

Bilateral Processing and Affect in Creative Language Comprehension

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Language is creative. One of the hallmarks of human language is that it is endlessly generative. People use a small set of syntactic rules and a large, but finite, set of words to create and comprehend a seemingly infinite variety of sentences. Beyond that, people regularly use language even more creatively to further enrich their message, add nuance and emotion, to entertain, and to creatively solve problems.

Before we begin, a couple of disclaimers: first, this chapter describes the cognitive and neural bases of *some* aspects of verbal creativity, but does not purport to comprehensively explain the brain bases of creativity. Second, we will argue that the right hemisphere (RH) plays a relatively stronger role in verbal creativity than in other verbal processes, but we are not suggesting that creativity resides in the RH, is solely dependent on it, or any other simplistic pop psychology notions of the “creative hemisphere.” However, there is now indisputable evidence that the RH does play a role in many aspects of verbal creativity, and it’s not our fault if others see that as somehow similar to simplistic pop psychology (Dietrich, 2007). After all, in choosing hemispheres, pop psychology had a coin toss chance of success. More importantly, verbal creativity can be seen as the orchestration of myriad cognitive and brain processes, which we are only now beginning to delineate.

Creativity has been challenging to define over the years, but most researchers agree that it involves production or creation of something new that is useful, appreciated, or appropriate to the context (e.g., Amabile, 1983). Language that is novel and well understood is creative, particularly if it creates some new meaning. Some language behavior happens with the explicit goal of being creative. Some readers may recall (perhaps with mixed emotions) high-school writing classes devoted to “creative writing.” Thus, other aspects of writing would seem to be, by default,

uncreative. Writing poetry and creative fiction, using (and comprehending) novel metaphors, and other word play are clearly creative.

However, viewing creativity in language as a rare commodity, used only for special purposes, severely under-represents a critical aspect of language that contributes to daily comprehension and expression every day of our lives. Whether consciously aware of it or not, people frequently draw on aspects of creativity in order to understand and express language in ordinary, everyday activities and conversations. Speakers and listeners imply and understand meanings that “go beyond the words,” and readers “read between the lines.” People use metaphors, sarcasm, and irony, devise riddles, get jokes, and draw inferences about information not explicitly given in language input. Creative language use is critical to complete understanding in all media. From understanding movies, TV shows, advertisements, musical lyrics, reading stories, and even holding everyday conversation, all of these behaviors in language comprehension and production rely on our ability to understand and use creativity in language.

In this chapter, we will describe some of the cognitive processes and neural substrates that underlie a few categories of creative language use, highlighting similarities (and a few differences). We discuss how each hemisphere contributes to processing jokes, drawing inferences, and creatively solving problems (metaphor comprehension is covered in Volume 1, Chapters 19, 20, and 21) and outline a theoretical mechanism for these hemispheric differences. Finally, we will examine how positive mood facilitates and anxiety impedes the ability to make the semantic connections necessary for particularly creative language.

Bilateral Activation, Integration, and Selection (BAIS), with Relatively Coarser Semantic Coding in the Right Hemisphere

Before discussing particular types of creative language, we provide a framework (more fully described in Jung-Beeman, 2005) for understanding how both hemispheres contribute to multiple semantic processes necessary for creative language use. One general dimension on which creative language varies from more straightforward, prosaic language is the degree to which distant semantic relations – creativity researchers might say divergent thinking – are necessary. Much creative language requires the comprehender to make use of semantic information that seems less central to a word’s definition, and of relatively distant associations rather than close, dominant associations. One way to describe such semantic processing is that it relies on *relatively coarser semantic coding*.

A great deal of evidence, including some to be discussed below, indicates that the RH codes semantic information more coarsely than the left hemisphere (LH; for review, see Jung-Beeman, 2005). When readers or listeners encounter a word, they activate (essentially, think about) a subset of concepts, properties, and associations (collectively referred to as *semantic fields*) related to that word. Evidence from a variety of sources suggests that the LH strongly activates a relatively smaller seman-

tic field, or set of semantic features, those features most closely related to the current (apparent) context, or if context is impoverished, the dominant semantic features and interpretations. In contrast, the RH weakly activates a relatively larger semantic field, including features that are distantly related to the word or context, and secondary word interpretations; not *everything* potentially related to the word, but a broader set of related features than is activated in the LH (Chiarello, 1988; Chiarello, Burgess, Gage, & Pollock, 1990). Despite some obvious drawbacks, coarser semantic coding has one big advantage: the less sharply each word’s meaning is specified, the more likely it is to connect in some distant way to other words in the context. These types of semantic connections appear central to creative language use.

The term “coarser semantic coding” provides a useful description of many language behaviors, but a further implication and goal is to link asymmetric semantic processing to asymmetric brain microcircuitry – specifically, to asymmetries in various features of neurons that influence the integration of inputs. As previously stated (Jung-Beeman, 2005), this is a huge leap, and there are many processing links between neuronal connections and understanding language. However, given that asymmetries exist in neuronal microcircuitries (for review, see Hutsler & Galuske, 2003) these are likely to have consequences in information processing; and, there must be some neuroanatomical basis for the asymmetries that indisputably exist in language processing.

Although the two hemispheres are roughly symmetrical, there are several established asymmetries. Some gross morphological asymmetries seem potentially related to language asymmetries, such as the LH having a relatively larger planum temporale (roughly speaking, the temporal plane just behind auditory cortex) and possibly Broca’s area. While these asymmetries seem to favor stronger LH processing in language-related skills, the association is weak at best (perhaps absent in women, e.g., Chiarello et al., 2009). The LH also has a relatively higher ratio of gray to white matter; conversely, the RH has relatively more white matter, and a higher degree of functional interconnectivity (Semmes, 1968; Tucker, Roth, & Blair, 1986).

Asymmetries in coarseness of coding may be attributable to asymmetries at the microanatomic level. In brief, pyramidal neurons collect inputs through their dendrites, and, as such, differences in synaptic distributions along dendrites influence the type of inputs that cause these pyramidal neurons to fire. The range of cortical area over which neurons collect input could be termed their *input fields*. In association cortex (i.e., not primary sensory or motor areas) in or near language-critical areas such as Wernicke’s area, Broca’s area, and anterior temporal cortex, RH neurons have larger input fields than LH neurons (e.g., Jacob, Schall, & Scheibel, 1993; Scheibel et al., 1985; Seldon, 1981; for review, see Hutsler & Galuske, 2003). Specifically, they have more synapses overall and especially far from the soma (i.e., well dispersed). The LH pyramidal neurons have more synapses close to the soma. Because cortical connections are topographical, the spatial layout of the input fields have informational consequences – more dispersed input fields (in the RH) collect more differentiated inputs, perhaps requiring a variety of inputs to fire. More tightly distributed input fields (in the LH) collect highly similar inputs, perhaps

causing the neuron to respond best to somewhat redundant inputs, and yielding relatively discrete processing units across cortical columns (Hutsler & Galuske, 2003). Similarly, outputs from neurons in superior temporal cortex are longer in the RH than in the LH, favoring more integrative processing in the RH (Tardif & Clarke, 2001).

These relative asymmetries in microcircuitry may allow each hemisphere to activate different fields of neurons in response to input. In terms of verbal processing, each hemisphere activates different semantic networks. Language areas of the LH, with neurons that have closely branching dendrites, are more adept at strongly activating smaller, more discrete semantic fields, i.e., engaging in relatively finer semantic coding (still coarse, but finer than in the RH). In contrast, language areas of the RH, with neurons that have broadly branching dendrites, are more adept at weakly activating larger, fuzzier semantic fields, i.e., engaging in relatively coarser semantic coding.

