



Hemispheric specialization for global and local processing: A direct comparison of linguistic and non-linguistic stimuli

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ABSTRACT

It is often assumed that the human brain processes the global and local properties of visual stimuli in a lateralized fashion, with a left hemisphere (LH) specialization for local detail, and a right hemisphere (RH) specialization for global form. However, the evidence for such global-local lateralization stems predominantly from studies using linguistic stimuli, the processing of which has shown to be LH lateralized in itself. In addition, some studies have reported a reversal of global-local lateralization when using non-linguistic stimuli. Accordingly, it remains unclear whether global-local lateralization may in fact be stimulus-specific. To address this issue, we asked participants to respond to linguistic and non-linguistic stimuli that were presented in the right and left visual fields, allowing for first access by the LH and RH, respectively. The results showed global-RH and local-LH advantages for both stimulus types, but the global lateralization effect was larger for linguistic stimuli. Furthermore, this pattern of results was found to be robust, as it was observed regardless of two other task manipulations. We conclude that the instantiation and direction of global and local lateralization is not stimulus-specific. However, the magnitude of global,—but not local—, lateralization is dependent on stimulus type.

1. Introduction

Functional hemispheric asymmetry, or *lateralization*, is a particular instance of cortical specialization that enables the brain to use dedicated or optimized processing routines, promoting efficiency in processing of different types of information. The left hemisphere's (LH) dominance for language-related processes and the right hemisphere's (RH) dominance for visuospatial processes are well-known examples of lateralization of the human brain (Cai, Van der Haegen, & Brysbaert, 2013; Hervé, Zago, Petit, Mazoyer, & Tzourio-Mazoyer, 2013; Stephan et al., 2003). In addition, lateralization has been argued to exist for the processing of different aspects of visual information (Hellige, Laeng, & Michimata, 2010). Specifically, studies on patients with unilateral brain lesions (e.g. Delis, Robertson, & Efron, 1986; Robertson, Lamb, & Knight, 1988), and neuroimaging studies with neurologically intact adults (e.g. Fink et al., 1996; Han et al., 2002) suggest that the LH may be specialized in identifying the local elements of visual stimuli, while the RH may be specialized in identifying their global form. These findings have been corroborated by behavioral studies, showing a left

visual field (LVF) superiority for global processing and a right visual field (RVF) superiority for local processing, congruent with RH and LH lateralization, respectively (e.g. Hübner, 1998; Van Kleeck, 1989; Yovel, Yovel, & Levy, 2001).

A potential caveat to the interpretation of these findings lies in the fact that a preponderance of global-local studies used linguistic stimuli, modeled after the classical hierarchical Navon letters (Navon, 1977). As letters themselves have been shown to induce predominantly LH fusiform gyrus activity (Callan, Callan, & Masaki, 2005; Flowers et al., 2004; Polk et al., 2002), the use of hierarchical letter stimuli to study global-local lateralization introduces a confounding factor. Consequently, results derived using letter stimuli can be interpreted in more than one way. On the one hand, the classic interpretation of local-LH/RVF and global-RH/LVF advantages can be made. This interpretation requires the underlying assumption that global-local lateralization is content-neutral, and as such is not affected by the linguistic nature of the stimuli. Alternatively, the pattern of results can be explained in terms of stimulus-specific lateralization, with linguistic-LH/RVF and visuospatial-RH/LVF advantages. This interpretation assumes that the

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more taxing local level (as shown by the *global precedence effect*, Navon, 1977) is processed by the hemisphere that is specialized for that stimulus type, predicting local-LH/RVF advantages for linguistic stimuli, but local-RH/LVF advantages for visuospatial stimuli (Fink et al., 1997a, 1997b; Kinsbourne, 1970). In addition, Fink et al. propose that the non-specialized hemisphere processes the global level, as this is the level that is processed by default, resulting in global-RH/LVF advantages for linguistic stimuli, but global-LH/RVF advantages for visuospatial stimuli (Fink et al., 1997a, 1997b).

Whether a content-neutral or stimulus-specific interpretation best explains global-local lateralization cannot be determined based on the available literature. The current study aims to resolve this issue by directly comparing global-local lateralization for linguistic (i.e. letter) and non-linguistic (i.e. figure) stimuli. Before we turn to the present study, we will shortly review the existing theoretical and empirical support for each of the accounts.

1.1. Support for content-neutral global-local lateralization

The content-neutral account of global-local lateralization finds support in the theory that perceptual lateralization is the result of hemispheric differences in spatial frequency processing (e.g. Christman, 1989; Han et al., 2002; Kitterle, Hellige, & Christman, 1992; Musel et al., 2014; Sergent, 1982). This hypothesis forms the basis of the Double Filtering by Frequency (DFF) theory (Flevaris & Robertson, 2016; Ivry & Robertson, 1998). According to the DFF theory, when confronted with visual input, first a spatial frequency range is selected from the incoming spectrum, during which no hemispheric asymmetries are present. Next, this selection is fed forward to each of the hemispheres, where the LH amplifies the high spatial frequency (HSF) range, and the RH amplifies the low spatial frequency (LSF) range of this pre-selection. As a consequence, the HSF amplification in the LH causes a local-LH advantage, and the LSF amplification in the RH causes a global-RH advantage. Thus, the DFF theory predicts that global-local lateralization can be observed for different stimulus types as long as these have similar spatial frequency spectra (for an overview, see Dien, 2008).

