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The nature of hemispheric specialization for linguistic and emotional prosodic perception: A meta-analysis of the lesion literature

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ABSTRACT

It is unclear whether there is hemispheric specialization for prosodic perception and, if so, what the nature of this hemispheric asymmetry is. Using the lesion-approach, many studies have attempted to test whether there is hemispheric specialization for emotional and linguistic prosodic perception by examining the impact of left vs. right hemispheric damage on prosodic perception task performance. However, so far no consensus has been reached. In an attempt to find a consistent pattern of lateralization for prosodic perception, a meta-analysis was performed on 38 lesion studies (including 450 left hemisphere damaged patients, 534 right hemisphere damaged patients and 491 controls) of prosodic perception. It was found that both left and right hemispheric damage compromise emotional and linguistic prosodic perception task performance. Furthermore, right hemispheric damage degraded emotional prosodic perception more than left hemispheric damage (trimmed $g = -0.37$, 95% CI [−0.66; −0.09], $N = 620$ patients). It is concluded that prosodic perception is under bihemispheric control with relative specialization of the right hemisphere for emotional prosodic perception.

1. Introduction

How we say something can be as important as *what* we say when conveying a message to our audience. This prosodic (supra-segmental) layer of speech uses a variety of acoustic cues such as speaking rate, pitch and intensity to convey different communicative functions. On the one hand, prosody can be used to convey information regarding the linguistic structure of an utterance (for a review of linguistic prosodic functions see Cutler, Dahan, & van Donselaar, 1997). This 'linguistic prosody' can be used to stress syllables, group words into intonational phrases, emphasize the importance of constituents in a sentence and signal whether an utterance is meant as a question or a statement. On the other hand, prosody can be used to convey paralinguistic information such as the emotional state of the speaker (for a review see Scherer, 1986), which henceforth will be referred to as 'emotional prosody'.

Over the last four decades a considerable body of literature has accumulated on the question how the brain processes prosody (for recent reviews see Alves, Fukusima, & Aznar-Casanova, 2008; Kotz, Meyer, & Paulmann, 2006; Kotz & Paulmann, 2011; Schirmer & Kotz, 2006; Wildgruber, Ackermann, Kreifelts, & Ethofer, 2006; Wong, 2002). Understanding how prosody is processed in the brain is not only interesting from a fundamental cognitive neuroscience point of view but could also be clinically relevant as, for instance, impairment of prosodic processing has recently been found to be a core deficit in schizophrenia (Hoekert, Kahn, Pijnenborg, & Aleman, 2007). A central question that has remained unresolved so far is whether there is hemispheric specialization for prosodic perception, and if so, which mechanism drives this hemispheric asymmetry.

Concerning lateralization of prosodic perception on the cortical level, four hypotheses have emerged:

(1) The right cerebral hemisphere is specialized in the processing of *all* prosodic information (Klouda, Robin, Graff-Radford, & Cooper, 1988).
(2) The *right hemisphere hypothesis* posits that the right hemisphere is specialized in emotional prosodic processing (Blonder, Bowers, & Heilman, 1991; Borod et al., 1998; Ross, 1981).

Abbreviations: LHD, left hemispheric damage; RHD, right hemispheric damage; NC, normal controls; ES, effect size; CI, confidence interval.

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(3) The *functional lateralization hypothesis* (Van Lancker, 1980) proposes that hemispheric specialization is dependent on the communicative function of prosodic material: emotional prosodic information is processed in the right hemisphere while linguistic prosody is processed in the left.
(4) The *cue dependent lateralization hypothesis* proposes that lateralization of prosodic processing depends on the acoustic cues that are critical for the extraction of meaning: the left hemisphere would be better adapted to processing of durational information while the right hemisphere is superior in spectral processing (Van Lancker & Sidtis, 1992). As variation in pitch is an important acoustic cue to the meaning of emotional prosody (but not the only cue; see Scherer, 2003), right hemispheric superiority for emotional prosodic processing could then be explained on the basis of rightward lateralization for pitch processing.

On the one hand, the first three hypotheses all assume a specialized (and lateralized) module for structuring of incoming acoustic information into *prosodic categories*. Note that these three "categorical" hypotheses need not necessarily be mutually exclusive; for instance, the functional lateralization hypothesis can be seen as a refinement of the right hemisphere hypothesis. On the other hand, cue-dependent hypotheses posit that lateralization of prosodic processing is determined by non-prosody specific acoustic processes. The cue-dependent and the "categorical" lateralization hypotheses are not mutually exclusive either: they could represent different stages of prosodic processing which might be differentially lateralized (see Schirmer & Kotz, 2006).

One way to test these hypotheses is through the lesion approach. Typically, lesion studies compare a group of patients with acquired left or right hemispheric brain damage to a group of healthy controls on a prosodic perception task. If there is hemispheric specialization for prosodic processing then damage to the specialized hemisphere should (1) compromise performance on prosodic tasks as compared to controls (and equivalent damage to the non-specialized hemisphere should degrade performance relative to controls less) and (2) deteriorate performance as compared to equivalent damage to the non-specialized hemisphere. This approach provides information about which hemisphere of the brain is *necessary* for prosodic perception.