The BAIS framework (Jung-Beeman, 2005) further specifies that this general hemispheric asymmetry occurs in at least three distinct semantic processes that contribute to higher-level language comprehension: activation, integration, and selection. Each process is suited for different components of creative language processing and is supported by a distinct cortical region. The three processes are posited to be highly interactive, both within and across the hemispheres.

Semantic activation, depending mostly on bilateral Wernicke's area (broadly construed, including posterior superior temporal gyrus or STG) provides initial access to semantic features and associations (semantic representations that are highly distributed), activating features and first-order associations of the input word. Related processes may be supported by angular and supramarginal gyri (Booth et al., 2003), and perhaps inferior temporal lobe (Sharp, Scott, & Wise, 2004), with distinct areas important for different modalities of input and characteristics of information. As noted above, each input word elicits a semantic field in each hemisphere, a strongly focused one in the LH and a diffuse one in the RH. The two hemispheres likely store similar representations, but differ in dynamically accessing information, with the ultimate shape and size of the semantic fields modulated by context, memory load, and possibly mood.

Semantic integration is the process by which activated semantic concepts are connected to form a meaningful semantic relationship. Integration, seeming to depend on anterior temporal areas (middle and superior temporal gyri, perhaps temporal pole), computes the degree of semantic overlap in chunks of input, and allows for the elaboration of potentially useful connections. It may best be illustrated by an early neuroimaging study in which people showed stronger positron emission tomography (PET) signal in anterior temporal lobe of the RH when they had to comprehend ambiguous stories without a theme compared to when the theme was given, in the form of a title, before the story (St George, Kutas, Martinez, & Sereno, 1999).

Semantic selection allows competing activated concepts to be sorted out, inhibiting some concepts while selecting others for action (including but not limited to

response production, for elaboration, or for consciousness). Selection modulates word-level semantic activation and message-level semantic integration. There is strong evidence that semantic selection depends on the inferior frontal gyrus (IFG). Indeed, it has been proposed that the IFG performs selection more generally, with semantic selection being just one aspect (e.g., Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997; Zhang, Feng, Fox, Gao, & Tan, 2004). It is posited to interact with the other components: the more activated a concept (or integrative connection) is, the easier it is to select; the more selection is engaged, the narrower the scope of activation of concepts. Selection allows comprehenders to select concepts – given by the text or derived through integration – for output or to build their mental representation of the language they are comprehending.

Summary of coarser semantic coding

By itself, coarse semantic coding (of the RH) would be inadequate for comprehending language – if one couldn't even decide which meaning of a word was intended by a speaker (or writer), one would quickly get lost in almost any discourse. However, in many situations, semantic features that seemed initially irrelevant may add color or nuance to an interpretation, allow for the accommodation of unexpected subsequent input, or contribute to a wholesale reinterpretation of the initial input (for review, see Beeman, et al., 1994; Beeman, 1998; Jung-Beeman, 2005). These are the types of linguistic behaviors that are often critical to verbal creativity.

Jokes and Humor

A thoughtful wife has pork chops ready when her husband comes home from . . . fishing.

One inherently creative use of language is telling or understanding jokes and humor. Understanding jokes often relies on our ability to comprehend alternate, nonliteral, or "creative" word or phrase meanings as opposed to literal, dominant, straightforward meanings. After reading the example premise (from Coulson & Wu, 2005), *A thoughtful wife has pork chops ready when her husband comes home from . . .* most people would expect the word *work* (or similar phrases) to occur next. However, when they instead see *fishing*, a less-expected completion, people can easily integrate it with the prior context and (if they sense it is a joke), reinterpret that prior context in a new and interesting way. In short, they stop thinking of a stereotypical scenario of a dutiful wife making dinner for her husband, and reinterpret the phrase as depicting a comical scenario: a sarcastic wife making dinner in anticipation of her husband's failure (Coulson & Wu, 2005).

Patients with RH brain damage had long been observed to have difficulties understanding and/or responding to humor (e.g., Eisenson, 1962). Several decades ago,

Brownell and colleagues investigated this clinical observation in groups of patients with damage to the RH. These patients were not overtly aphasic, and seemed to understand simple straightforward sentences. However, they had a variety of more subtle difficulties understanding longer, more natural language while reading, listening to, or watching stories (for review, see Molloy, Brownell, & Gardner, 1988; also Beeman, 1993; 1998). Among their difficulties was understanding humor.

Historically, RH-damaged patients' difficulties with humor were sometimes assumed to be a function of impaired emotionality. However, another possibility is that the difficulty lay in making the unusual connections upon which humor (and inference, as discussed later) often turns. Brownell, Michel, Powelson, & Gardner (1983) postulated that jokes provide both coherence and surprise. The punchline fits the premise of the joke, but not in the expected way. Rather, understanding the punchline requires reinterpreting the prior context, in order to accommodate the new input, as we've seen above when readers encounter *fishing*.

In one study, nonaphasic patients with RH brain damage had difficulty understanding jokes, but they made systematic errors. After hearing and reading a premise, patients were asked to choose a "funny ending" from among several alternatives. When they erred, patients with RH damage chose surprising, but noncoherent endings (for the example above, they could choose *ballet*; Brownell et al., 1983). In contrast, patients with LH damage (the ones who could perform the task) also erred systematically, most often choosing coherent but nonsurprising endings (*work*, in above example; Bihrlé, Brownell, Powelson, & Gardner, 1986). So it's not that RH-damaged patients had no sense of humor, but they didn't recognize the ways that a proper joke ending should fit with the premise.

Neuroimaging studies also suggest that joke comprehension makes particular demands on semantic processing of the RH. One functional magnetic resonance imaging (fMRI) study demonstrated increased fMRI signal in the middle temporal gyrus of the RH specifically related to "getting" semantic jokes (Goel & Dolan, 2001). Different brain areas seemed more sensitive to the affective component of the jokes, and to phonological processing related to jokes; but understanding jokes that turn on twists of meaning increased processing in the RH temporal lobe.

More recently, the process of reanalyzing and reorganizing prior context in light of new input has been termed *frame-shifting*, and is thought to be central to understanding many jokes and forms of humor (Coulson, 2001; see also Coulson & Davenport, Volume 1, Chapter 19). A series of event-related brain potential (ERP) experiments demonstrated differential sensitivity of the LH and RH to joke-related information (Coulson & Williams, 2005; Coulson & Wu, 2005).

In one study, jokes were one-liners such as the *fishing* joke above, with the joke being clinched in the final word, a *punch-word* so to speak (Coulson & Williams, 2005). The stem of the joke (everything up to *fishing*) was presented, one word at a time, in the center of the screen. ERPs were measured for the punch-word and a similarly unexpected but coherent straight ending. ERPs to these two target endings were contrasted with those elicited by a highly predictable ending. It is well established that predictability of a word inversely correlates with the N400 component

of ERP signals: the more surprising and difficult to integrate a word is, given the preceding context, the bigger the N400. Thus, the N400 is often used as an index of priming, or how easily understood a word is, in context.

Because the researchers wished to examine hemispheric differences in joke comprehension and the source generators of ERP effects cannot be easily localized, the punch-words were briefly presented laterally, i.e., to the left or right of fixation. Thus, the critical word was presented to either the left visual field (LVF) or right visual field (RVF), thereby being directed initially to the RH or LH, respectively. Naturally, the highly expected endings elicited the smallest N400, regardless of which hemifield-hemisphere it was presented to. Critically, although the joke endings elicited a bigger N400 than the straight endings when viewed in the RVF/LH, the N400s to LVF/RH target words did not differ. In other words, the joke ending was just as well understood as the straight ending, when presented to the LVF/RH (Coulson & Williams, 2005).

