

**Symmetry Detection in Typically and  
Atypically Speech Lateralized Individuals:  
A Visual Half-field Study**

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## Abstract

Visuospatial functions are typically lateralized to the right cerebral hemisphere, giving rise to a left visual field advantage in visual half-field tasks. In a first study we investigated whether this is also true for symmetry detection off fixation. Twenty right-handed participants with left hemisphere speech dominance took part in a visual half-field experiment requiring them to judge the symmetry of 2-dimensional figures made by joining rectangles in symmetrical or asymmetrical ways. As expected, a significant left visual field advantage was observed for the symmetrical figures. In a second study, we replicated the study with 37 left-handed participants and left hemisphere speech dominance. We again found a left visual field advantage. Finally, in a third study, we included 17 participants with known right hemisphere dominance for speech (speech dominance had been identified with fMRI in an earlier study; Van der Haegen et al, 2011). Around half of these individuals showed a reversed pattern, i.e. a right visual half-field advantage for symmetric figures while the other half replicated the left visual-field advantage. These findings suggest that symmetry detection is indeed a cognitive function lateralized to the right hemisphere for the majority of the population. The data of the participants with atypical speech dominance are more in line with the idea that language and visuospatial functions are lateralized in opposite brain hemispheres than with the idea that different functions lateralize independently, although there seems to be more variability in this group.

# **Symmetry Detection in Typically and Atypically Speech Lateralized**

## **Individuals:**

### **A Visual Half-field Study**

The brain is divided in a left and a right half. Decades of research have shown through a variety of methods that a number of cognitive functions are unequally represented in both hemispheres. Asymmetries have been documented in both structure and functioning. For instance, the planum temporale region of the brain has been found to be larger in the left than in the right hemisphere (for recent reviews, see Amunts, 2010; Greve, Van der Haegen, Cai, Stufflebeam, Sabuncu, Fischl, & Brysbaert, in press). In most people language is lateralized to the left hemisphere. This hemisphere has also been reported to be superior in processing local elements, while the right hemisphere has been reported to be specialized in processing global elements (Bradshaw & Nettleton, 1981). Along the same lines it has been pointed out that the left hemisphere is good at categorical decisions whereas the right hemisphere is relatively better at coordinate decisions (Kosslyn, 1987). Finally, the two hemispheres are supposed to be differentially adept at processing spatial frequency; the left hemisphere has an advantage for processing higher spatial frequencies, whereas the right hemisphere would be better at processing low spatial frequencies (Sergent, 1983).

Several fundamental principles (e.g., analytic vs. holistic) have been proposed to understand the asymmetries of the two hemispheres (both structural and functional), but these have not been very successful (Hellige, 1993). Hugdahl (2000) observed that of all dichotomies put forward none has produced more consistent findings than the traditional distinction between language functions in the left hemisphere and a range of visuospatial functions in the right hemisphere. He argued that the functional asymmetry of the brain is the result of evolutionary pressure towards specialization for behaviors unique to the evolution of modern man. The emergence of language capabilities is one of the most plausible candidates to serve as a fundamental force for a functional division of the brain into a right and left half. Another facility of humans that can serve this function is the ability to represent the 3-dimensional environment as a visuospatial map. While the ability and need to communicate symbolically may have led to the evolution of the left hemisphere as specialized in language and related functions, the right hemisphere specialization could be due to the fact that orientation in space required rapid identification of objects and their relations. Hence, according to Hugdahl (2000) the language-left hemisphere and the visuospatial right hemisphere dichotomy is the guiding principle to understand brain asymmetries in human cognitive performance.

While many studies have documented the left hemisphere dominance for language processing, comparatively little behavioral research has been dedicated to the functions of the right hemisphere. Most of these studies were done with the visual half-field (VHF) task. In this task stimuli are presented in the left and right parafovea, and more efficient processing in the left visual field (LVF) than in the right visual field (RVF) is interpreted as evidence for right brain laterality. Bryden (1982) pointed out that on the basis of this evidence the right hemisphere is likely to be better able to handle a variety of cognitive functions, such as spatial abilities (Benton, Hannay & Varney, 1975), face recognition (Geffen, Bradshaw & Wallace, 1971), and emotional expression (Ley & Bryden, 1981). The specialization for spatial abilities was attested by LVF advantages for lightness discrimination (Davidoff, 1975), color perception (Hannay, 1979; Pennal, 1977), dot detection (Davidoff, 1977; Umiltà, Salmaso, Bagnara, & Simion, 1979), dot localization (Bryden, 1976), perception of line orientation (Atkinson & Egeth, 1973), stereopsis (Carmon & Bechtoldt, 1969), and depth perception (Kimura & Durnford, 1974). Music perception was another function ascribed to the right hemisphere (e.g., Gates & Bradshaw, 1977) and Hughdahl (2000) further pointed to the critical involvement of the right parietal cortex in the allocation of attention, as exemplified by hemineglect after damage to this region (but not to the left homologue). It must be noted, however, that most of these studies reflect

lateralization in relative terms. While many visual field advantages have been corroborated by later neuro-imaging studies, it is often the case that the tasks evoke bilateral activation, with one hemisphere being more active than the other.

The initial findings with the VHF task and other related behavioral paradigms (such as dichotic listening) have since been replicated and extended with the use of neuroscientific methods like fMRI, PET, MEG, etc. Shulman, Pope, Astafiev, McAvoy, Snyder, & Corbetta (2010) used fMRI to measure hemispheric asymmetries during shifts of spatial attention evoked by a peripheral cue stimulus and during target detection at the cued location. They found right hemisphere dominant activity at the temporoparietal junction during the shifting of spatial attention. During later target detection they also observed a more widespread right hemisphere dominant activity in the frontal, parietal and temporal cortices. Yovel, Tambini, & Brandman (2008) and Hemond, Kanwisher, & Op de Beeck (2007) correlated the much documented LVF advantage for face detection with fMRI-measured brain activity, and argued that it was related to a processing asymmetry in the fusiform gyrus (FFA). Also based on fMRI data, Mashal, Faust, Tendler, & Jung-Beeman (2008) claimed that the right hemisphere plays a major role in solving semantic ambiguities and in processing non-salient meanings of idiomatic expressions. In a related domain, Marinkovic, Baldwin, Courtney, Witzel, Dale, & Halgren, E. (2011) on the basis of MEG data proposed that

activations stemming from the right prefrontal cortex play a vital role in joke appreciation and consequently in humor understanding. Other evidence for right hemispheric specialization was obtained by Klosterman, Loui, & Shimamura (2009), who examined retrieval of agrammatical musical sequences (i.e. non-verbalizable sequences of tones) and found that particularly the right posterior parietal cortex (PPC) was involved.

