. A more recent study (Lehman-Blake and Lesniewicz 2005) clarified these results. The experimenters reported that RHD participants were not only able to generate predictive inferences, but were able to generate multiple predictive inferences as well. As mentioned above, contextual support in this study was systematically manipulated, with RHD participants generating inferences in both strong and moderate context conditions. However, and crucial to a neural resource account of the effects of RHD on inferencing, patients were less able to maintain those inferences in the absence of strongly supportive context, that is, moderately supported inferences were not maintained over time. Given the finding (Lehman-Blake and Tompkins 2001) that maintenance of inferences was related to working memory capacity, assessment of the demands of inference maintenance is clearly important. In addition, this result coheres nicely with findings that RHD does not impair contextual sensitivity, but suggests that considering qualitative differences in contextual constraint may be vital in future research.

It is also worth noting that explicit in the suppression failure account of RH contributions to inferencing is the notion that patients' performance is significantly affected by variation in task demands and individual skill differences. That is, because suppression draws on the same limited pool of neural resources as other vital cognitive processes (such as working memory and attentional allocation), individuals with RHD will be less able to 'clean up' their representations of texts by suppressing information irrelevant to the general task. In

this regard, Tompkins has shown that adults with RHD exhibited a significant correlation between their estimated working memory capacity and performance of a demanding comprehension task designed to assess inferencing (Tompkins et al. 1994). In addition, use of a dual-task paradigm to increase attentional processing demands resulted in poorer suppression performance for clinical and NBD participants (Tompkins et al. 2002). It might be argued that Leonard and Baum (2005), in assessing the effects of RHD on use of contextual information to recognize words successfully, increased task demands by using a dual-task paradigm and found that no RHD impairments resulted. However, Leonard and Baum (2005) only speaks to the idea that RHD does not prevent activation and use of semantic associations between words. This result does not contradict the suppression failure hypothesis, which argues that RHD results in problems suppressing the activation of irrelevant and/or mistaken information, which, therefore, depletes the resources available to negotiate discourse processing.³

Overall, these findings strongly suggest that damage to the RH does not result in a deficit in the ability to generate inferences, but instead may affect the ability to manipulate inferences, perhaps by reducing suppression ability, or by impairing maintenance of multiple inferences. In addition, future investigation of the effects of RHD on language function should give serious consideration to the interaction of individual differences on a range of cognitive functions supporting language processing and task demands (for a summary of RHD effects on attentional and memory processes, see Lehman-Blake 2004).

Right Hemisphere Damage and Figurative/Non-Literal Language: Humor

Researchers who study the relationship between RHD and humor appreciation have focused on a subset of comedic forms that includes cartoons, irony, and jokes with punchlines. Relatively unimpaired (although often unusual, atypical, or off-color) humor appreciation by RHD patients has been observed in case studies and clinical interviews (e.g., Wapner et al. 1981). Relatively unimpaired humor production following RHD has also been reported (Heath and Blonder 2005): in-home assessments of RHD and LHD patients' and NBD controls' attempts at humor with a spouse found no difference in the number of humorous efforts between the three groups. However, spouses of RHD patients did report that these attempts were less successful and interpretable than before brain injury, suggesting some breakdown in humor processes. Along these lines, a large body of research suggests that impairments may emerge in more structured, experimental settings. These experiments most frequently involve humorous stimuli requiring the integration of ideas across textual elements and/or knowledge of internal states or intentions. RHD patients' idiosyncratic appreciation of humor suggests that broader cognitive impairments (such as in inferential processing) may make it difficult for RHD patients to recognize humor in the 'typical' research format.

³It is also notable, from a limited resources perspective, that RHD does not seem to affect use of script knowledge (Roman et al. 1987). Scripts, defined by their characteristically routinized and structured sequences, perhaps do not require non-automatic inferences or the active imposition of a macrostructure for organization, and so place fewer demands on the neural resources available following RHD.