But were those joke endings presented to the LVF/RH understood, or were the straight endings simply equally misunderstood? Although the N400 to both joke and straight endings presented to the LVF/RH appeared smaller than the joke N400 in the RVF/LH, a direct contrast of N400 effects across the hemifield conditions could be misleading. So, in another study, words related to joke understanding were contrasted with unrelated words. People viewed jokes that could be summarized with a single word, (such as *failure* for the fishing joke above, although the jokes were two-liners for the second study). After each joke, either the summarizing word or an unrelated word was presented as a target word. When presented to the LVF/RH, unrelated words elicited larger N400s than joke words; in contrast, no such difference was observed for RVF/LH target words (Coulson & Wu, 2005).

Other brain processes are also involved in comprehending jokes. Both the above ERP studies also observed later effects at the frontal scalp electrodes, likely related to working memory, retrieval, and selection processes that take advantage of RH semantic processing to further integrate and understand the joke (e.g., Coulson & Williams, 2005). Several different asymmetries could account for the increased role of RH semantic processing in joke comprehension, including coarser semantic coding (e.g., Beeman et al., 1994; Jung-Beeman, 2005), or more integrative (RH), rather than predictive (LH) processing (e.g., Federmeier & Kutas, 1999). In any case, the semantic information produced more strongly by the RH than by the LH allows people to see the distant connections between the punchline and the premise that allow them to reinterpret, or shift the frame, to see how a surprising ending may cohere after all.

As people encounter language, they expect it to make sense. If something initially doesn't make sense, people generally work harder to understand it. Fortunately, very often semantic processing prepares us to, if not expect particular input, at least be prepared for it. New input is often primed, because it fits so well with the context. In fact, the brain seems almost to predict what words will come next (one interpretation of the N400 is that it occurs to the extent these predictions are violated). When new input is surprising, comprehenders try to make sense of it. They could

assume the topic has been completely changed, that they missed some input, or they could try to reread the context or use echoic memory and working memory to "replay" auditory input. Or, they could search internally for semantic overlap, however small, despite the surprise evoked by the more recent input. Coarser semantic coding, especially if it rises and falls over a slower timescale, is more likely to detect weak activation related to overlap of distant semantic relations. So, when people unexpectedly hear *the husband comes home from . . . fishing*, they may be surprised; but there may already be weak semantic activation somewhere in the brain – more likely as a result of RH than LH semantic processing – indicating potential connections between the new input and *thoughtful wife* and *pork chops ready*. That weak activation does not suffice to completely comprehend the utterance immediately, but it points the way to shifting the frame of the premise, which can then lead to fuller comprehension – and hopefully a small chuckle.

Story Theme and Inferences

There are other, more subtle ways that coarse semantic coding aids comprehension, sometimes in creative fashion. During comprehension, readers and listeners build mental representations of what they are hearing or reading (for review, see Zwaan & Rapp, 2006). In doing so, they try to maintain coherence between consecutive words and sentences (local coherence) as well as maintain overall coherence, or the big picture of the passage (global coherence). People are able to get the gist, or understand the theme of discourse, even when it is not explicitly stated. Patients with RH damage seem to have some difficulty doing so (Hough, 1990), and having to derive the gist of a long passage increases metabolism in the RH anterior temporal lobe, compared to when the theme was presented prior to the passage (St George et al., 1999).

Sometimes, maintaining coherence and getting the gist of a story requires people to "read between the lines," i.e., to draw connective inferences that bridge gaps in explicit input. In other words, comprehenders create meaning where none was explicitly given. Consider the following excerpt from a story:

Although Barney had been planning his wife's fortieth birthday for weeks, he'd only managed to make one cake, and he wasn't quite finished with it. So he grabbed a spatula and took out the plain brown cake, setting it on the counter. After a few minutes, he put the colorful cake in the refrigerator.

In order to comprehend this passage, you needed to draw the inference that Barney frosted or decorated the cake. At the point that Barney grabbed a spatula and took out the plain brown cake, setting it on the counter, you could, potentially, predict that he was going to frost the cake. Evidence is somewhat mixed about how strongly people make such predictions, or *predictive inferences*. Later, when he put the colorful cake in the refrigerator, the coherence of the passage would be broken

if you hadn't inferred that he frosted the cake. Such a point is sometimes called a *coherence point* (or *break*), and this type of inference is referred to as *backward* or *bridging* inference. As readers and listeners of language, we are constantly required to fill in gaps that are not explicitly stated in order to maintain coherence between changing states or events in what we are reading or hearing. Drawing inferences is an essential process in building locally and globally coherent mental representations (Albrecht & O'Brien, 1993; for review, see Graesser, Singer, & Trabasso, 1994; Singer, 2007).

Like understanding jokes, drawing inferences requires making distal or unusual connections between concepts (cf. Long, Johns, Jonathan, & Baynes, Volume 1, Chapter 5). Frost is only distantly related to the words *plain*, *brown*, and *cake*. It is somewhat more related to the whole phrase *plain brown cake*. It is slightly more related in the context of an upcoming birthday party. It is distantly related to *colorful cake*. But if comprehenders assume that the *colorful cake* is the same one as the *plain brown cake*, semantic overlap on the concept *frost* greatly facilitates drawing an inference that makes sense of it all.

As with jokes, patients with RH damage have also long been observed to have difficulties drawing connective inferences (e.g., Beeman, 1993; Brownell, Potter, Bihle, & Gardner, 1986; McDonald & Wales, 1986). For example, after listening to (and simultaneously reading) very short scenarios implying an event, patients with RH damage answered questions about explicitly stated facts just as accurately as healthy elderly participants, but they answered questions about inferences at chance accuracy (Brownell et al., 1986). One could argue that they simply encoded inferences less strongly than explicitly stated information, hence forgot inferences more easily. However, another study showed that not only did patients with RH damage have difficulty answering inference questions, they also failed to show inference-related facilitation on a lexical decision task that occurred during the stories. That is, while listening to the above episode (during a longer story), participants simultaneously made lexical decisions to target words – some of which described the events being implied (*frost*). Age- and education-matched controls responded to the inference-related words more quickly than unrelated words (inference words for the other stories they heard), but patients with RH damage did not (Beeman, 1993). This suggests that, even at the moment the event was implied, these patients lacked semantic activation that would make it easier to draw the correct inferences. Other interpretations of the inference deficit with RH brain damage have been offered. E.g., it is possible that patients with RH damage have difficulty with inferences because they activate multiple interpretations (Tompkins, Fassbinder, Blake, Baumgaertner, & Jayaram, 2004), and do not effectively select the appropriate one. We suggest that the difficulty in selection is due to insufficient semantic overlap due to disrupted coarse semantic coding.

This is not to say that it would be impossible for these patients to draw inferences – merely that they could not draw them in an optimal way. What is the optimal way to draw such inferences? We suggest that while people comprehend stories, weak activation of concepts distantly related to input words can sometimes overlap and

summate. Either activation on these concepts builds until it is just as strong as that from explicitly stated input, or when comprehenders detect a gap in coherence, the summated activation points them to concepts and events that may fill the gap and forge stronger connections across the text.

Evidence that the RH contributes to drawing inferences in healthy young comprehenders comes from both behavioral and neuroimaging studies. For instance, summation priming from three distantly related words (*foot-glass-pain*) appears to facilitate naming of a briefly presented target word (*cut*) more strongly in the LVF/RH than in the RVF/LH (Beeman et al., 1994). Furthermore, while listening to narratives participants show priming (or facilitation) for inference-related target words (e.g., after hearing the above excerpt, *frost* is read faster than *rain* – the inference-related word from a different story). Inference-related priming was examined at an early, predictive point (after hearing *he grabbed a spatula and took out the plain brown cake, setting it on the counter*) or at a late, bridging point (after hearing that *he put the colorful cake in the refrigerator*). At the predictive point, participants showed inference-related priming only for target words presented to the LVF/RH, and priming for RVF/LH target words only kicked in at the bridging point (Jung-Beeman, Bowden, & Gernsbacher, 2000). As noted above, it seems that RH coarser semantic coding is more likely to detect potential semantic overlap, and detect it earlier, so that when people need to draw inferences, information to fill the gap is already primed.