In the present research, we examined whether symmetry detection is another right hemisphere dominant task. Symmetry refers to the property of a visual object wherein two (or more) parts of the object are separated by an imaginary axis and related to each other. Symmetry can be of various types. *Mirror symmetry* refers to situations where the two half planes obtained by dividing the object/display along an invisible central axis are mirror images of each other. Cases where the central axis is vertical manifest *vertical symmetry*, those where the central axis is horizontal manifest *horizontal symmetry*, and when the axis is diagonal the pattern reflects *diagonal symmetry*. *Rotational symmetry* is found when the rotation of a pattern aligns with the original pattern. Because symmetry perception is particularly efficient when the symmetry axis coincides with the vertical midline (Herbert & Humphrey, 1996), a further distinction is made between *symmetry at fixation* (when the stimulus is in the center of the visual field) and *symmetry off fixation* (when the stimulus is in parafoveal vision).

Symmetry is everywhere in the visual world and thus it is no surprise that biological vision systems are endowed with adaptive strategies for perceiving and utilizing this property (Wagemans, 1995). Pigeons can discriminate and classify shapes on the basis of symmetry (Delius & Nowak, 1982) and experiments with human infants have provided evidence for an innate preference of symmetric patterns (Bornstein et al. 1981). Symmetry is also easily detected in random dot configurations presented for less than 150 ms (Barlow & Reeves, 1979). This is particularly true for the detection of vertical symmetry at fixation (Royer, 1981).

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Symmetry is used in various other visuospatial functions as well. Koffka (1935) noted that it was a helpful cue for figure-ground segregation, which was empirically confirmed for vertical mirror symmetry by Machilsen, Pauwels, & Wagemans (2009). Marr (1982) proposed that symmetry is an important non-accidental feature for determining the principal axis of a shape, prior to deriving an object centered description relative to this axis. Bayliss & Driver (1994) suggested that memory representations of objects involved information about their symmetry. Finally, studies have shown superior recognition for faces in case of symmetric facial features; hence demonstrating the importance of symmetry in face perception (Little & Jones, 2006; Rhodes, Peters, Lee, Morrone, & Burr, 2005; Troje & Bulthoff, 1997).

Because of the importance of symmetry detection, authors have speculated about whether it could be a basic, preattentive feature used for image segmentation, just like orientation, brightness, color, or movement. Kootstra, de Boer, & Schomaker (2011), for instance, found that when participants were viewing complex photographic images, their early fixations predominantly were on highly symmetrical areas of the image. The authors further showed that a computational model of eye guidance, including symmetry information to predict eye-movements, outperformed the existing models based on contrast features. On the other hand, Gurnsey, Herbert, & Kenemy (1998) reported evidence that the detection of vertical bilateral symmetry embedded in random noise is poor unless the axis of symmetry is at the point of fixation, and they argued that symmetry does not play a role in image segmentation until an object has been fixated. This message was recently repeated by Roddy & Gurnsey (2011), who showed that symmetrical stimuli in parafoveal vision are subject to interference from other stimuli (crowding) and on the basis of this finding argued that symmetry is not special to the early visual system (see Olivers & van der Helm, 1998, for a similar argument).

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Whatever the exact status of symmetry detection in human perception (preattentive or not), no author denies its importance for visuospatial cognition. Consequently we hypothesized that it was likely to be a right-hemisphere function

and to give rise to a significant LVF advantage in a VHF task. Examination of the literature revealed some hints to such an effect. As far as we could ascertain, four studies have provided evidence for right lateralization of symmetry detection.

In a study by Corballis & Roldan (1974), participants were presented with lateralized tachistoscopic dot patterns and had to tell whether these were symmetrical around the vertical axis or not. It was found that the yes-responses were 11ms faster in LVF than RVF, suggesting different abilities for processing symmetry in the two hemispheres. Brysbaert (1994) examined the effects of lateral preferences (handedness, footedness, eye and ear preference) on VHF asymmetries and used symmetry detection as one of the tasks. He reported a small but significant LVF advantage for the task. More recently, Wilkinson & Halligan (2002) examined stimulus bisection in LVF and RVF (i.e., the so-called landmark task) and reported that stimulus symmetry contributed to the performance in LVF but not in RVF. From this finding they concluded that “the detection of visual symmetry is preferentially lateralized to the right hemisphere” (p. 1045). These findings were confirmed in a later fMRI study (Wilkinson & Halligan, 2003) when it was found that the presence/absence of symmetry corresponded to activity in the right anterior cingulate gyrus, an area associated with a variety of higher level attentional functions. The superior perception of line bisection in LVF was associated with activation in the right superior temporal gyrus.

However, other studies failed to find evidence for right hemisphere superiority in symmetry perception. Herbert & Humphrey (1996), for instance, examined whether the quick perception of vertical symmetry at fixation could be due to interhemispheric comparison and indeed found that the detection of vertical symmetry at fixation was anomalous in two persons born without corpus callosum, but relatively normal for presentation off fixation. More importantly for the present purpose, they did not report a significant advantage for stimuli presented in LVF.

Neuroscientific methods also point to a strong bilateral brain activation in symmetry detection tasks. In an fMRI study, Tyler et al. (2005) presented observers with symmetric and random dot patterns. The symmetric configurations were found to selectively activate a region in the dorsolateral occipital cortex (DLO) and activity did not differ significantly between hemispheres. Sasaki et al. (2005) also reported that symmetrical patterns (both of dots and lines) activated the extrastriate visual cortex in human and non-human primates (areas V3A, V4, V7 and LO); they did not observe hemispheric differences either (at least none were reported in the ms). Finally, Cattaneo et al. (2011) used TMS to investigate the neural correlates of symmetry perception. As expected, they found that pulses to DLP affected symmetry detection, whereas pulses to V1/V2 did not have an adverse effect. Importantly for the present discussion, no hemispheric differences were reported (in one analysis there even was a tendency towards left-hemisphere

dominance). For the correct interpretation of the neuroscientific findings it is important to keep in mind that they all involved large stimuli (up to 20 degree of visual angle) extending into both VHF. As illustrated by Herbert & Humphrey (1996), particularly for vertical symmetry there is a likely difference between symmetry perception at fixation and symmetry detection off fixation, with strong interhemispheric interactions in the former case.