In order to differentiate between the "categorical" lateralization hypotheses it is necessary for lesion studies to have (1) a right hemispheric damage (RHD) group, a left hemispheric damage (LHD) group and a normal control (NC) group as well as (2) an emotional and a linguistic prosodic perception task. Unfortunately, most lesion studies that have been published to date do not fulfill these criteria. The studies that did fulfill these criteria give an inconsistent picture with some presenting evidence favoring global right-hemisphere superiority for prosodic processing (Blonder et al., 1991; Borod et al., 1998) the right hemisphere hypothesis (Heilman, Bowers, Speedie, & Coslett, 1984) and the functional lateralization hypothesis (Walker, Daigle, & Buzzard, 2002) while others do not support any of the hypotheses (Breitenstein, Daum, & Ackermann, 1998; Geigenberger & Ziegler, 2001; Kho et al., 2008; Pell, 1998; Pell & Baum, 1997; Zgaljardic, Borod, & Sliwinski, 2002). When these studies and studies that included all relevant groups but imposed only one prosodic task find detrimental effects of hemispheric damage, many find that damage to *each* of the two hemispheres compromises emotional (Breitenstein et al., 1998; Heilman et al., 1984; Kho et al., 2008; Kucharska-Pietura, Phillips, Gernand, & David, 2003; Lalande, Braun, Charlevois, & Whitaker, 1992; Pell, 1998, 2006; Peper & Irle, 1997; Shamay-Tsoory, Tomer, Goldsher, Berger, & Aharon-Peretz, 2004; Van Lancker & Sidtis, 1992; Zaidel, Kasher, Soroker, & Batori, 2002, but for evidence of hemisphere specific degradation see Blonder et al., 1991; Bowers, Coslet, Bauer, Speedie, & Heilman, 1987; Charbonneau, Scherzer, Aspirot, & Cohen, 2003; Geigenberger & Ziegler, 2001; Tompkins & Flowers, 1985; Walker et al., 2002) and linguistic (Aasland & Baum, 2003; Abada & Baum, 2006; Baum, 1998; Blonder et al., 1991; Borod et al., 1998; Geigenberger & Ziegler, 2001; Heilman et al., 1984; Pell, 1998; Pell & Baum, 1997; Perkins, Baran, & Gandour, 1996; Seddoh, 2006a, but for hemisphere specific degradation see Bryan, 1989; Walker et al., 2002; Walker, Fongemie, & Daigle, 2001) prosodic perception performance, suggesting that both hemispheres provide necessary contributions to both prosodic functions.

To disentangle the contribution of "categorical" vs. cue-dependent hemispheric specialization in prosodic perception it is necessary to vary the function of the prosodic material while keeping acoustics constant or vice versa and observe whether there is differential impact of left vs. right hemispheric damage on prosodic perception performance as compared to performance by NC. One approach has been to selectively remove durational or fundamental frequency (F_0) variation in linguistic or emotional prosodic stimuli and to observe whether LHD or RHD differentially degrades perception performance as compared to NC. Unfortunately these studies (Aasland & Baum, 2003; Baum, 1998; Pell, 1998) have not consistently found differential degradation of performance after removal of F_0 variation for LHD and after removal of durational information for RHD, as would have been expected based on the cue-dependent lateralization hypothesis (Van Lancker & Sidtis, 1992). Adopting a different approach, Van Lancker and Sidtis (1992) used discriminant analysis to analyze which acoustic properties of emotional prosody could predict the pattern of errors made by LHD and RHD patients on an emotional categorization task. It was shown that the errors of the RHD patients could be predicted by misuse of F_0 variability. The authors concluded that the right hemisphere might contribute to emotional prosodic perception through a specialization in pitch processing. However, this conclusion must be considered with caution as Pell and Baum (1997) failed to replicate the result.

Several factors have been suggested in the literature that can moderate the impact of lateralized brain damage on prosodic perception performance. Ross, Thompson, and Yenkosky (1997) propose that apparent emotional prosodic processing deficits after LHD are not caused by emotional prosodic processing deficits per se, but that these patients have problems linking emotional meaning from the prosodic layer to the propositional layer of the speech signal. These authors predict that when the 'verbal-articulatory demands' (whether lexical meaning and syllables are present) of an (affective) prosodic perception task are increased LHD performance should degrade while RHD performance should remain unaffected. Secondly, as was already evident in our discussion of the non-mutual exclusivity of the cue-dependent vs. "categorical" hypotheses of prosodic perception, prosodic processing can be conceptualized as a *process* consisting of several stages. For instance, in a recent review Schirmer and Kotz (2006) propose that there are at least three stages in prosodic perception (see also Kotz et al., 2006). In an initial stage, complex acoustical analysis of the speech signal is performed; in the second stage, emotional or linguistic information is identified; and in a final stage, this information becomes available to higher-order cognitive processes for further evaluation or integration with other layers of speech (such as the propositional content). This proposal implies that performance for prosodic perception tasks such as those used in the lesion literature reflects a combination (i.e. summation or even interaction) of these stages, each of which might be differentially lateralized (Gandour et al., 2004). Lastly, as Hoekert et al. (2007) have pointed out in a meta-analytic review of emotional prosodic impairment in schizophrenia, the quality of the prosodic perception task used might influence the findings. Tasks with high psychometric quality can be expected to give a better picture of prosodic performance