Neuroimaging data has further elucidated the specific cortical areas that support the component processes of drawing inferences. People reading sentence pairs that are moderately related, and thus encourage inferences to connect them, show greater activation in the RH, especially in the temporal lobe, than when they read either highly connected pairs that don't require inferences, or unrelated pairs for which no connection can be inferred (Mason & Just, 2004). But perhaps these sentence pairs, with varying degrees of relatedness, encouraged participants to adopt specialized strategies to connect them.

In our lab, whether using patients or healthy controls, or behavioral or neuroimaging methods, we've always used longer, natural-sounding stories, usually with multiple paragraphs each implying causal events. The belief is that participants will be more engaged, and at the same time, unable to adopt specialized strategies. Participants naturally listening to longer narratives (with no overt response required during the stories), showed stronger fMRI signal during stories that implied events compared to nearly identical stories – varying by only a few words – that explicitly stated the same events (Virtue, Haberman, Clancy, Parrish, & Jung-Beeman, 2006; Virtue, Parrish, & Beeman, 2008). At the predictive point (at which time an event was implied or explicitly stated), stronger signal for the implied or inference condition occurred in the STG of the RH (Virtue et al., 2006). At the coherence point (e.g., *colorful cake*), stronger signal for the implied condition occurred in the LH or bilaterally, in both STG and IFG (Virtue et al., 2006, 2008). Interestingly, the set of participants with the highest reading span (verbal working memory), who are most adept at drawing inferences, showed stronger fMRI signal in RH STG and IFG

compared to participants lower in reading span (Virtue et al., 2006, 2008). While speculative, based on prior studies, these results may indicate that high working memory participants (St George, Mannes, & Hoffman, 1997) may have been integrating (anterior STG) and selecting (IFG) the inference at the coherence break, while low working memory participants were still activating (posterior STG) the concepts necessary to draw the inference (Virtue et al., 2006).

Of course other areas, such as medial frontal gyrus, are also likely important in detecting gaps in coherence (Ferstl, Rinck, & von Cramon, 2005). When no inferable concept readily presents itself, it appears that the search for connections depends largely on the IFG of the LH. This area seems to be highly active in many tasks involving more strategic, directed semantic search. It remains an open question whether in cases where the inference concept is primed, the final selection of an inference depends more crucially on frontal areas in the LH or RH (e.g., Virtue et al., 2006, 2008).

Drawing inferences is a subtle form of verbal creativity – when people comprehend concepts that weren't explicitly stated, they are essentially creating meaning. Drawing inferences is especially useful when comprehending creative language, or input that has multiple layers of meaning. Now we move on to other, more transparently creative aspects of language processing.

Verbal Creativity

There are numerous ways in which creativity can be expressed, even within the verbal domain. Inventing and understanding novel metaphors, including poetic metaphors, are discussed elsewhere in this volume (see Volume 1, Chapters 19, 20, and 21). In this section, we briefly cover a few other instances of generating creative verbal output. Such studies are more difficult to control than studies of experimenter-generated linguistic stimuli, and thus not unexpectedly remain relatively rare.

One study examined brain activity as people generated creative stories under various conditions (Howard-Jones, Blakemore, Samuel, Summers, & Claxton, 2005). Participants were instructed to generate either creative or uncreative stories, based on sets of three stimulus words that were either related or unrelated. As predicted, outside the brain scanner, people generated more creative stories when instructed to do so, and when generating stories that encompassed the unrelated words.

Inside the brain scanner, when the same participants were given the same types of instructions and stimuli (but not allowed to vocalize responses), different patterns of brain activity were recorded across the conditions. fMRI signal was stronger in extensive bilateral frontal areas (lateral and medial) when people were instructed to be creative than when instructed to be uncreative. Differences due to the word relatedness manipulation were smaller, but still, the unrelated condition – which elicited more creative stories, also elicited more activity in frontal brain areas. The two "creative" manipulations jointly increased activity in prefrontal cortex of the

RH, particularly the right medial frontal gyrus (Howard-Jones et al., 2005). Thus, the creative conditions seemed to evoke more top-down cognitive processing, mediated by prefrontal cortex, particularly in the RH. In contrast, the “uncreative” instruction and related word stimuli both elicited stronger activity than the creative conditions in the occipital lobes – as if participants were processing the visual input more intensely, to engage in “bottom-up” cognitive processing.

Several recent studies have examined how individuals generate simpler creative ideas, rather than whole stories. One used near-infrared spectroscopy to examine brain activity as musicians and matched nonmusicians performed a version of the classic divergent thinking task: to generate as many and as original ways to use a brick as possible. The musicians outperformed the controls in generating creative uses (as scored by blind judges). Musicians also showed stronger bilateral signal on the forehead, indicative of brain activity in bilateral frontal poles, whereas the non-musicians showed left-lateralized activity for the divergent thinking task compared to a perceptual control task (Gibson, Folley, & Park, 2009).

Another study presented people with unusual situations (e.g., “a light in the darkness”) and asked them to provide as many and as original ideas as possible to account for the situations (Grabner, Fink, & Neubauer, 2007). In this case, participants themselves rated the originality of each idea produced, and patterns of brain activity measured by electroencephalography (EEG) were contrasted for the more original versus less original ideas. In two different measures of EEG power, stronger activity for more original over less original ideas was observed in electrodes over the RH, particularly over right frontal cortex (Grabner et al., 2007).

In all these tasks, people were encouraged to come up with creative or original responses that still made sense given the stimuli and task demands. In all cases, it was assumed that more divergent thinking was required to generate more creative ideas; it is easy to see how coarser semantic coding would be advantageous for divergent thinking. Thus, it is not surprising that these experiments all showed the production of more creative ideas was associated with increased activity in right prefrontal cortical areas.

Insight and Creative Problem Solving

Another form of verbal creativity is creative problem solving, of which insight solving is one example. As with other forms of creativity, divergent thinking is often thought to be important. However, it should be noted that after an initial phase of divergence, achieving solution requires convergence – all pieces of the puzzle must fit together. Of course, to meet the typical criteria for creativity, of generating something both original and useful or appreciated, even stories generally converge in order to make sense. Likewise, as described above, even the surprise endings of jokes must cohere with the earlier premise, just in an unexpected way.

Our laboratory has been studying how people solve problems with insight for over a decade. Much of this work has been reviewed elsewhere (e.g., Kounios &

Beeman, 2009), so we will be brief here. The original motivation for beginning these studies was that the processes involved in solving with insight seemed uncannily similar to higher-level language processes, including drawing inferences, for which the RH seemed to contribute. Indeed, solving by insight seemed even more strongly to rely on the type of semantic processing posited to result from the relatively coarse semantic coding of the RH. Specifically, achieving solution insight is believed to occur when, after initially reaching impasse because the predominant solution strategies or associations to problem elements failed to bring a person closer to solution, people mentally restructure the problem. That is, they see the problem in a new light, in which the elements of the problem are related in a different way than initially interpreted. Often, this new structure appears suddenly, and as a whole – rather than being pieced together, and the whole influences the perception or understanding of the parts.

A variety of evidence suggests that unconscious processing contributes to restructuring, and solution, in important ways. People are often unaware of when they will approach solution by insight (Metcalfe & Wiebe, 1987), yet they recognize when a problem is solvable long before they can solve it (e.g., Bolte, Goschke, & Kuhl, 2003). Time away from the problem, called an incubation period, has long been thought to help people later achieve solution (e.g., Wallas, 1926). Indeed, people respond to solution words to problems that they haven’t solved faster than to unrelated words (solutions to other problems), and this solution priming is especially evident in the LVE/RH (Bowden & Jung-Beeman, 1998). In fact, this solution priming occurs only when people report that they recognized the solution with a feeling of insight – that it came to them suddenly, and instantly they recognized that the solution fit the whole problem – as opposed to recognizing the solution more analytically (Bowden & Jung-Beeman, 2003).