In the present study, we first examined whether we could replicate the LVF advantage for parafoveal symmetry detection in right-handed participants, as reported in the four studies discussed above. One reason why other researchers may have failed to find the effect is that not all VHF studies adhere to good methodological standards (Hunter & Brysbaert, 2008). In particular, it has been found that VHF asymmetries are much more stable and consistent when independent information is presented simultaneously in LVF and RVF and participants have to respond to the stimulus indicated by a central arrow. Because of the bilateral presentation, the influence of attention capture by the stimulus onset is reduced. In addition, the simultaneous arrival of information in the two hemispheres gives the dominant hemisphere more chances to outperform the non-dominant hemisphere. Also, the central arrow forces the participant to pay attention to the fixation location before stimulus onset. Therefore, we first wanted to see whether the LVF advantage for parafoveal symmetry detection can be

replicated under suitable methodological conditions (Experiment 1). To further extend the results, the same experiment was tested in a group of left-handed subjects with typical left hemispheric speech lateralization (Experiment 2). Their lateralization was assessed with two VHF naming tasks and in some cases confirmed with an fMRI silent word generation task, comparing left and right hemisphere activity in Broca's area (see Hunter & Brysbaert, 2008; Van der Haegen, Cai, Seurinck & Brysbaert, 2011, for further details). Finally, left-handers with known atypical right speech lateralization took part in the VHF task (Experiment 3). This allowed us to test whether the lateralizations of speech and symmetry detection are statistically independent or whether there is a bias to have both functions separated (see Cai, Van der Haegen, & Brysbaert, 2013, for a recent review of this literature).

## **Experiment 1**

Research about symmetry detection has been done with very different stimulus materials ranging from simple dot patterns to polygons and complex art displays (Carmody, Nodine & Locher, 1977; Locher & Nodine, 1989; Locher & Wagemans, 1993; Donnelly, Humphreys, & Riddoch, 1991). Here, we chose to use symmetric and asymmetric arrangements of rectangles, because these stimuli were

used in previous studies suggesting a right-hemisphere advantage for symmetry detection (Brysbaert, 1994; Wilkinson & Halligan, 2002, 2003).

## **Method**

***Participants:*** Participants were 20 right-handed students from Ghent University. Handedness was assessed with a Dutch translation of the Edinburg Handedness Inventory (Oldfield, 1971). A questionnaire about eye preference, ear preference, and footedness was also administered (Porac & Coren, 1981). Participants were asked to use a number between -3 and -1 to indicate their degree of left side preference and between +1 and +3 to indicate their degree of right side preference (Brysbaert, 1994). Miles' (1930) test of eye-dominance was also administered to the participants. Finally, all participants had been diagnosed as left lateralized for speech production in an earlier fMRI study by Van der Haegen et al. (2011).

***Stimuli:*** The stimuli were figures made in black lines against a white background. They were made by joining three horizontal rectangles, one above another giving rise to a symmetric or an asymmetric arrangement (Figure 1). There were 60 different symmetric and 60 different asymmetric stimuli. They were up to 4° wide and 2° high.

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Insert Figure 1 here

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***Procedure:*** Participants were seated in front of a 17” inch computer screen at a distance of 80 cm. Before the start of each session, they were familiarized with the stimuli, by giving them a central tachistoscopic presentation of the various stimuli on the computer screen.

Stimulus presentation followed the VHF protocol outlined by Hunter and Brysbaert (2008). A trial started with the presentation of a blank screen for 1000 ms. Then a fixation cross (sized  $1^\circ$  of visual angle) appeared at the centre of the screen for 300 ms. Participants were instructed to focus on the cross when it appeared. The cross was followed by a slide with two stimulus figures presented left and right at a distance of  $3^\circ$  from the fixation location, and a centrally presented arrow (sized  $1^\circ$  of visual angle). The arrow could point towards LVF or RVF and participants had to respond to the stimulus at the side indicated. Because stimulus presentation was bilateral and participants had to process the central arrow, the stimuli could be presented for 200 ms without running the risk of fast saccades to one of them (Walker & McSorley, 2006). The stimuli appearing in LVF or RVF could be symmetric or asymmetric. For symmetric stimuli

participants had to press buttons with their left and right index fingers simultaneously; for asymmetric stimuli they had to press with the left and right middle fingers. Bimanual responses were used to avoid the stimulus-response compatibility effect (i.e. the fact that responses with the right hand are faster to stimuli in RVF while responses with the left hand are faster to stimuli in LVF).

There were four types of trials depending on the direction of the central arrow and whether or not the target stimulus was symmetric or asymmetric. The four types were Left Symmetric (central arrow pointing towards LVF, symmetric figure presented in LVF), Left Asymmetric (central arrow pointing towards LVF, asymmetric figure in LVF), Right Symmetric (central arrow pointing towards RVF, symmetric figure in RVF), and Right Asymmetric (central arrow pointing towards RVF, asymmetric figure in RVF). The stimulus in the non-target VHF was always incompatible with the target stimulus (i.e., if a symmetric figure had to be attended to, the distractor stimulus was of the asymmetric type).<sup>1</sup> The specific stimuli (out of the 60 possibilities) were randomly selected by the experiment presentation software. The experiment was preceded by 40 practice trials, while the main block contained 160 trials (40 trials of each type). As there were 120 stimuli

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<sup>1</sup> In other experiments we sometimes present stimuli of both the compatible and the incompatible type in the distractor VHF (e.g., Hunter & Brysbaert, 2008). We did not do so here, because it would have required us to make the experiment longer if we wanted to have a decent number of observations in all conditions. Based on pilot testing we also had the fear that bilateral symmetry presentation might be too salient (i.e., would elicit particularly fast responses). As the participants were instructed to constantly fixate at the center of the screen and to respond as rapidly as possible to the indicated stimulus, we did not have the impression that they were able to make use of any redundancy in the distractor stimulus, an impression that seems to be borne out by the findings.

and 200 trials each involving 2 randomly drawn stimuli, some trials contained a stimulus in LVF or RVF that had been shown before. Stimulus repetition does not affect the VHF asymmetry in the Hunter & Brysbaert (2008) protocol, not even with word stimuli (e.g., Van der Haegen et al., 2011). As a matter of fact, Hunter and Brysbaert (2008) recommend the repetition of stimuli over VHFs, as this ensures that the stimulus materials presented in LVF and RVF are matched. In the present studies there were no indications either that the asymmetry was different in the first half of the experiment than in the last half.