The principal deficit following RHD seems to involve integrating different elements of humorous situations, rather than a general inability to appreciate humor. Humor appreciation in RHD patients has been investigated using tasks evaluating their continuation judgment with both visual and verbal stimuli. In such tasks, for example, patients might view a series of panels that make up a humorous story (as would be seen on the comics page of a newspaper; see Figure 1); the patients' task is to select a panel that completes the cartoon story. The choices include panels that are either conventionally funny, because they are both surprising and semantically related to the preceding context, surprising but not funny, or semantically unrelated to the preceding context and not funny. Right hemisphere damage patients are more likely to select the surprising but unfunny continuations than are age-matched healthy controls and LHD patients (Brownell et al. 1983).

Explaining RHD patients' underperformance on experimental humor appreciation tasks requires a model of those processes people normally use to interpret jokes. One possible model suggests that humorous set-ups are frequently designed to elicit a specific inference about a protagonist's motives. Many jokes are funny because the actual continuation negates the inference and replaces it with a different, but still semantically related, continuation. For example, in the cartoon in Figure 1, the context elicits the inference that the person on the beach will try to help the drowning swimmer (as this is the most likely action that would occur in a real-world setting). In the humorous conclusion, this altruistic motive is negated and replaced by a self-interested motive (stealing the watch). The initially inferred motive and the motive that is actually supported by the joke continuation are incompatible. Appreciating the humorous implications of this conclusion depends upon reanalyzing the situation to resolve the incongruity between the two motives. Thus, the resulting process model contains operations of inference, incongruity detection, and incongruity reconciliation (requiring a revision of the initial inference).

Following this model, impaired humor appreciation may follow failure at any of these stages. Disruption of an initial inferential processing stage, for example, may result if the comprehender fails to make the initial inference altogether, as suggested by the activation failure account of RHD inference impairment. Alternatively, comprehenders may activate, but fail to maintain, all the inferences necessary for the model's subsequent operations to succeed (as proposed by Lehman-Blake and Tompkins 2001; and Lehman-Blake and Lesniewicz 2005).

Disruption of a subsequent incongruity detection stage may result if the mismatch between initial inference and final resolution goes unrealized. Such incongruity detection seems to pose particular problems for patients with LHD. LHD patients tend to select semantically related but unfunny conclusions on the continuation judgment task (Bihle et al. 1986). This suggests that LHD patients may have a deficit in understanding of the overall structure of these jokes – which involves a twist or surprise at the end. In contrast, RHD patients seem to understand that jokes involve surprising relations between their contexts and their conclusions (Brownell et al. 1983), making disruptions of an incongruity detection stage an unlikely explanation for impaired humor appreciation in RHD populations. RHD patients' problem therefore appears to be in their ability to resolve incongruities between story elements in cartoons, and not in their ability to detect the presence of these incongruities. As

suggested by Bihrlé et al. (1986), RHD patients may have reduced ability to resolve the inferential incongruity necessary to develop an integrated, unified representation of the disparate elements of jokes, demonstrating disruption of the final stage of the humor process model.

While studies of NBD populations indicate that the LH also plays a key role in appreciating humor, they complement the RHD patient literature by suggesting that the RH makes unique contributions to humor processing. In fact, research with intact subjects bolsters the humor process model posited above. For example, Bartolo et al. (2006) used event-related functional magnetic resonance imaging (fMRI) to examine humor processing in healthy young adults (age 23–36, average 28 years old). Participants viewed two-panel cartoon sequences in two conditions: in one, cartoons that were judged as being funny were presented for a total of 6 seconds, 3 seconds per panel with a 0.5-second delay between the two panels; in the control condition, the second panel was semantically related to the first panel, but judged to be unfunny. Bilateral activation was observed, with BOLD signal differences in multiple regions of both hemispheres. In the LH, funny cartoons led to activation patterns that differed significantly from those elicited by unfunny cartoons in the superior temporal gyrus, middle temporal gyrus, inferior frontal gyrus, and the cerebellum. In the RH, funny cartoons led to significantly different activations from the unfunny cartoons in the inferior frontal gyrus, fusiform gyrus, and the cerebellum. This finding is crucial, suggesting both that the RH plays a critical role in humor appreciation in healthy persons, and that the cortical networks underlying humor processes are bilateral in nature.