Neuroimaging studies reveal several key brain areas that are more active as people solve with insight compared to when they solve analytically. Given that insight solutions seem to come as a whole, we expected that semantic integration in anterior STG of the RH might contribute to solving by insight. Indeed, just prior to the moment people solve with insight, fMRI signal increases in the temporal lobe of the RH, in anterior cingulate cortex (ACC), and in hippocampal regions (Jung-Beeman et al., 2004; Subramaniam, Parrish, Kounios, & Jung-Beeman, 2009). EEG also reveals a sudden burst of gamma band activity over the right temporal cortex just prior to insight solutions (Jung-Beeman et al., 2004). Prior to that gamma band activity, alpha band activity increases – again prior to insight solutions – over the occipital cortex. This likely reflects sensory gating, i.e., attenuation of visual processing, that allows individuals close to solution to quiet the sensory input to allow further processing of an idea that is weakly developing. It also implies that some part of the brain senses this weakly active potential solution – or simply a new association that, in this case, leads to solution.

Other distinctive brain processes precede successful solution by insight, earlier in the solving process, including reduced beta band EEG activity observed at electrodes over parieto-occipital cortex, and increased gamma band activity in right frontal

electrodes (Sheth, Sandkühler, & Bhattacharya, 2009). Moreover, in the preparation interval before problems are presented, distinct patterns of brain activity are observed in both fMRI and EEG that distinguish trials in which people go on to solve problems with insight from those in which people go on to solve problems analytically (Kounios et al., 2006; Subramaniam et al., 2009). Preparation for insight (conscious and intentional or otherwise) is associated with increased activity in bilateral temporal lobes, presumably signaling readiness to pursue close and distant associations, and ACC, presumably signaling readiness to detect and/or switch between competing solution paths. Prior to problems being solved analytically, people showed relatively stronger activity in the occipital lobes (Kounios et al., 2006; Subramaniam et al., 2009), as if they were ready to concentrate on the stimuli and engage strictly bottom-up stimulus driven processing – just like those who generated uncreative stories (Howard-Jones et al., 2005).

Interestingly, EEG-measured patterns of brain activity during a resting state, before participants even knew what kind of tasks they would be performing, differed in people who tended to solve anagrams by insight, compared to people who tended to solve more analytically (by self-reports obtained after each successful anagram solution). Insight solvers showed stronger activity in electrodes over right temporal cortex as well as activity over occipital cortex that suggested more diffuse activation of the visual system – at rest (Kounios et al., 2008).

These patterns during resting state could reflect either individuals' preferred mode of spontaneous thought, or relatively stable – possibly even hardwired – differences in default network brain activity. Even if these observed differences originate in relatively stable traits, that doesn't mean they cannot vary across time (Kounios et al., 2008). The next section examines one variable that does vary across time and has been shown to influence cognitive and neural processing during creative verbal behavior – an individual's mood.

Mood Modulation of Creative Comprehension

Why does it seem that creativity flows freely at times, while at other times we can work methodically, but not achieve any breakthrough? Do we have any control over our creativity? Among other possible factors, *mood* seems to influence how creatively people use and comprehend language. Specifically, positive mood appears to facilitate creative comprehension, whereas anxiety likely impedes it. The mechanisms by which mood influences creative comprehension, perhaps via working memory, attention, or semantic access, are not yet completely clear.

Negative affect

While negative affect, such as sadness, anxiety (state, trait, and test anxiety), frustration, and depression can be beneficial to some types of cognitive processing, in

many cases it has been shown to impair complex cognitive processing, such as learning new information, solving problems, and understanding discourse. Previous research has shown that negative affect, especially anxiety, can restrict working memory capacity and/or attentional focus, which in turn influence cognitive performance, for better or worse – worse, in the case of higher-level language processes that contribute to verbal creativity.

Working memory, or the capacity to maintain and manipulate information in mind (Baddeley, 1992) is important for many types of cognition, such as understanding written and spoken discourse, and may be especially important for more creative uses of discourse. Elevated anxiety (especially the anxiety felt at that moment, or *state* anxiety) seems to restrict functional working memory capacity, which then inhibits cognitive performance (Eysenck & Calvo, 1992).

Anxiety seems to impair, among other behaviors, the ability to draw inferences. In one study, high and low test-anxiety participants read sentence pairs and verified whether a following sentence was true – which could be judged only on the basis of inference (Richards, French, Keogh, & Carter, 2000). Compared to low test-anxiety participants, high test-anxiety participants made slower and less accurate judgments about the potential inferences. Also, high test-anxiety participants were slower to verify the unnecessary inferences than the necessary inferences, whereas low test-anxiety participants responded equally quickly to both inference types. Both effects suggest that high anxiety impedes working memory, which is especially important for verifying the unnecessary, elaborative inferences. In further support of this interpretation, directly increasing memory load (by requiring participants to keep six digits in mind while reading, rather than two) similarly impaired the performance of both groups, suggesting that perhaps high test-anxious participants put forth extra effort that helped them maintain similar levels of task effectiveness compared to low test-anxious participants (in line with the processing efficiency theory, Eysenck & Calvo, 1992).

Negative affect also restricts attentional resources and impairs cognitive performance (though working memory and attention effects may be related). For example, compared to neutral-mood college students, depressed college students were less able to detect inconsistencies in stories, and their judgments of passage difficulty less reliably predicted performance (Ellis, Ottaway, Varner, Becker, & Moore, 1997). When participants were notified that contradictions were present (to increase motivation), depressed students incorrectly identified noncontradictory statements as contradictory more often than participants in a neutral mood. The authors attributed these differences to the resource allocation model (Ellis & Ashbrook, 1988), which posits that during a depressed mood state, irrelevant and intrusive thoughts compete and interfere with cognition, meaning that the attentional resources that would otherwise be devoted to the task at hand are not fully available.

Besides competition from intrusive thoughts, negative affect may actually restrict attentional focus, highlighting relatively detail-oriented and local information, rather than global information (Gasper & Clore, 2002). Under negative affect, focus of attention can be even more specifically biased toward *particular* details, such as

threatening stimuli (Easterbrook, 1959). In the context of text comprehension, for example, trait anxiety is associated with a bias toward making predictive inferences about ambiguous events that could be interpreted as threatening, but not toward nonthreatening events (Calvo & Castillo, 2001a,b; for further discussion, Blanchette & Richards, 2003).

Given that negative affect (sadness or anxiety, in different studies) narrows visual attention, it may also narrow conceptual attention, at least in contrast with positive affect. Thus it is not surprising that negative affect impairs processes like drawing inferences (Mirous & Beeman, submitted) and creative problem solving (Rowe, Hirsh, & Anderson, 2007; Subramaniam et al., 2009). We shall discuss such effects below, because they were observed together with the converse effect: positive affect facilitated inference processing and creative problem solving.

Positive affect

Contrary to negative affect, a positive mood, independent of arousal, enhances performance on several types of cognitive tasks. For example, positive affect facilitates creative thinking, problem solving, verbal fluency, classification of items, strategies used to make decisions, learning of a specific task, and even performance on previously mastered material, such as recall of addition and subtraction facts (for review, see Ashby, Isen, & Turken, 1999; Ashby, Valentin, & Turken, 2002) in adults and adolescents (Yasutake & Bryan, 1995) and in young children (Bryan & Bryan, 1991; Masters, Barden, & Ford, 1979).