## **Results**

Separate 2x2 analyses of variance (ANOVAs) were run on the reaction times (RT) of the correct trials and the percentages of errors (PE). The factors were VHF (left and right) and Stimulus Type (Symmetric and Asymmetric). For the RT data, this resulted in a significant main effect of VHF (LVF= 484 ms, RVF= 522 ms;  $F(1, 19) = 12.859, p < 0.01$ ). Also, a significant main effect of Stimulus Type was observed (Symmetric= 485 ms, Asymmetric= 521 ms;  $F(1, 19) = 20.299, p < 0.01$ ). The interaction of VHF and Stimulus Type was not significant,  $F(1, 19) = 1.748, p = 0.202$ ; although there was a trend towards a larger LVF advantage for symmetric figures than for asymmetric figures on the basis of the mean scores. For symmetric

figures, the LVF advantage was 55 ms while for asymmetric figures the advantage was only 23 ms. In all, 16 out of the 20 right-handed participants showed the left-visual field advantage for symmetric figures, while only 12 participants showed the advantage for asymmetric figures.

For the error data, the main effect of VHF was significant, (LVF=13.7%, RVF=19.3%;  $F(1, 19) = 14.129, p < 0.01$ ). There was no significant effect of Stimulus Type, but the interaction between VHF and Stimulus Type was significant ( $F(1, 19) = 8.058, p < 0.05$ ), because the LVF advantage was larger for symmetric than asymmetric pictures. In terms of errors 18/20 participants showed an LVF advantage for symmetric figures, while only 8 participants showed the LVF advantage for asymmetric figures.

The fact that a high number of participants show the difference is reassuring as it confirms that the LVF advantage is not due to a small number of participants with very large asymmetries. Also the fact that the advantage is larger for symmetric figures than for asymmetric figures provides support for our speculation that the advantage can be attributed specifically to symmetry detection and is not due to the visual properties of the 2-d shapes we used as stimuli. The data are shown in Figure 2.

We also checked for any kind of practice effects for the symmetric and asymmetric stimuli by comparing the first and second halves of each of the four conditions, but did not find any statistically significant difference, neither in terms of RT nor accuracy.

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Insert Figure 2 Here

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## **Discussion**

In the first experiment we sought to investigate whether we could replicate the LVF advantage for symmetry detection reported in a few studies primarily aimed at other variables (the influence of lateral preferences on VHF asymmetries; Brysbaert, 1994; and the contribution of stimulus symmetry to performance on the landmark task; Wilkinson & Halligan, 2002). In both RTs and PEs, our hypothesis of right hemisphere dominance was confirmed for right-handers with known left hemisphere speech dominance. The effect was larger for symmetric stimuli than for asymmetric stimuli, a finding that is often reported in yes/no-decision tasks. Indeed, in many lexical decision experiments the robust RVF advantage is only observed for words and not for non-words (Howell & Bryden, 1987; Laine &

Koivisto, 1998; Measso & Zaidel, 1990; Mohr et al. 1994; Nieto et al. 1999). In the next experiment we investigate what happens in left-handers with typical left hemispheric language lateralization.

## **Experiment 2**

Now that we have shown an LVF advantage for most right-handers with confirmed left hemispheric speech lateralization when taking strict methodological considerations into account, the next step is to evaluate the robustness of this effect. In general, more variability of functional brain organization has been found in left-handers (Bradshaw & Nettleton, 1981), making them a suitable group to test the reproducibility of the LVF advantage observed in Experiment 1. Part of the variability in left-handers is due to the fact that they more often have atypical speech dominance. It is estimated that 20-25% of the left-handers have atypical dominance (Knecht et al., 2000), against only 1-5% of the right-handers. In addition, it might be expected that left-handed participants with left speech dominance show more variability in the laterality scores of various functions than right-handers. In genetic models of hand preference, left-handedness is thought to be the result of a gene generating random laterality preferences (e.g., McManus, 1985). This may lead to more cross-lateralization of functions (such as speech production and symmetry detection) in left-handers than in right-handers.

In Experiment 2, we first tested the VHF asymmetry for symmetry detection in a rather large group of left-handers, who were comparable to the participants of Experiment 1 in terms of left hemisphere language functioning. In Experiment 3, we looked at a smaller group with known right hemisphere speech dominance, to see what consequences a specialization shift from the left to the right inferior frontal gyrus has for the brain functions underlying symmetry detection.

## **Method**

***Participants:*** Participants were 37 left-handed participants from Ghent University. The group originally consisted of 19 individuals who had been confirmed as left hemisphere speech dominant with fMRI (for more details, see Van der Haegen et al., 2011). Because the findings with the original group were somewhat ambiguous (a clear trend, but no significance), we nearly doubled the group to maximize the power of the study<sup>2</sup>. We were unable to scan the additional individuals, but they were selected on the basis of a VHF word and picture naming task. All had a clear RVF naming advantage of more than 20 ms in one of the tasks, and no LVF advantage in the other task. Based on the results of Hunter & Brysbaert (2008) and Van der Haegen et al. (2011), we can be confident that this approach reduced the chances of including an atypically lateralized participant to almost zero. The 37

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<sup>2</sup> The authors thank an anonymous reviewer for this suggestion.

left-handers were given the same test as in Experiment 1 and were paid for participating in the experiment.

***Stimuli and procedure:*** The stimuli and the procedure were exactly the same as in Experiment 1.

## **Results**

We ran a 2 x 2 ANOVA with VHF (2 levels: LVF, RVF) and Stimulus type (2 levels: Symmetric, Asymmetric) as factors. For the reaction time (RT) data, the ANOVA yielded neither a significant main effect of VHF nor Stimulus type. However, the interaction effect was significant ( $F(1,36)= 16.28, p<0.01$ ). For the percentage error data, there was no significant main effect of VHF or Stimulus type either. Again, the interaction was significant ( $F(1,36) = 10.75, p<0.01$ ). One-way ANOVAs, indicated that the VHF effect was significant for the symmetric stimuli (RT: LVF = 519 ms, RVF = 553 ms,  $F(1, 36) = 13.34, p<0.01$ ; PE: LVF = 18.5%, RVF = 26.5%,  $F(1, 36) = 15.42, p<0.01$ ) and for the asymmetric stimuli. However, for the latter, the direction was opposite with evidence of a RVF advantage, which was significant for RT (LVF = 562 ms, RVF = 546 ms;  $F(1,36) = 5.29, p<0.05$ ), but not for PE (LVF = 21.6%, RVF = 17.7%;  $F(1,36) = 2.93, p=.095$ ).