Electrophysiological studies of joke processing also offer evidence of unique RH contributions to humor processing. Coulson and Wu (2005) assessed college students' reactions to punchlines using event-related potentials (ERPs). Participants read one-liner set-ups, such as *Everyone was having so much fun diving in the pool we decided to add a little. ...* These were followed either by unfunny control continuations (*platform*) or by funny punchlines (*water*). While both continuations are semantically related to the preamble, the humorous one requires detection and reconciliation of the incongruity between the initially drawn inference that the pool already contains water, and the ultimately drawn inference that it actually does not. Probe words related to the funny context appeared after the critical funny/control words. These probes were presented in either the left or right visual fields, an experimental technique hinging on the finding that such information is initially processed in the target hemisphere before callosal transfer of information to the other hemisphere, and that these initial computations result in measurable processing differences (see Banich 2002, for a review of the divided visual field technique). The N400 effect, which is a negative deflection in the ERP waveform that usually peaks around 400 ms and is maximal over posterior electrode sites (Kutas and Hillyard 1980), is often interpreted as indexing the ease of integrating stimuli with the preceding context, differed between the funny and unfunny conditions. When preceded by joke contexts, reduced N400 effects were found when the probe word was presented in the left visual field (where RH response would dominate the ERP waveform) relative to when the probe word was presented to the right visual field/LH presentation. This finding implicates the RH in the processes necessary to interpret jokes. In this case, the RH appeared to respond more to the inconsistency with jumping into a pool

and the fact that the pool was empty, and then made sense of this inconsistency by interpreting the intention of the statement as being humorous.

Studies like these support the position that appreciating humor depends on RH resources in the normally functioning brain. They provide converging evidence that the disruption of humor processing following RHD differs qualitatively from disruption following LHD, and suggest that deficits following RHD are not simply general effects resulting from brain injury, reorganization of function, or compensatory processes. However, the possibility still remains that RHD patients have other cognitive deficits that make understanding certain types of humor more difficult.

Right Hemisphere Damage and Figurative/Non-Literal Language: Metaphoric Language

Psycholinguistic theories make a distinction between literal expressions and metaphoric expressions. Literal expressions describe phenomena in a real or imagined world in a direct manner, while metaphoric expressions offer more indirect ways of describing such phenomena. Metaphors come in a variety of forms, but they typically use a vehicle to provide information about a topic in an efficient or elegant way. To illustrate, consider the following metaphoric expression: *Kenny is a pop-up ad whenever he's around*. This expression conveys information about the topic, *Kenny*, using the vehicle *pop-up ad*. According to Glucksberg and Keysar (1993), comprehenders interpret metaphoric expressions by treating the vehicle as the prototype of an ad-hoc category, and then assigning the topic as being a member of that category. In the example, *pop-up ad* would be the prototype for a category of surprising, unwanted, and mildly annoying things. The speaker could use the equivalent literal statement *Kenny is surprising, unwanted, and mildly annoying whenever he's around*, but the metaphoric expression conveys the same meaning in a more condensed, efficient form.

A number of models have been proposed to explain how normally functioning people process metaphoric statements. One possibility is that literal meanings are derived first, but if they prove to be defective (*Kenny* is not an actual, literal pop-up ad, after all), then an alternative metaphoric meaning is attempted (Clark and Lucy 1975). However, reaction time studies show that people interpret metaphoric statements as quickly as they interpret equivalent literal statements (Gibbs 1984; Ortony et al. 1978; Blasko and Connine 1993). Most psycholinguistic theories therefore propose that literal and metaphoric meanings are computed simultaneously (except in cases where the metaphoric meaning is left underspecified, as in Fauconnier 1994).