As will become clear below, it seems likely that positive mood facilitates cognitive processing through broadened attention or otherwise altered cognitive control. One important potential mechanism involves a link between positive affect and the release of dopamine (Ashby, Isen, & Turken, 1999). This dopaminergic theory of positive affect suggests that during positive affect, moderate levels of dopamine released into the ACC facilitates executive attention, while moderate levels of dopamine released into prefrontal cortex facilitates working memory, both of which benefit creative processing (for further discussion, see Ashby, Valentin, & Turken, 2002).

Enhanced positive mood, whether simply assessed in participants or induced by experimenters, has been shown to enhance creative problem solving by a long, gradually building corpus of studies. Various types of creative problem solving improve when people are in a positive mood: from classic insight problems and the Remote Associate Test (Isen, Daubman, & Nowicki, 1987), to medical diagnostic hypothesis testing (Estrada, Isen, & Young, 1997), to negotiations (Carnevale & Isen, 1986), to workplace creativity (Amabile, Barsade, Mueller, & Staw, 2005). Being in a positive mood also improves people's rapid and intuitive judgments about the solvability of remote associate problems (Bolte et al., 2003).

Possibly, positive mood directly facilitates the retrieval of semantic information in response to input (Isen & Daubman, 1984; Isen, Johnson, Mertz, & Robinson,

1985). Indeed, the N400 effect indexing semantic relatedness is modulated by mood, such that positive affect causes more distantly related target words to elicit relatively smaller N400, as if the words seem more related when people are in a positive mood (Federmeier, Kirson, Moreno, & Kutas, 2001).

Alternatively, just as anxiety (or negative affect) narrows attention, positive affect broadens it (e.g., Gasper & Clore, 2002), and both do so in the conceptual domain as well as in the visual perceptual domain. Indeed, following induction into a more positive mood (compared to neutral or sad moods), participants demonstrated broader visual attention on the flanker task (when identifying the central letter, people were more influenced by the flanking letters they were supposed to ignore) and also solved remote associate problems better (Rowe et al., 2007). Moreover, under the positive mood induction, the two tasks were correlated: the better people performed on the Remote Associate Test items, the broader their visual attention was, as indexed by interference from the flanker letters.

We have observed similar effects in our lab while brain activity was assessed with fMRI. The more positive participants feel, the more compound remote associate problems they solve, and the increase in solutions is entirely attributable to solutions reportedly achieved by insight, rather than by analysis. In contrast, the more anxious people were, the more they solved problems analytically, and the less they solved problems by insight (Subramaniam et al., 2009).

Participants' mood was associated with changes in brain activity. Specifically, during the preparation period prior to problem onset, positive mood was associated with increased activation in the ACC. Note that this same area increases in activation prior to problems subsequently solved by insight, and also increases at the moment of solution. ACC is associated with both emotional response (ventral areas) and cognitive control (dorsal areas), such as detecting competing responses and switching attention between them in order to select the correct response. Given this, plus connections to other cognitive control regions such as dorsolateral prefrontal cortex, dorsal ACC seems well placed to help emotion modulate cognition. In terms of insight solving, we believe positive affect increased the breadth of attention (Gasper & Clore, 2002; Rowe et al., 2007), or decreased inhibition of nondominant word associations, allowing participants to detect weakly activated competing ideas. Weakly activated concepts that integrate distantly related problem elements in a new way are most likely processed in right STG. Thus, positive mood did not "turn on" the RH, but altered attention to make people more sensitive to quiet, weakly activated, but useful, concepts.

Like solving problems with insight, drawing inferences relies on connecting distantly related information, so mood could analogously modulate inference processing. In one recent study (Mirous & Beeman, submitted), we predicted that positive affect would facilitate drawing inferences (relative to anxious and neutral moods), while anxiety would impair drawing inferences (relative to positive and neutral moods). In a series of three experiments (positive vs. anxious mood, positive vs. neutral mood, and anxious vs. neutral mood), participants listened to stories that implied causal events.

While they listened to stories, participants named target words that either described or were unrelated to the implied inferences. As predicted, participants showed inference-related priming, naming the inference-related words faster than the unrelated words, when they appeared at the coherence point, the point in the story when coherence is broken if the inference is not drawn. To maintain coherence, comprehenders should select the appropriate inference concept to be included in their story representation at, or shortly after, the coherence point. Prior studies show IFG to be active at this point, either in the LH (Virtue et al., 2006), or bilaterally in comprehenders with higher working memory capacity (Virtue et al., 2008).

Importantly, this inference-related priming was modulated by mood, which was experimentally induced. Prior to each set of stories, participants viewed comical film clips to induce positive affect, scary film clips to induce anxiety, or neutral (nature) film clips to induce a more neutral mood (self-reported mood ratings confirmed that intended moods were established). Neither the causal events themselves nor the target words were particularly emotional, although some of the events might lead to emotional responses (more often negative than positive) for the story characters. Yet, participants showed reliably more priming when they were in a positive mood than when in a neutral or anxious mood, and reliably less priming (in fact, no priming) when they were in an anxious mood than when in a neutral or positive mood (Mirous & Beeman, submitted). This demonstrates that when people are in positive mood, they have better access to semantic information that will help them draw inferences important for fully comprehending stories.

Conclusion

Whether comprehending or producing it, creative language places greater emphasis on some processes than does more straightforward language behavior. This is not to say there are creative and uncreative language processes. Rather, creative language tends to emphasize the generation or detection of unusual semantic relations. As such, the RH's coarser coding version of semantic integration and semantic selection (particularly in generating creative ideas) plays a greater role in creative than in less creative language. Ultimately, truly creative language necessitates the use of many processes, across both hemispheres – especially as there can be a fine line between creative and nonsensical language.

Mood influences creative comprehension, as well as creative problem solving. Negative affect, particularly anxiety, restricts working memory and attention, and impairs creative cognition. Negative affect also has been linked to a narrow, detail-oriented, local focus of attention, which could be helpful in some cognitive tasks and harmful in others. Positive affect, on the other hand, has been linked to a wider, more global focus of attention, as well as to cognitive flexibility, both of which have

proved helpful in creative comprehension tasks, but may be disruptive when intense focus is necessary. It is also possible that affect more directly influences the activation, integration, and/or selection of concepts needed to complete cognitive tasks, such as understanding and producing everyday discourse, which often relies on some creativity.

References

- Albrecht, J. E., & O'Brien, E. J. (1993). Updating a mental model: Maintaining both local and global coherence. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 19, 1061–1070.
- Amabile, T. M. (1983). The social psychology of creativity: A componential definition. *Journal of Personality and Social Psychology*, 45, 356–357.
- Amabile, T. M., Barsade, S. G., Mueller, J. S., & Staw, B. M. (2005). Affect and creativity at work. *Administrative Science Quarterly*, 50, 367–403.
- Ashby, F. G., Isen, A. M., & Turken, A. U. (1999). A neuropsychological theory of positive affect and its influence on cognition. *Psychological Review*, 106, 529–550.
- Ashby, F. G., Valentin, V. V., & Turken, A. U. (2002). The effects of positive affect and arousal on working memory and executive attention: Neurobiology and computational models. In S. Moore & M. Oaksford (Eds.), *Emotional cognition: From brain to behavior* (pp. 245–287). Amsterdam: John Benjamins.
- Baddeley, A. (1992). Working memory. *Science*, 225, 556–559.
- Beeman, M. (1993). Semantic processing in the right hemisphere may contribute to drawing inferences. *Brain and Language*, 44, 80–120.
- Beeman, M. (1998). Coarse semantic coding and discourse comprehension. In M. Beeman & C. Chiarello (Eds.), *Right hemisphere language comprehension: Perspectives from cognitive neuroscience* (pp. 255–284). Mahwah, NJ: Erlbaum.
- Beeman, M., Friedman, R. B., Grafman, J., Perez, E., Diamond, S., & Lindsay, M. B. (1994). Summation priming and coarse semantic coding in the right hemisphere. *Journal of Cognitive Neuroscience*, 6, 26–45.
- Bihle, A. M., Brownell, H. H., Powelson, J. A., & Gardner, H. (1986). Comprehension of humorous and nonhumorous materials by left and right brain-damaged patients. *Brain and Cognition*, 5, 399–411.
- Blanchette, I., & Richards, A. (2003). Anxiety and the interpretation of ambiguous information: Beyond the emotion-congruent effect. *Journal of Experimental Psychology: General*, 132, 294–309.
- Bolte, A., Goschke, T., & Kuhl, J. (2003). Emotion and intuition: Effects of positive and negative mood on implicit judgments of semantic coherence. *Psychological Science*, 14, 416–421.
- Bowden, E. M., & Jung-Beeman, M. (2003). Aha! Insight experience correlates with solution activation in the right hemisphere. *Psychonomic Bulletin and Review*, 10, 730–737.
- Bowden, E. M., & Jung-Beeman, M. (1998). Getting the right idea: Semantic activation in the right hemisphere may help solve insight problems. *Psychological Science*, 9, 435–440.