When we looked at the individual data, we saw that 29/37 (78.4%) of the participants showed the LVF advantage for the symmetric stimuli in terms of RTs, and 28/37 (75.7%) in terms of accuracy. For the asymmetric stimuli, 25/37 (67.5%) of the participants had the opposite RVF advantage in RTs, and 23/37 (62.1%) in terms of accuracy.

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Insert Figure 3 about here

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## **Discussion**

In line with the right-handed group of Experiment 1, the left dominant left-handers of Experiment 2 had a clear LVF advantage for symmetric stimuli, although the size of the advantage (RT = 34 ms, PE = 8.0%) tended to be smaller than in Experiment 1 (RT = 55 ms, PE = 13.7%). At the same time, there was evidence for more distributed processing in left-handers than in right-handers, as we observed some evidence for a RVF advantage in the processing of asymmetric stimuli (Figure 3).

In terms of individual differences, there were few indications that the LVF advantage for symmetric stimuli was less stable in left-handers than in right-

handers, as the percentage of participants showing the effects was remarkable similar for RT (16/20 or 80% in right-handers vs. 29/37 or 78.4% in left-handers). For accuracy there was a trend towards less consistency in left-handers (18/20 or 90% of the right-handers vs. 28/37 or 75.7% of the left-handers made fewer errors in the LVF condition).

### **Experiment 3**

In a final experiment, we addressed the question whether different functions lateralize independently or whether atypical speech dominance creates atypical laterality for visuospatial functions as well. The first view says that verbal and visuospatial abilities are independent functions and, therefore, lateralize separately. This possibility was first raised by Bryden, Hecaen, & DeAgostini (1983) who reported that “an analysis of the concurrent incidence of aphasia and spatial disorder in 270 patients with unilateral brain damage suggests that the two functions are statistically independent” (p. 249). Although aphasia was more frequent after left hemisphere damage and spatial disorders after right hemisphere damage, the incidence of combined disorders was not less than predicted on the basis of statistical independence. From this finding Bryden et al. (1983) concluded that the complementary specialization of the hemispheres is not causal in nature

and that atypical laterality of one function has no implication for the other. Similar suggestions were made by Kosslyn (1987), Whitehouse & Bishop (2009), Badzakova-Trajkov, Häberling, Roberts, & Corballis (2010), and Pinel & Dehaene (2010).

The alternative view says that atypical laterality of language will result in reversed laterality for other functions. Such a result can be expected on the basis of the *cognitive crowding hypothesis* (Lansdell, 1969; Levy, 1969; Teuber, 1974). According to this hypothesis, visuospatial abilities cannot fully develop in the language hemisphere and are “crowded out” to the other brain half. Supporting evidence for this theory was recently reported by Cai, Van der Haegen & Brysbaert (2013) who ran an fMRI study on a visuospatial attention task (the landmark task) with the same participants as in the present study. In the landmark task brain activity was compared between an experimental condition, in which participants had to judge whether a vertically displayed line bisected a horizontal line in the middle, and a control condition, in which participants had to indicate whether the vertical line touched the horizontal line. The landmark task is known to activate a dorsal fronto-parietal pathway in the right hemisphere. Cai et al. (2013) found that their data were almost completely in line with the crowding hypothesis: Whereas 15 of 16 participants with LH speech dominance showed the expected RH asymmetry, all 13 participants with RH speech had a reversed LH laterality in the

landmark task. The authors argued that the complementarity pattern had been obscured in previous studies, because inadequate comparison conditions had been used and/or the reliability of the measures had not been ascertained, so that measurement noise could have been mistaken for independence of cognitive functions.

Given the findings of Cai et al. (2013), it would be interesting to know whether their results can be replicated with the present symmetry task. The predictions are straightforward. According to the cognitive crowding hypothesis, we should observe a reversed RVF advantage for symmetric stimuli in participants with right hemisphere language dominance. In contrast, according to the statistical independence hypothesis, atypical lateralization of language should have no influence on the laterality of symmetry detection and, hence, participants with right speech dominance should show the same LVF advantage for symmetric stimuli. Seventeen left-handers with known atypical RH dominance (Van der Haegen et al., 2011) took part in the symmetry detection task. Given the data of Experiment 2, this is a rather small sample. However, it is the best we could achieve, given the difficulty to find participants with atypical brain asymmetry.

## **Method**

**Participants:** Participants were 17 left-handed participants from Ghent University who were recruited from the study by Van der Haegen et al. (2011). They were all identified as being clearly atypically right lateralized for speech by the fMRI study. Participants were paid for their participation.

**Stimuli and procedure:** The stimuli and the procedure were exactly the same as in Experiments 1 and 2.

## Results

The data are shown in the lower part of Figure 3. As in Experiment 2, we performed 2 x 2 ANOVAs on the RTs en PEs with VHF (2) and Stimulus type (2) as factors. There was no significant main effect of VHF, neither for RT (LVF = 578 ms, RVF = 562 ms;  $F(1,16) = 1.59, p=.22$ ), nor for PE (LVF = 19.2%, RVF = 16.6%;  $F(1,16) = 2.24, p=.15$ ). The main effect of stimulus type was significant for RT (symmetric = 554 ms, asymmetric = 586 ms;  $F(1,16) = 7.56, p<0.05$ ), but not for PE (symmetric = 18.3%, asymmetric = 17.4%;  $F(1,16) = .09, p=.76$ ). Although the interaction between VHF and Stimulus type was not significant (RT:  $F(1,16) = .05, p=.81$ , PE:  $F(1,16) = .37, p=.55$ ), we ran one-way anova for the symmetric and asymmetric stimuli separately, given their central roles in our prediction. For symmetric figures, there was a RVF advantage of 19 ms and 4.7%, but this failed to reach significance both in RT (LVF = 563 ms, RVF = 544 ms;  $F(1,16) = .852$ ,

$p=.370$ ) and PE (LVF = 20.7%, RVF = 16.0 %;  $F(1,16) = 1.415$ ,  $p=0.252$ ). For the asymmetric figures, a similar but even smaller trend to RVF advantage was found, which was far from significant, both in RT (LVF = 592 ms, RVF = 579 ms,  $F(1,16) = .699$ ,  $p=.416$ ) and PE (LVF = 17.7%, RVF = 17.1% ;  $F(1,16) = .034$ ,  $p=.857$ ).