A number of patient studies, using both linguistic and pictorial stimuli, suggest that damage to the RH is correlated with deficits in the interpretation of figurative linguistic forms like metaphors (McIntyre et al. 1976; Winner and Gardner 1977; Brownell et al. 1984, 1990; Van Lancker and Kempler 1987; Kempler et al. 1999; Klepousniotou and Baum 2005b; but see Klepousniotou and Baum 2005a, where no group differences between clinical and normal populations emerged in a word-level priming task). As in humor comprehension, these observed deficits are unlikely to be the result of damage to a RH-specific mechanism

for metaphor processing; studies with intact subjects consistently implicate both hemispheres in such operations. Impairment following RHD may be due to a breakdown of more general cognitive processes to which the RH critically contributes, such as the ability to activate, maintain, and/or compare distinct concepts; the ability to select and integrate the concept that successfully resolves the metaphor; and/or the ability to suppress those concepts that do not. All of these may be necessary to make sense of metaphorical language, and a large body of research with healthy and RHD participants using a variety of methods appears to support such a hypothesis (see *Right Hemisphere Damage and Inferential Processes*, above).

In their classic study, Winner and Gardner (1977) found that RHD patients had trouble matching metaphors with their appropriate pictorial representations. Given the metaphor *Kenny has a heavy heart*, RHD patients were more likely to choose a literal depiction of a person holding a large heavy heart, rather than the metaphorical depiction of a person crying. Surprisingly, most of the RHD patients in the study were able to verbally explain the metaphorical meanings of the phrases. This implies that metaphorical knowledge is still intact in RHD patients, though they appear to have difficulty integrating this knowledge in different contexts (such as picture matching). In contrast, LHD patients showed something of a reverse pattern, choosing the correct pictorial depictions of metaphoric meaning, but being unable to adequately explain the meanings of pictures in relation to metaphors. Obviously, production problems associated with aphasia are likely to at least partially account for this deficiency. However, Winner and Gardner implicate both hemispheres in the understanding and application of metaphorical knowledge in language use. Along these lines, McIntyre et al. (1976) found that when RH and LH temporal lobe epileptic (TLE) patients were asked to choose one word out of five to describe emotionally charged scenes, the RH-TLE patients chose fewer metaphoric descriptors than the LH-TLE patients (although they still made some metaphoric interpretations). Similarly, Brownell et al. (1984, 1990) showed that when RHD and LHD stroke patients were asked to choose two words out of three that were the most related in meaning, the RHD patients selected the metaphorical targets less often than the LHD patients. This early patient work suggests that there is something special about the RH with respect to metaphorical processing. However, it does not suggest which aspects of metaphor processing may be active in the RH, nor does it imply what regions of the RH are involved in these processes.

In order to better discriminate which (if any) aspects of metaphor processing takes place in the RH, Bottini et al. (1994) employed positron emission tomography and used healthy, NBD participants. Their findings suggest that the RH is critically involved in the processing of metaphoric language, showing bilateral (but distinct) hemispheric activation during metaphor processing relative to the processing of literal statements. Participants read metaphorical and literal sentences and made a plausibility judgment after each sentence by raising either their left or right index finger. Comparisons of regional cerebral blood flow following each type of sentence revealed several RH brain regions that were active during the metaphor processing that were not active as literal sentences were processed. Among those implicated in metaphor processing were the anterior cingulate, middle temporal gyrus, posterior cingulate, and the precuneus. The authors suggest that RH dominance in figurative

vs. literal language processing occurs, because metaphors contain denotative violations (whereas literal language does not), which require extra processing and may recruit episodic memory and mental imagery systems (which at least partially take place in the RH) to resolve these violations. It is important to note, however, that there were also left hemisphere regions with greater activations during metaphor processing, such as left prefrontal cortex and the central cingulate; this study, therefore, cannot explain which (if any) aspects of metaphor processing rely solely on the RH, which (if any) rely solely on the left hemisphere, and which (if any) rely on bilateral processing. In addition, there are some methodological concerns about this study: the use of a dual task paradigm and a blocked design complicates interpretation of the findings, and critics have also suggested both that inappropriate baseline comparisons were made, and that stimuli with poorly normed plausibility scores were used.