- Booth, J. R., Burman, D. D., Meyer, J. R., Gitelman, D. R., Parrish, T. B., & Mesulam, M. M. (2003). Relation between brain activation and lexical performance. *Human Brain Mapping, 19*, 155–169.
- Brownell, H. H., Michel, D., Powelson, J. A., & Gardner, H. (1983). Surprise but not coherence: Sensitivity to verbal humor in right hemisphere patients. *Brain and Language, 18*, 20–27.
- Brownell, H. H., Potter, H. H., Bihrl, A. M., & Gardner, H. (1986). Inference deficits in right brain-damaged patients. *Brain and Language, 29*, 310–321.
- Bryan, T., & Bryan, J. (1991). Positive mood and math performance. *Journal of Learning Disabilities, 24*, 490–494.
- Calvo, M. G., & Castillo, M. D. (2001a). Bias in predictive inferences during reading. *Discourse Processes, 32*, 43–71.
- Calvo, M. G., & Castillo, M. D. (2001b). Selective interpretation in anxiety: Uncertainty for threatening events. *Cognition and Emotion, 15*, 299–320.
- Carnevale, P. J. D., & Isen, A. M. (1986). The influence of positive affect and visual access on the discovery of integrative solutions in bilateral negotiation. *Organizational Behavior and Human Decision Processes, 37*, 1–13.
- Chiarello, C. (1988). Lateralization of lexical processes in the normal brain: A review of visual half-field research. In H. A. Whitaker (Ed.), *Contemporary reviews in neuropsychology* (pp. 36–76). New York: Springer-Verlag.
- Chiarello, C., Burgess, C., Gage, L., & Pollock, A. (1990). Semantic and associative priming in the cerebral hemispheres: Some words do, some words don't, . . . sometimes, some places. *Brain and Language, 38*, 75–104.
- Chiarello, C., Welton, S. E., Halderman, L. K., Towler, S., Julagay, J., Otto, R., & Leonard, C. M. (2009). A large-scale investigation of lateralization in cortical anatomy and word reading: Are there sex differences? *Neuropsychology, 23*, 210–222.
- Coulson, S. (2001). *Semantic leaps: Frame-shifting and conceptual blending in meaning construction*. Cambridge: Cambridge University Press.
- Coulson, S., & Williams, R. F. (2005). Hemispheric differences and joke comprehension. *Neuropsychologia, 43*, 128–141.
- Coulson, S., & Wu, Y. C. (2005). Right hemisphere activation of joke-related information: An event-related brain potential study. *Journal of Cognitive Neuroscience, 17*, 494–506.
- Dietrich, A. (2007). Who's afraid of a cognitive neuroscience of creativity? *Methods, 42*, 22–27.
- Easterbrook, J. A. (1959). The effect of emotion on cue utilization and the organization of behavior. *Psychological Review, 66*, 183–201.
- Eisenson, J. (1962). Language and intellectual modifications associated with right cerebral damage. *Language and Speech, 5*, 49–53.
- Ellis, H. C., & Ashbrook, P. W. (1988). Resource allocation model of the effects of depressed mood states on memory. In K. Fiedler & J. Forgas (Eds.), *Affect, cognition and social behavior* (pp. 25–43). Toronto: Hogrefe.
- Ellis, H. C., Ottaway, S. A., Varner, L. J., Becker, A. S., & Moore, B. A. (1997). Emotion, motivation, and text comprehension: The detection of contradictions in passages. *Journal of Experimental Psychology: General, 126*, 131–146.
- Estrada, C. A., Isen, A. M., & Young, M. (1997). Positive affect facilitates integration of information and decreases anchoring in reasoning among physicians. *Organizational and Human Decision Processes, 72*, 117–135.

- Eysenck, M. W., & Calvo, M. G. (1992). Anxiety and performance: The processing efficiency theory. *Cognition and Emotion, 6*, 409–434.
- Federmeier, K. D., & Kutas, M. (1999). Right words and left words: Electrophysiological evidence for hemispheric differences in meaning processing. *Cognitive Brain Research, 8*, 373–392.
- Federmeier, K. D., Kirson, D. A., Moreno, E. M., & Kutas, M. (2001). Effects of transient, mild mood states on semantic memory organization and use: An event-related potential investigation in humans. *Neuroscience Letters, 305*, 149–152.
- Ferstl, E. C., Rinck, M., & von Cramon, Y. (2005). Emotional and temporal aspects of situation model processing during text comprehension: An event-related fMRI study. *Journal of Cognitive Neuroscience, 17*, 724–739.
- Gasper, K., & Clore, G. L. (2002). Attending to the big picture: Mood and global versus local processing of visual information. *Psychological Science, 13*, 34–40.
- Gibson, C., Folley, B. S., & Park, S. (2009). Enhanced divergent thinking and creativity in musicians: A behavioral and near-infrared spectroscopy study. *Brain and Cognition, 69*, 162–169.
- Goel, V., & Dolan, R. J. (2001). The functional anatomy of humor: Segregating cognitive and affective components. *Nature Neuroscience, 4*, 237–238.
- Grabner, R. H., Fink, A., & Neubauer, A. C. (2007). Brain correlates of self-rated originality of ideas: Evidence from event-related power and phase-locking changes in the EEG. *Behavioral Neuroscience, 121*, 224–230.
- Graesser, A. C., Singer, M., & Trabasso, T. (1994). Constructing inferences during narrative text comprehension. *Psychological Review, 101*, 371–395.
- Hough, M. S. (1990). Narrative comprehension in adults with right and left hemisphere brain-damage: Theme organization. *Brain and Language, 38*, 253–277.
- Howard-Jones, P. A., Blakemore, S.-J., Samuel, E. A., Summers, I. R., & Claxton, G. (2005). Semantic divergence and creative story generation: An fMRI investigation. *Cognitive Brain Research, 25*, 240–250.
- Hutsler, J., & Galuske, R. A. W. (2003). Hemispheric asymmetries in cerebral cortical networks. *Trends in Neurosciences, 26*, 429–435.
- Isen, A. M., & Daubman, K. A. (1984). The influence of affect on categorization. *Journal of Personality and Social Psychology, 47*, 1206–1217.
- Isen, A. M., Daubman, K. A., & Nowicki, G. P. (1987). Positive affect facilitates creative problem solving. *Journal of Personality and Social Psychology, 52*, 1122–1131.
- Isen, A. M., Johnson, M. M., Mertz, E., & Robinson, G. F. (1985). The influence of positive affect on the unusualness of word associations. *Journal of Personality and Social Psychology, 48*, 1413–1426.
- Jacob, R., Schall, M., & Scheibel, A. B. (1993). A quantitative dendritic analysis of Wernicke's area in humans. II. Gender, hemispheric, and environmental factors. *The Journal of Comparative Neurology, 327*, 97–111.
- Jung-Beeman, M. (2005). Bilateral brain processes for comprehending natural language. *Trends in Cognitive Science, 9*, 512–518.
- Jung-Beeman, M., Bowden, E. M., & Gernsbacher, M. A. (2000). Right and left hemisphere cooperation for drawing predictive and coherence inferences during normal story comprehension. *Brain and Language, 71*, 310–336.
- Jung-Beeman, M., Bowden, E. M., Haberman, J., Frymiare, J. L., Arambel-Liu, S., Greenblatt, R., et al. (2004). Neural activity when people solve verbal problems with insight. *Public Library of Science – Biology, 2*, 500–510.