In terms of individual scores, for the symmetric stimuli in the reaction time (RT) data only 8 out of 17 participants had the RVF advantage predicted by the crowding hypothesis while 9 participants showed a LVF advantage. For the percentage of errors, 9 out of 17 participants had a RVF advantage while the other 8 participants showed a LVF advantage. For the asymmetric stimuli, in terms of reaction times 9 out of 17 participants displayed the RVF advantage for RT and 8 out of 17 participants for PE.

To further test the relationship between speech dominance and laterality of symmetry detection, we correlated the VHF differences in RT obtained in the present experiment with the participants' speech laterality indices, as reported by Van der Haegen et al. (2011). These laterality indices were based on the difference in brain activity in Broca's area between the left and the right hemisphere (measured with fMRI) while the participants were silently generating words starting with a target letter (see Van der Haegen et al., 2011, for further details about the task and the calculation of the laterality index). This analysis was limited

to the 19 left-handed participants of Experiment 2 and the 17 left-handed participants of Experiment 3, who took part in the earlier fMRI study, as the speech laterality index could not be calculated for the 18 additional participants of Experiment 2 and we wanted to avoid a confound with handedness (therefore excluding the right-handed participants from Experiment 1). There was a positive correlation of  $r = .299$  ( $N = 36$ ,  $p = .076$ ) for symmetric figures (indicating that participants with a strong LH dominance for language showed a larger LVF advantage for symmetry detection) while only a correlation of  $0.144$  ( $N = 36$ ,  $p = .403$ ) was found for asymmetric figures.

## **Discussion**

Experiment 3 revealed a trend towards a RVF advantage for parafoveal symmetry detection in participants with atypical right hemispheric speech dominance. This finding is more in line with the predictions of the cognitive crowding hypothesis than the statistical independence hypothesis, which would have been confirmed if the participants with atypical speech dominance had shown a LVF advantage as well. This suggests that the consequences of atypical speech laterality go beyond language-related functions. Cai et al. (2013) reached the same conclusion on the basis of the landmark task. At the same time, it must be acknowledged that there was much more variability among the participants with atypical speech dominance, because the RVF advantage was found in only half of the sample. As a result, the

RVF advantage was not statistically significant. So, although the data point against the statistical independence hypothesis, they do not point against a view of more variability in participants with atypical speech dominance.

Further of interest is the observation that the VHF advantage was the same for symmetric and asymmetric figures, in line with the results of Experiment 1 and opposite to those of Experiment 2. A possible interpretation could be that the left-handed LH dominant participants of Experiment 2 had their control centers for speech and dominant hand in opposite hemispheres, whereas for all other participants these centers were in the same hemisphere (either LH or RH).

Future studies with larger samples of atypically lateralized subjects are needed to confirm the explorative findings of Experiment 3. In conjunction with the correlational analysis of the lateralization indices and VHF differences, these data do give a first indication that symmetry detection lateralizes to the language non-dominant hemisphere.

## **General discussion**

In this paper we addressed two questions:

- a) Whether symmetry detection is a right hemisphere function resulting in a LVF advantage in a VHF-paradigm.
- b) Whether the VHF advantage differs in people with typical and atypical language dominance.

For the first question we sought to replicate a pattern we discerned in the literature (Corballis & Roldan, 1974; Brysbaert, 1994; Wilkinson & Halligan, 2002, 2003) but which had mainly been investigated as a secondary phenomenon. Given that symmetry detection is a fast-acting visual function and given that most visuospatial functions are lateralized to the right in the majority of people, we hypothesized that we should observe a robust LVF advantage in a properly run VHF task (Hunter & Brysbaert, 2008). We indeed were able to do so (Experiments 1 and 2). For the correct interpretation of this finding it is important to keep in mind that the symmetry detection we studied consisted of symmetry outside the fixation location. As discussed in the introduction, there is evidence that symmetry detection at fixation may be based on other processes (Herbert & Humphrey, 1996)

with bilateral involvement of the extrastriate dorsolateral occipital cortex (Cattaneo et al., 2011; Sasaki et al., 2005; Tyler et al., 2005).

We used Hugdahl's (2000) distinction between language and visuospatial functions as the basis of our prediction. However, we do not want to exclude the possibility that the finding is in line with other hypotheses of brain asymmetry as well. One of these hypotheses is the *spatial frequency hypothesis* (Sergent, 1983; De Valois & De Valois, 1988; Kosslyn, Chabris, Marsolek & Koenig, 1992). According to this hypothesis, the right hemisphere is specialized in processing low spatial frequencies, whereas the left hemisphere is better at processing high spatial frequencies. Our data are in line with this hypothesis if we assume that the symmetry decision in our task was based on low spatial frequency information. Indeed, some early theories postulated that symmetry detection largely depended on low level spatial grouping (Barlow & Reeves, 1979; Julesz, 1979). However, more recent models of symmetry perception no longer assume a dominance of low-frequency information but include filters of different frequencies and orientations, which are used flexibly as a function of stimulus complexity (Dakin & Hess, 1997; Poirier & Wilson, 2010).

Another hypothesis of hemispheric specialization is that the right hemisphere may be specialized in identifying the global forms of stimuli, whereas the left hemisphere would be more specialized at processing details (Lamb, Robertson, &

Knight, 1989, 1990). Our data are in line with this view if we can assume that the symmetry perception for our stimuli was based on the global form of the stimulus. There indeed seem to be two particularly informative regions of information for symmetry perception: one around the symmetry axis and one consisting of the stimulus outline (Wenderoth, 1995).

The two alternative views illustrate that the division between language processing vs. visuospatial processing need not be the only distinction explaining the right hemisphere dominance for symmetry detection in the stimuli we used. An intriguing possibility of the alternative views is that different types of stimuli may induce different hemispheric superiorities (and VHF advantages) for more complex figures or figures with asymmetries in the details. This could also explain why not all studies have found a LVF-advantage for symmetry perception, which is an attractive option for future research.