Another line of support for the content-neutral account can be found in studies that report the classical global-local lateralization pattern when using non-linguistic stimuli. In such a study, using functional magnetic resonance imaging (fMRI), Martinez et al. (1997) found enhanced activity over the LH occipito-temporal junction during local processing, and enhanced activation of the RH occipito-temporal junction during global processing. Similarly, the classical local-RVF and global-LVF effects have been found in behavioral studies using non-linguistic stimuli (e.g. Hübner & Studer, 2009; Kimchi & Merhav, 1991).

In further support for the content-neutral account, a study that compared global-local lateralization for linguistic and non-linguistic stimuli found the classical pattern of results for both types of stimuli (Bedson & Turnbull, 2002). Using a change detection paradigm, they showed that participants more accurately detected global changes in the LVF, regardless of the nature of the stimuli.

1.2. Support for stimulus-specific global-local lateralization

The strongest support for a stimulus-specific account of global-local lateralization comes from two contrasting studies by Fink et al., 1996, 1997a, 1997b. In a positron emission tomography (PET) experiment using linguistic stimuli, they found the LH inferior cortex to be more involved in processing of the local level, and the RH lingual gyrus in processing of the global level (Fink et al., 1996, 1997b). In contrast, when using non-linguistic stimuli in the same paradigm, they found these effects to be reversed to enhanced RH lingual gyrus activity for local processing, and enhanced LH inferior occipital activity for global processing (Fink et al., 1997a, 1997b). In accounting for these results, Fink et al. proposed that processing of the local level of a stimulus is

managed by the hemisphere that is specialized for the presented stimulus type. For linguistic stimuli this would entail the LH, and for non-linguistic stimuli the RH. They further proposed that the other, non-specialized hemisphere engages in processing of the global level of the stimulus, this being the default processing mode (Fink et al., 1997a, 1997b).

Also favoring a stimulus-specific account are some of the results of studies by Kéïta and colleagues. In a series of behavioral experiments, they found a local-RVF advantage for linguistic stimuli that was absent (Kéïta, Bedoin, Burack, & Lepore, 2014), or reversed to a local-LVF advantage (Kéïta & Bedoin, 2011, Experiment 2) when non-linguistic were used.

While the complete reversal of global-local lateralization is, to our knowledge, limited to the experiments by Fink et al. (1997a, 1997b) and Kéïta and Bedoin (2011, Experiment 2), there are also a number of studies that used non-linguistic stimuli and found no lateralization effects. For example, in the behavioral studies by Polich and Aguilar (1990) and Blanca and López-Montiel (2009), no significant global-local lateralization effects were found. However, it must be noted that there also exist studies using linguistic stimuli that failed to find global-local lateralization effects (Boles, 1984; Van Kleeck, 1989), and even one reporting a reversed local-LVF advantage, when stimulus duration was limited (Boles & Karner, 1996).

1.3. Confounding factors in letter-figure comparison studies

Aside from presenting mixed results, another problem in interpreting the results from previous studies is that the results might have been suboptimal due to potential confounding factors. Most notably, in the studies that found reversed lateralization for non-linguistic stimuli, the used letter and figure stimuli differed substantially on a number of crucial aspects.

Firstly, the number of local elements that made out one global stimulus was much higher for figures than for letters. The studies by Fink et al. used global letters that were made out of 9 or 15 (example stimuli in Fink et al., 1996), or 11 or 18 (example stimuli Fink et al., 1997b) local letters, while their figure stimuli were made out of 48 local elements (example stimuli Fink et al., 1997a, 1997b). Likewise, Kéïta et al. used letter stimuli that were made out of 16–26 elements, while their figure stimuli consisted of 24–32 elements (Kéïta & Bedoin, 2011; Kéïta et al., 2014). This might be problematic for the interpretation of their letter-figure comparison, because it has been shown that the number of local elements that a global stimulus is made out of has an effect on lateralization effects. More precisely, stimuli consisting of fewer local elements are more likely to produce local-RVF effects than those consisting of many local elements, and this may be due to the fact that local elements will be perceived as texture, rather than as individual stimuli, when their numbers increase (Christman & Weiner, 1997; Kimchi & Merhav, 1991).

Secondly, the global/local size ratio differed between letters and figures. Letter stimuli in Fink et al.'s studies, for example, had a size ratio of 1/6 or 1/5, whereas it was 1/16 for their figure stimuli. These differences in global/local size ratio might be problematic because it has been shown that lateralization effects are less robust when a smaller global/local ratio is used (Yovel et al., 2001).

Lastly, as explicitly stated by Kéïta and Bedoin (2011), their figure stimuli were more complex than their letter stimuli. This forms a third confounding factor that might play a role in the observed differences in lateralization, as a shift in visual field asymmetries has been shown to be the result of increasing the complexity of stimuli (Fontenot, 1973). In this study by Fontenot, an RVF advantage was apparent for 3-letter nonsense words. In contrast, an LVF advantage was found for figures, but only when these were high in complexity.

In sum, reversals of the classic lateralization pattern might be related to a number of confounding factors, rather than by the modulation of stimulus type.

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