Rapp et al. (2004) attempted to address some of the methodological shortcomings found in Bottini et al. (1994), using fMRI to examine the neural correlates of metaphor processing. In this study, participants were asked to decide whether the sentences had a positive or negative connotation (rather than make plausibility judgments), and stimuli were presented in a pseudo-random (not blocked) order. Metaphoric sentences showed greater activation than the literal sentences overall, but none of the areas of increased activation were in the RH; in fact, functional comparisons showed greater activation in left hemisphere structures (such as the left inferior frontal gyrus and left inferior temporal gyrus) for the metaphoric sentences. The authors suggest that because the metaphors used in this study were all novel (non-conventionalized) and simple in structure and semantic relationship (whereas the stimuli used by Bottini et al. were not), semantic complexity may be driving the specific RH activations found in Bottini et al. (1994). The RH may therefore not be necessary to process metaphorical language, but may rather be recruited to help process language that is semantically complex at the sentence and discourse levels.

Coulson and Van Petten (2002) also support the claim that the RH is vitally involved in dealing with linguistic complexity. They were able to use the fine-grained temporal resolution of the ERP technique to show that metaphors are likely more difficult (require more processing resources) than literal sentences, even though they are processed as quickly as literal sentences. In this study, words suggesting metaphorical rather than literal meanings resulted in increased N400 amplitude, despite the respective N400 waveforms following the same time course. This increased processing load is potentially the result of the distal semantic relationships in the metaphorical sentences rather than the fact that these sentences are figurative in nature. Under this view, more processing and/or neural resources may be needed to make the semantic link between metaphorical elements, and the RH may be recruited in these instances.

Besides being complex, figurative language also allows for new and different meanings of words to be created by relating them to words with established meanings, as with the example above relating *Kenny* to a *pop-up ad*. In this example, *Kenny* is not just any male person; he also possesses the attributes of a pop-up ad (annoying and unwelcome). However, the idea that novelty is inherent in a metaphor has eroded to a certain degree, as many metaphors have become frequently used and familiar. Consider, for example, the expression

Kenny is a bright student. This metaphor is almost universally understood to mean that *Kenny is intelligent*, and has become so familiar that it is hard to believe that anyone would mistake the expression to mean *Kenny is visibly emitting light*. Novelty, therefore, is a plausible facet of metaphorical language that may explain RH involvement in non-literal language processing. This idea is supported by Mashal et al.'s (2005) fMRI study that found greater RH activation for metaphorical phrases relative to literal phrases (dog bite), but only when the metaphors were novel (crystal river) and not conventional (bright student). Analyses revealed an overall core network of cortical regions that is involved in processing of the phrases of all conditions. Of primary interest was the finding that the RH homologue of Wernicke's area showed greater activation for only the novel metaphor condition. Subsequent research by Pobric et al. (2007) using repetitive transcranial magnetic stimulation supports the hypothesis that the RH is sensitive to the novelty of a metaphoric relationship. After stimulation of the right posterior temporal sulcus, the processing of novel metaphoric expressions was disrupted, while that of conventional metaphors was not. Other authors have also found that the RH is specifically involved in processing language with novel metaphorical meanings (e.g., Schmidt et al. 2007). Conversely, in a pair of sentence priming studies using a divided visual field paradigm, Kacinik and Chiarello (2007) found that both hemispheres were able to activate non-literal/metaphoric meanings of sentences. Together, these findings suggest that the RH is unlikely to be essential to accurately process metaphorical meanings, though it may sometimes be recruited to do so, perhaps when processing novel linguistic expressions in general, rather than figurative language such as metaphor per se.

In summary, early patient studies showed that individuals with RH damage had trouble with figurative language such as metaphor, often showing very literal interpretation of language. These studies suggested that the RH might have a specific role in dealing with metaphoric language. This proposition was novel, because most of the research up until that point had primarily implicated the left hemisphere as being dominant in all language processes. However, neuroimaging findings that the RH is not always active during metaphor processing do not support the idea that the RH is the main brain region responsible for the processing of metaphorical language. Current behavioral and neuroimaging findings suggest that the RH may be specialized for making novel semantic connections, or may aid in the additional processing required to connect distally related semantic features. These processes are sometimes necessary to make sense of metaphors, but are not confined to the processing of figurative language. Additional research is still necessary to further delineate the exact brain regions and cognitive processes that support the interpretation of metaphorical language. However, at present the evidence that the RH is specialized to interpret figurative and metaphorical language is weak, and the balance of the evidence suggests that a bilateral network of cortical areas is active during metaphor processing.