The second question addressed in this paper is what consequences atypical language laterality has for the lateralization of other functions. This is still a much under-investigated issue in brain research. At first, researchers assumed complementarity of the brain hemispheres with a causal role of speech laterality. Lateralization of speech implied that all language-related functions were localized in the same hemisphere, and that other functions, in particular visuospatial functions, were forced to the other hemisphere. An example of this view is the

cognitive crowding hypothesis (Lansdell, 1969; Levy, 1969; Teuber, 1974), discussed in the Introduction (see also Plaut & Behrmann, 2011, for a recent computational implementation of this view).

The complementarity view was questioned by Bryden et al. (1983), who observed a higher incidence of combined language and spatial disorders after unilateral brain damage than predicted. In their view, the pattern of results was more in line with a statistical independence interpretation, according to which there is bias to left lateralization of language and a bias to right lateralization of visuospatial functions, but no cross-talk between both biases. Such an interpretation was in line with the modularity model of the brain that became dominant in the 1980s (Fodor, 1983). According to this model, the brain consisted of several independent (encapsulated) modules functioning autonomously. The idea was taken up by several laterality researchers (e.g., Kosslyn, 1987; Brysbaert, 1994) and is still used as a framework for the interpretation of brain imaging data (Badzakova-Trajkov, Häberling, Roberts, & Corballis, 2010; Pinel & Dehaene, 2010). Surprisingly, when it was investigated in the largest group of people with atypical speech dominance examined thus far, the statistical independence idea failed to predict the findings (Cai et al., 2013). As a matter of fact, the findings were almost completely in line with the complementarity view (only one exception on a total of 29 participants tested).

Our data (Experiment 3) are also more in favor of the complementarity view than the statistical independence view. Whereas right-handed and left-handed participants with LH speech dominance showed a LVF advantage of 30 ms and more (Experiments 1 and 2), left handed participants with RH dominance showed a reverse RVF advantage of some 20 ms (Experiment 3). According to the statistical independence hypothesis, atypical lateralization of language should have had no influence on the laterality of symmetry detection and, hence, all groups should have shown the same LVF advantage for symmetry detection. At the same time, there was quite some variability in the data of the RH dominant participants, preventing the RVF advantage from being significant. Therefore, it is safer to consider Experiment 3 as a pilot experiment to be backed up and extended by future investigations.

## **Conclusion**

In the present study, we set out to determine whether symmetry detection off fixation is a cognitive function lateralized to the right hemisphere, like the other visuospatial functions. For this purpose we chose a behavioral VHF task along the lines recommended by Hunter & Brysbaert (2008). In two experiments we found a clear LVF advantage for the detection of symmetrical figures in LH speech

dominant participants. In the last experiment we observed a trend towards a reversed RVF advantage for participants with RH speech dominance. These findings are in line with the proposal that visuospatial functions lateralize to the brain half opposite to the hemisphere involved in language processing (Hugdahl, 2000).

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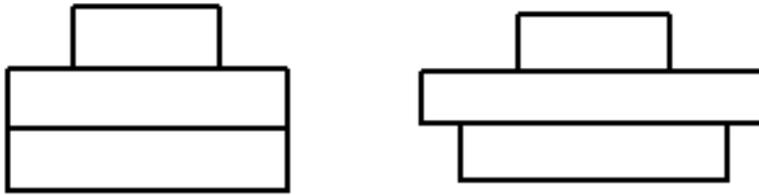
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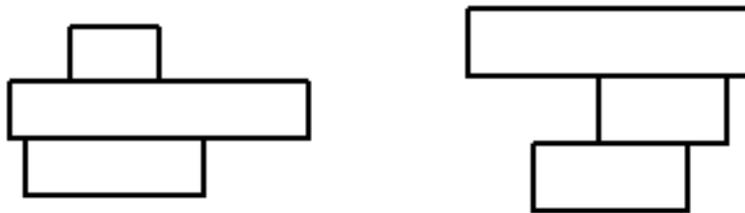
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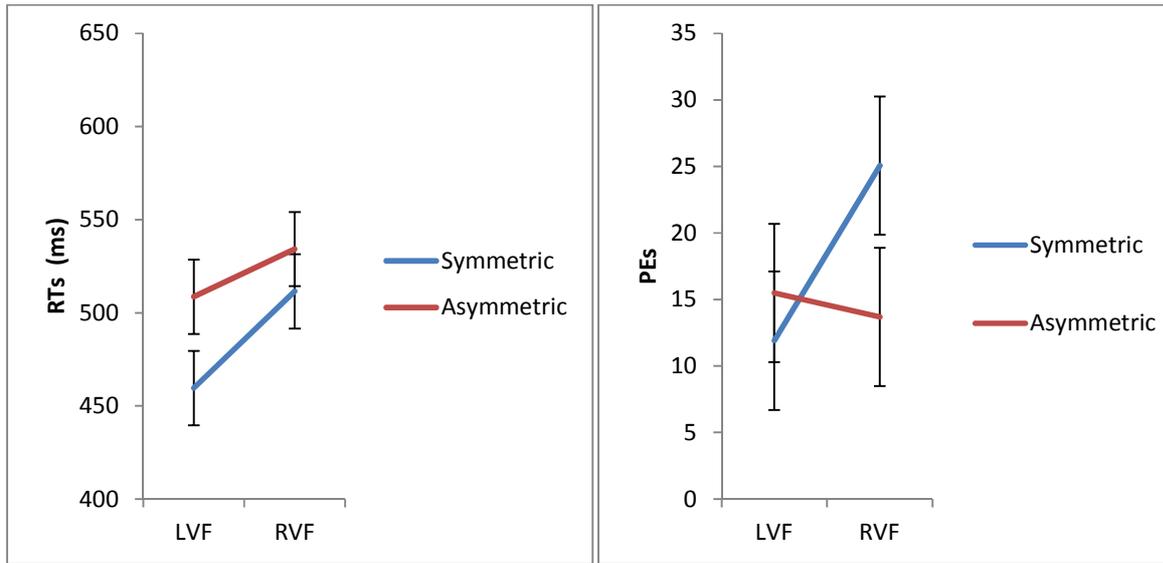


