ORIGINAL ARTICLE

Brain asymmetry for verbal stimuli in relation to dichotic listening performance, verbal and nonverbal intellectual abilities

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Abstract

OBJECTIVES: A degree of lateralization of verbal functions could explain at least some performance variation in verbal tasks. The aim of the present paper was to investigate the relationship between perceptual asymmetry for verbal auditory stimuli and dichotic listening performance, verbal and nonverbal intellectual abilities. Since both verbal and nonverbal abilities tests were delivered through the visual modality, they allowed us to consider whether the relationship between functional asymmetry and task performance is dependent on a sensory modality.

METHODS: Seventy-six right-handers with normal hearing were presented with a verbal dichotic listening task (six stop-consonant-vowel syllables ‚ba', ‚da', ‚ga', ‚ka', ‚pa', and ‚ta'). A free recall dichotic listening paradigm was employed without time limit for the answer. Subsequently, nonverbal and verbal ability tests were completed.

RESULTS: A u-shaped relationship between the asymmetry for verbal stimuli and overall dichotic listening performance was found: individuals with greater hemispheric asymmetry reported more stimuli correctly. Moreover, a similar u-shaped relationship between the asymmetry for verbal stimuli and nonverbal abilities emerged: stronger asymmetry was connected with better performance.

CONCLUSION: Our results might indicate that the asymmetry for verbal stimuli is connected not only with performance in the auditory verbal task but also with the general nonverbal intellectual abilities such as the ability to reason and solve novel problems independent of any previous knowledge .

Introduction

For the study of perceptual brain asymmetries, a dichotic listening paradigm and a visual half-field technique are widely used. In both of these behavioral techniques, different stimuli are presented simultaneously to each ear or visual half-field. The stimuli presented to the right ear (or the right visual half-field) are transmitted preferentially to the left hemisphere, whereas the stimuli presented to the left ear (or the left visual half-field) are transmitted preferentially to the right hemisphere. If verbal stimuli are presented, higher accuracy of recall typically occurs in the stimuli presented to the right ear and the right visual hemifield (for a review see Bryden 1982; Beaumont 1982). This is interpreted as a consequence of the left hemisphere specialization for language processing (Hugdahl 2003; Tervaniemi & Hugdahl 2003).

Previous research has shown that nearly all higher mental functions (such as perception, spatial cognition, memory, attention) show some degree of hemispheric specialization (e.g. Bryden 1982; Hellige 1993; Davidson & Hugdahl 1995; Voyer 1996). This functional brain asymmetry probably helps to utilize available sensory information in a better way, e.g. faster and more appropriately (Jagla 2014). The degree of asymmetry is subject to interindividual differences. For example, as shown by the dichotic listening and visual half-field techniques, verbal processing is more lateralized toward the left hemisphere in men compared to women (Bryden 1979, 1982; Hiscock *et al* 1994, 1995; Voyer 1996). These results are supported by functional neuroimaging studies (Shaywitz *et al* 1995; Jaeger *et al* 1998; Kansaku *et al* 2000; Gur *et al* 2000; Baxter *et al* 2003). It has been shown that women tend to perform better in verbal tasks (Hyde & Linn 1988), and therefore it seems that at least some performance variation in verbal tasks might be explained by a degree of lateralization of verbal functions. Indeed, there are several studies showing that stronger language lateralization is correlated with better performance in various verbal tasks, such as verbal abilities tests (Everts *et al* 2009; van Ettinger-Veenstra *et al* 2010), reading (Chiarello *et al* 2009) and verbal memory (Catani *et al* 2007). However, the exact mechanisms by which brain asymmetry influences performance are not clear. Using dichotic listening, Boles *et al* (2008) obtained inconsistent results finding a positive relationship between the degree of lateralization and performance in the auditory linguistic task, and a negative relationship for the visual lexical task.

Most of the above studies utilized the correlation approach assuming a linear relationship between variables and used different tasks (mostly visual half-field technique) for assessing the functional asymmetry and for assessing performance. Using the same task (dichotic listening to verbal stimuli) to assess both a degree of asymmetry and a verbal performance Barth *et al* (2012) found that stronger asymmetry was in a relationship with higher overall accuracy in dichotic listening task. A similar result was obtained on an extensive sample by Hirnstein *et al* (2014). On the contrary, using visual half-field tasks Hirstein *et al* (2010) found an inverted u-shape relationship between the asymmetry and performance.

The aim of the present paper was to investigate the relationship between the perceptual asymmetry for verbal auditory stimuli and (1) overall dichotic listening performance, (2) performance in the verbal ability test and (3) performance in the nonverbal ability test. A Quadratic approach was utilized to evaluate the complex relationship between the variables. Since both verbal and nonverbal abilities tests were delivered through the visual modality, it allowed us to consider whether the relationship between the functional asymmetry and task performance is generic or dependent on a sensory modality (auditory vs. visual).