Right Hemisphere Damage and Discourse Impairment: Conclusions and Caveats

The primary objective of this review was to determine, define, and delineate those discourse-level linguistic deficits that may result from unilateral damage to the right cerebral

hemisphere. Such impairments, when they present, tend to differ in qualitative ways from those resulting from insult to the left cerebral hemisphere – aphasia is a rare consequence of RHD, while other cognitively complex language processes seem to exhibit varying levels of deterioration. The range of discourse deficits attributed to damage to the RH is broad and varied: patients with RHD have shown difficulty in constructing and/or maintaining the macrostructural information that healthy comprehenders use to organize and understand discourse; their inferencing processes may be compromised; they may have problems resolving the intended meanings of humorous and metaphoric language. The reviewed literature makes it clear, however, that the evidence that the RH plays an exclusive or specialized role is tenuous at best; for example, bilateral cortical networks seem to underlie metaphor processing, while the inference deficits often associated with RH damage may instead be the result of impairment to more general cognitive mechanisms of suppression or maintenance. (Indeed, there is mounting evidence that the RH may be sensitive to the non-linguistic affective content of both written and spoken discourse; see, for example, Rehak et al. 1992, where RHD participants showed deficits when comprehending ‘dull’ stories, but not stories containing emotionally charged situations; and Ross and Monnot 2008, for a thorough examination of the role of the RH in processing affective prosody.)

In considering the implications of RH damage for language processing, the reviewed literature also highlights the need to keep several significant caveats in mind. Caveat the first: as one prominent investigator notes, ‘conflicting results are the rule’ in the literature on language processing following RHD (Tompkins et al. 2004, p. 1380). While many studies assert that RHD disables some linguistic process or other, other studies have reported no such deficit following unilateral RH damage. In addition, the size and location of RH lesions have historically not been reported, although this is not the case for more recent literature. Accounting for this and other individuating factors (such as working memory differences, attentional deficits, etc.) is vital. The presence of such disparities in the literature is not unrelated to a second caveat: much research on the effects of RHD on language processing has proceeded without accounting for psycholinguistic theories of whatever process is being examined. This may result in confounded findings when, for example, the type of inference (coherence, instrument, predictive, etc.), or the type of metaphor (conventional, novel, etc.) under investigation is not rigorously defined. Caveat the third: a wide variety of tasks purporting to measure a given linguistic process have been employed and, given the first and second caveats, it is probable that some percentage of these is not precise enough to accurately engage the processes ostensibly under investigation. And finally, a fourth caveat: in order to ascribe an RHD deficit to some aspect of language processing, one would like some assurance that the problem does not result from a more general cognitive deficit, such as a Theory of Mind deficit (which would encompass skills and abilities that are not typically classified as involving language processing). It has been suggested that deficient Theory of Mind operations result in the kinds of inferential idiosyncrasies often exhibited by patients with RHD (Siegal et al. 1996; Happé et al. 1999, 2001). However, other research suggests that characteristics of the stimuli used in these studies may be responsible for the observed results. Tompkins et al. (2008) suggest that the control and experimental stimuli differed in a critical way, with the experimental items necessitating maintenance of multiple inferential possibilities that the control items did not. Tompkins and colleagues corrected for

this mismatch; their subsequent results suggest that RHD participants were as accurate as NBD participants were at making inferences. Nonetheless, it is clear that future researchers need to carefully construct stimuli that will truly assess Theory of Mind performance before attributing linguistic deficits to it. The converse is also true, though, and care must be taken to precisely identify and control for those aspects of linguistic processing RHD is purported to impair, so that strong, unambiguous conclusions may be drawn.

The end result is that, while the body of research investigating RHD and language processing is extensive, it must be considered with care, and comparisons across studies made conservatively and cautiously. As future research is undertaken, we hope to see a more complete understanding of the linguistic consequences of damage to the right cerebral hemisphere.

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Fig. 1.
Example of a funny cartoon pair (source: http://www.tuttogratis.it/attualita/vignette_umoristiche_gratis.html).