Symmetric Shapes



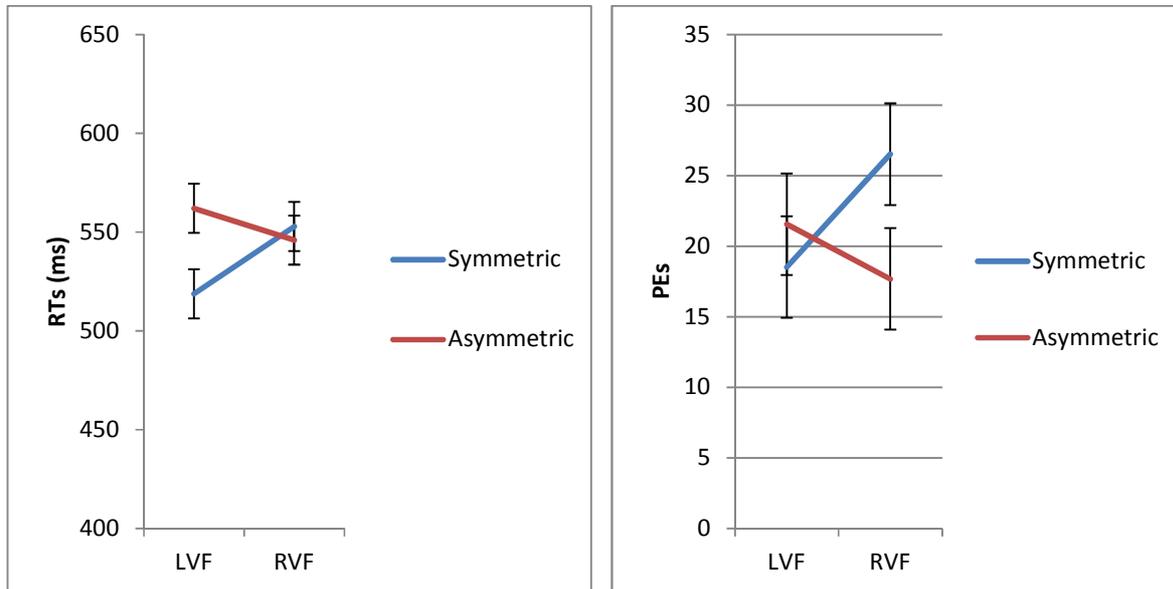
Asymmetric Shapes

Figure 1: Two examples of the symmetric and the asymmetric shapes used as stimuli in the experiments. All stimuli were made by joining three horizontal rectangles that could differ in length.

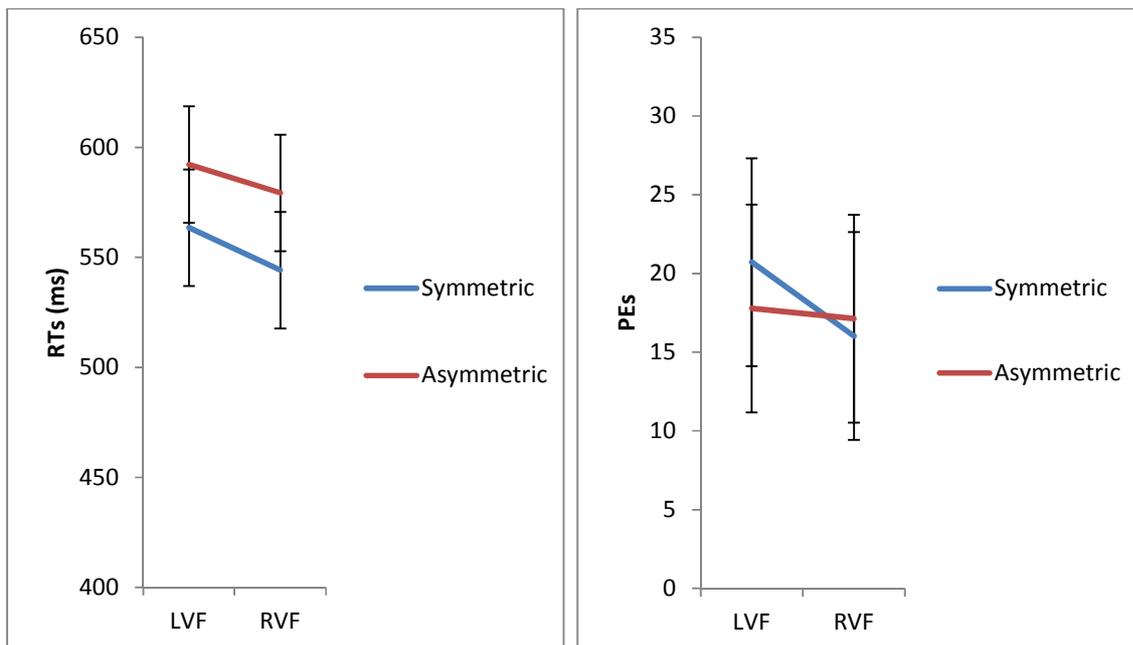


**Figure 2: A LVF advantage for symmetry detection in right-handers (left panel: RT; right panel: PE). The VHF asymmetry is clearer for symmetric pictures (responses) than for asymmetric pictures (responses), in line with the observation in lexical decision that the VHF asymmetry is clearer for yes-responses to words than for the slower no-responses to non-words. Error bars indicate the 95% confidence intervals and are based on the error terms of the VHF \* Stimulus type ANOVA (Masson & Loftus, 2003).**

Panel A: Left Dominant (typically lateralized) participants



Panel B: Right Dominant (atypically lateralized) participants



**Figure 3: VHF asymmetries of left-handers as a function of language dominance. Panel A shows the performance of the left hemisphere dominant (typically lateralized) participants (left: RT; right: PE). Panel B shows the performance of the right hemisphere dominant (atypically lateralized) participants. For the symmetric**

**figures, there is a clear interaction between VHF and cerebral dominance (a LVF advantage for the typically lateralized participants and a trend towards RVF advantage for the atypically lateralized participants). Contrary to the findings of the participants with language and motor control in the same hemisphere, the left-handed participants with LH language control tended to show an opposite VHF advantage for the asymmetric figures than the symmetric figures (top panel). Error bars indicate the 95% confidence intervals and are based on the error terms of the VHF \* Stimulus type ANOVA (Masson & Loftus, 2003).**