Material and Methods

Participants

Seventy-six right-handers (36 females, 40 males) aged 20–30 years (mean = 25.3; SD=8.37) participated in the study. All subjects were right-handed – handedness was assessed through the Hand Preference Questionnaire (Bryden 1982). Normal hearing for pure tones at 250 Hz, 500 Hz, 1000 Hz, and 2000 Hz was tested. All participants had no history of neurological disorder or traumatic brain injury.

Dichotic listening

Each subject was presented with a verbal dichotic listening task (Jariabková 1987). Six stop-consonant-vowel (CV) syllables ‚ba', ‚da', ‚ga', ‚ka', ‚pa', and ‚ta' pronounced by a female speaker were used as the stimuli. The dichotic task consisted of four trials with a single pair of syllables, four trials with two pairs of syllables, and four trials with three pairs of syllables. The stimuli were paired randomly, with the restriction of the occurrence of the same stimulus in both channels within a trial. The stimuli were digitally remastered, recorded on a CD (Špajdel & Jariabková 2008; Špajdel 2009). The stimuli were played from a CD player via supraaural headphones (total harmonic distortion < 0.7%) at a sound level of 75 dB. A free recall dichotic listening paradigm was employed without time limit for the answer.

Nonverbal ability test

Nonverbal ability test (TIP) developed by Říčan (1971) tests the capacity to reason and solve novel problems, independent of any previous knowledge. It focuses on the ability to analyze novel problems, identify patterns and relationships that underpin these problems and extrapolate them using logical reasoning. The test is based on a relationship between figures (A:B=C:? or A:B=B:C=C:?). In each of the 29 tasks, the subject is asked to complete a sequence of 3 successive figures with one figure chosen from 6 alternatives.

Verbal ability test

Verbal ability test (KVIT) is a shortened form of a Wort-Bild-Test WBT (Anger *et al* 1971). Slovak version of the test was published by Psychodiagnostika in 1995. In each of the 20 tasks, the subject is asked to match a word with one of 4 pictures which fits the meaning of the word best.

Results

A laterality index (LI) was calculated for the dichotic listening task for each subject according to the formula: LI = (R–L)/(R+L), where 'R' and 'L' are numbers of correct responses delivered from the right and left ear respectively. LI varies between −1 (lateralization towards the right hemisphere) to +1 (lateralization towards the left hemisphere).

Quadratic regression was chosen to consider the complex relationship among the variables. The observed values were approximated by the quadratic function and the parabola coefficients were determined by the method of least squares. Three separate regression models were analyzed.

In the first analysis, the overall dichotic listening performance was modeled as a function laterality index (Figure 1). The regression model was significant ($F(2,73)=5.23$; $p=0.008$) and explained 12.5% of variance ($r^2=0.125$).

The second regression model evaluating the performance in the verbal ability test as a function of the laterality index was not significant ($F(2,73)=4.08$; $p=0.622$).

In the last analysis, the performance in the nonverbal ability test was modeled as a function of the laterality index (Figure 2). The regression model was significant ($F(2,73)=4.20$; $p=0.019$) and explained 10.3% of variance ($r^2=0.103$).

Discussion

Our results showed a considerable interindividual variability in the direction and degree of the hemispheric asymmetry measured by the laterality index. Examination of the relationship between the asymmetry and the overall dichotic listening performance revealed a significant quadratic model: a u-shaped curve emerged, where individuals with greater hemispheric asymmetry reported more verbal stimuli correctly. This result is in alignment with Hirnstein *et al* (2014) who used a one-response dichotic listening paradigm with CV syllables. A positive correlation between hemispheric asymmetry and overall dichotic listening performance found by Boles *et al* (2008) does not contradict our results as it corresponds with the right side of the u-shaped regression curve identified in our study.

The interpretation of why greater hemispheric asymmetry is associated with higher performance is not clear yet. Hirnstein *et al* (2014) proposed an explanation based on the fusion phenomenon (when two CV syllables are presented simultaneously, participants sometimes experience sound fusions: for example ‚ba' and ‚da' syllables are merged into the sound ‚pa'). In participants with a clear hemispheric preference, the signal strength for the stimuli from the dominant ear should be consistently higher (with less fusions with the signal from the non-dominant ear) leading to high accuracy for the stimuli delivered to the dominant ear. This interpretation (Hirnstein *et al* 2014) was based on the results obtained by the one-response (either from the left or the right ear) dichotic listening paradigm. In our study, response could be from the left, the right ear or both what at first glance may be in conflict with the proposed interpretation. Considering the fact that the overall dichotic listening performance in our study was relatively low (mean=44.95; SD=6.33), the interpretation proposed by Hirnstein *et al* (2014) cannot be rejected on the basis of our results.