- Kounios, J., & Beeman, M. (2009). The Aha! moment: The cognitive neuroscience of insight. *Current Directions in Psychological Science*, 18, 210–216.
- Kounios, J., Fleck, J. I., Green, D. L., Payne, L., Stevenson, J. L., Bowden, E. M., et al. (2008). The origins of insight in resting-state brain activity. *Neuropsychologia*, 46, 281–291.
- Kounios, J., Frymiare, J. L., Bowden, E. M., Fleck, J. I., Subramaniam, K., Parrish, T. B., et al. (2006). The prepared mind: Neural activity prior to problem presentation predicts subsequent solution by sudden insight. *Psychological Science*, 17, 882–890.
- McDonald, S., & Wales, R. (1986). An investigation of the ability to process inferences in language following right hemisphere brain damage. *Brain and Language*, 29, 68–80.
- Mason, R., & Just, M. (2004). How the brain processes causal inferences in text. *Psychological Science*, 15, 1–7.
- Masters, J. C., Barden, C., & Ford, M. E. (1979). Affective states, expressive behavior, and learning in children. *Journal of Personality and Social Psychology*, 37, 380–390.
- Metcalfe, J., & Weibe, D. (1987). Intuition in insight and noninsight problem solving. *Memory and Cognition*, 15, 238–246.
- Mirov, H. J., & Beeman, M. (submitted). Mood makes or breaks meaning? Mood modulation of inference priming during story comprehension.
- Molloy, R., Brownell, H. H., & Gardner, H. (1988). Discourse comprehension by right hemisphere stroke patients: Deficits of prediction and revision. In Y. Joanette & H. H. Brownell (Eds.), *Discourse ability and brain damage: Theoretical and empirical perspectives* (pp. 113–130). New York: Springer.
- Richards, A., French, C. C., Keogh, E., & Carter, C. (2000). Test-anxiety, inferential reasoning and working memory load. *Anxiety, Stress and Coping*, 13, 87–109.
- Rowe, G., Hirsh, J. B., & Anderson, A. K. (2007). Positive affect increases the breadth of attentional selection. *Proceedings of the National Academy of Science of the United States of America (PNAS)*, 104, 383–388.
- St George, M., Kutas, M., Martinez, A., & Sereno, M. I. (1999). Semantic integration in reading: Engagement of the right hemisphere during discourse processing. *Brain*, 122, 1317–1325.
- St George, M., Mannes, S., & Hoffman, J. E. (1997). Individual differences in inference generation: An ERP analysis. *Journal of Cognitive Neuroscience*, 9, 776–788.
- Scheibel, A. B., Fried, I., Paul, L., Forsythe, A., Tomiyasu, U., Wechsler, A., et al. (1985). Differentiating characteristics of the human speech cortex: A quantitative Golgi study. In D. F. Benson & E. Zaidel (Eds.), *The dual brain: Hemispheric specialization in humans* (pp. 65–74). New York: Guilford Press.
- Seldon, H. L. (1981). Structure of human auditory cortex. II. Cytoarchitectonics and dendritic distributions. *Brain Research*, 229, 277–294.
- Semmes, J. (1968). Hemispheric specialization: A possible clue to mechanism. *Neuropsychologia*, 6, 11–26.
- Sharp, D. J., Scott, S. K., & Wise, R. J. S. (2004). Retrieving meaning after temporal lobe infarction: The role of the basal language area. *Annals of Neurology*, 56, 836–846.
- Sheth, B. R., Sandkühler, S., & Bhattacharya, J. (2009). Posterior beta and anterior gamma predict cognitive insight. *Journal of Cognitive Neuroscience*, 21, 1269–1279.
- Singer, M. (2007). Inference processing in discourse comprehension. In G. Gaskell (Ed.), *Oxford handbook of psycholinguistics* (pp. 343–359). New York: Oxford University Press.
- Subramaniam, K., Parrish, T., Kounios, J., & Jung-Beeman, M. (2009). A brain mechanism for facilitation of insight by positive affect. *Journal of Cognitive Neuroscience*, 21, 415–432.

- ive neuroscience of insight.
- owden, E. M., et al. (2008). *Psychologia*, 46, 281–291.
- iam, K., Parrish, T. B., et al. *Problem presentation predicts*, 17, 882–890.
- ty to process inferences in *and Language*, 29, 68–80.
- ences in text. *Psychological*
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- problem solving. *Memory*
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- ety, inferential reasoning
–109.
- increases the breadth of
ience of the United States
- Semantic integration in
e processing. *Brain*, 122,
- rences in inference gen-
776–788.
- hsler, A., et al. (1985). *uantitative Golgi study. pecialization in humans*
- rchitectonics and den-
- nism. *Neuropsychologia*,
- g after temporal lobe
ogy, 56, 836–846.
- a and anterior gamma
269–1279.
- i. In G. Gaskell (Ed.), *xford University P*
- Tardif, E., & Clarke, S. (2001). Intrinsic connectivity of human auditory areas: A tracing study with Dil. *European Journal of Neuroscience*, 13, 1045–1050.
- Thompson-Schill, S. L., D'Esposito, M., Aguirre, G. K., & Farah, M. J. (1997). Role of left inferior prefrontal cortex in retrieval of semantic knowledge: A re-evaluation. *Proceedings of the National Academy of Science*, 94, 14792–14797.
- Tompkins, C. A., Fassbinder, W., Blake, M. O., Baumgaertner, A., & Jayaram, N. (2004). Inference generation during text comprehension by adults with right hemisphere brain damage: Activation failure versus multiple activation. *Journal of Speech, Language, and Hearing Research*, 47, 1380–1395.
- Tucker, D. M., Roth, D. L., & Blair, T. B. (1986). Functional connections among cortical regions: Topography of EEG coherence. *Electroencephalography Clinical Neurophysiology*, 63, 242–250.
- Virtue, S., Haberman, J., Clancy, Z., Parrish, T., & Jung-Beeman, M. (2006). Neural activity of inferences during story comprehension. *Brain Research*, 1084, 104–114.
- Virtue, S., Parrish, T., & Beeman, M. (2008). Inferences during story comprehension: Cortical recruitment affected by predictability of events and working memory capacity. *Journal of Cognitive Neuroscience*, 20, 2274–2284.
- Wallas, G. (1926). *The art of thought*. New York: Franklin Watts.
- Yasutake, D., & Bryan, T. (1995). The influence of affect on the achievement and behavior of students with learning disabilities. *Journal of Learning Disabilities*, 28, 329–334.
- Zhang, J. X., Feng, C., Fox, P. T., Gao, J., & Tan, L. H. (2004). Is left inferior frontal gyrus a general mechanism for selection? *NeuroImage*, 23, 596–603.
- Zwaan, R. A., & Rapp, D. N. (2006). Discourse Comprehension. In M. J. Traxler & M. A. Gernsbacher (Eds.), *Handbook of Psycholinguistics, Second Edition* (pp. 725–764). Amsterdam: Elsevier, Inc.