Examination of the relationship between the asymmetry and performance in verbal and nonverbal ability tests revealed that asymmetry-performance relationships are task-dependent. Interestingly, regression model was not significant for the verbal ability test. Since the verbal abilities test was delivered through the visual modality, a possible explanation could be that a relationship between the asymmetry for the verbal stimuli is exclusively connected with the performance in the auditory modality. However, for the nonverbal ability test (administered through the visual modality)

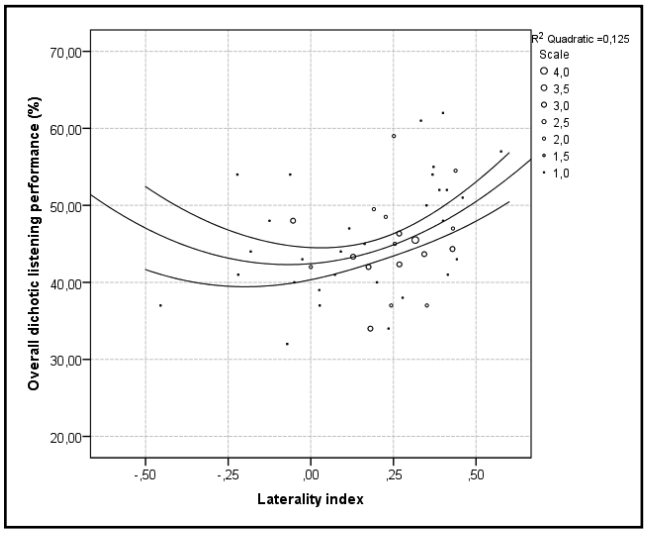

Fig. 1. Relationship between the overall dichotic listening performance in the CV syllables task and laterality index for CV syllables (negative LI values represent lateralization towards the right hemisphere and positive LI values represent lateralization towards the left hemisphere). The corresponding quadratic function and 95% CI are depicted.

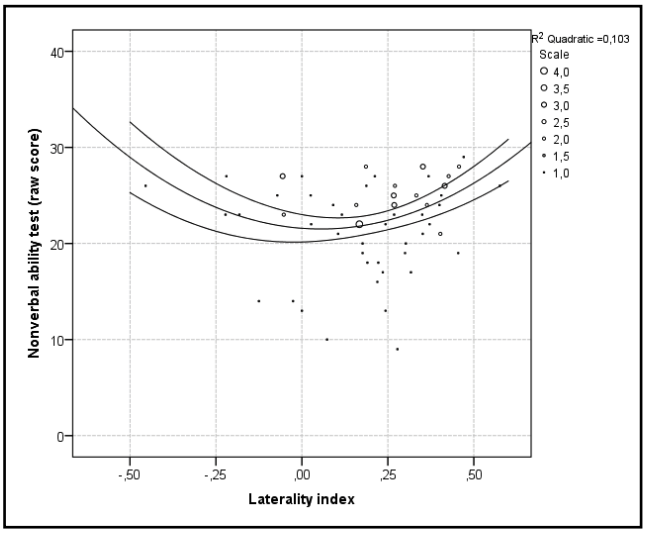

Fig. 2. Relationship between the performance in the nonverbal ability test and laterality index for CV syllables (negative LI values represent lateralization towards the right hemisphere and positive LI values represent lateralization towards the left hemisphere). The corresponding quadratic function and 95% CI are depicted.

the regression model was significant and a u-shaped curve was identified: individuals with stronger hemispheric asymmetry (either left or right) scored better than those with low asymmetry. Stronger asymmetry for the verbal stimuli was connected with a higher ability to reason and solve novel problems, identify patterns and relationships independent of any previous knowledge. At the current state of knowledge, the interpretation of this finding is rather speculative and we cannot take a clear position. Presumably, the role of inner speech should be considered. Inner speech appears to perform significant functions in human cognition as a cognitive tool supporting working memory and other complex cognitive processes. Inner speech has also been claimed to be important for problem solving across different contexts (for a review see Alderson-Day & Femyhough 2015). However, a precise role of inner speech in our results requires examination of its deployment in different tasks and domains.

Interpretation of our results is rather complicated by the fact that verbal and nonverbal abilities are subject to intraindividual variability. A number of studies have documented a relationship between actual testosterone levels and intellectual performance (e.g. Gouchie & Kimura 1991; Tan & Tan 1998; Ostatníková *et al* 2002; Ostatníková *et al* 2007; Durdiaková *et al* 2012; Ostatníková *et al* 2016). Moreover, verbal and nonverbal abilities vary across the female ovarian cycle (verbal skills are better during the late follicular and the luteal phase, when estrogen and progesterone levels are high; Hampson, 1990; Hampson & Kimura, 1992) and in spite of extensive research there is not enough firm knowledge. Therefore, at the current level of knowledge, conclusions are highly speculative.

Conclusion

Using a free-recall dichotic listening paradigm, our results confirmed the relationship between the asymmetry for verbal stimuli and overall dichotic listening performance: a u-shaped curve emerged, where individuals with greater hemispheric asymmetry reported more stimuli correctly. Moreover, we also identified a u-shaped relationship between the asymmetry for verbal stimuli and a nonverbal abilities (stronger asymmetry for verbal stimuli was connected with higher ability to reason and solve novel problems independent of any knowledge from the past). These results might indicate that asymmetry for verbal stimuli is connected not to the performance in the auditory verbal task alone but also to the general nonverbal intellectual abilities.

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