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Increases in language lateralization in normal children as observed using magnetoencephalography

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Abstract

Previous functional magnetic resonance imaging (fMRI) studies investigating hemispheric dominance for language have shown that hemispheric specialization increases with age. We employed magnetoencephalography (MEG) to investigate these effects as a function of normal development. In sum, 22 healthy children aged 7–16 years were investigated using two language tasks: a *verb-generation* (VG) task and a *vowel-identification* (VI) task. Significant hemispheric differences were found for both tasks in cerebral language areas using oscillatory MEG spectral analyses, confirming the MEG's ability to detect hemispheric specialization for language in children. Additionally, a significant increase of this lateralization as a function of age was observed for both tasks. As performance in the VI task showed no correlation with age, this increase seems to be unrelated to performance. These results confirm an increase in hemispheric specialization as a function of normal brain maturation.

Keywords: Brain development; Children; Hemispheric dominance; Language development; Language lateralization; Magnetoencephalography

1. Introduction

The human brain undergoes enormous changes as part of its normal maturation in childhood (Wilke, Krägeloh-Mann, & Holland, 2006). Most remarkable in this context is the ability of the developing brain to compensate early damage by functional reorganization (Chugani, 1999; Muller et al., 1998; Staudt et al., 2001). This potential for plasticity holds great promise for understanding physiological and pathological neuronal repair mechanisms also later in life, when neurological insults regularly have serious consequences (Claesson, Linden, Skoog, & Blomstrand, 2005). Recent studies have attempted to elucidate the process of normal, functional brain development, mainly through non-invasive imaging methods like functional magnetic resonance imaging (fMRI). A prominent example is the lateralization of language functions, which has been shown to increase in childhood (Holland et al., 2001).

Since Broca's (1861) initial descriptions, it has been well accepted that language is lateralized to the left hemisphere of the brain. The amazingly effortless acquisition of language during the early years of childhood, even in the presence of large brain lesions, has sparked numerous investigations of the localization and normal development of language functions. Already in three-month-old infants, functional neuroimaging techniques demonstrated the left-lateralization of speech perception (Dehaene-Lambertz, Dehaene, & Hertz-Pannier, 2002). Many studies have focused on localizing receptive or productive language regions in older children, but only a few concentrated on

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the interplay between language functions and age, using fMRI (Holland et al., 2001; Szaflarski, Holland, Schmithorst, & Byars, 2006) or magnetoencephalography (MEG; Simos et al., 2001). While functional magnetic resonance imaging provides greater spatial resolution, it only permits assessment of an indirect marker of neuronal activation and has a rather low temporal resolution. Additionally, MEG provides a less restrictive study environment for children as opposed to the more confined fMRI-setup.

In the last years, MEG has increasingly been used to investigate the neural basis of language and hemispheric dominance (Salmelin, 2007). It was also compared with the Wada-test, a standard invasive method (Wada & Rasmussen, 1960), demonstrating that it is a reliable tool for the determination of language dominance (Hirata et al., 2004; Kamada et al., 2007; Papanicolaou et al., 2004). Other studies focused on the localization of specific language regions in patients with epilepsy. While healthy subjects showed a left hemispheric dominance (Herdman, Pang, Ressel, Gaetz, & Cheyne, 2007; Ressel et al., 2006; Shtyrov, Pihko, & Pulvermuller, 2005), patients with epilepsy showed a more atypical language organization (Breier et al., 2005; Pataraia et al., 2005), pointing towards a possible role of the MEG in presurgical examinations (Sobel, Aung, Otsubo, & Smith, 2000). Most of these studies investigated language lateralization in adults or in sick children, while data from healthy children is still scarce. Notable exceptions include the localization of auditory evoked potentials (Pang, Gaetz, Otsubo, Chuang, & Cheyne, 2003; Pihko et al., 2003) or the effect of age on language perception (Papanicolaou et al., 2006; Simos et al., 2001).

Given the lack of research on healthy children's language development and the particular advantages of MEG to study such a phenomenon, this study aimed to use MEG to investigate language lateralization and the development of hemispheric dominance in healthy children. To this end, two paradigms were used: a verb-generation task and a vowel-identification task. These tasks involve active language production and phonological processing and are thus prone to show a higher hemispheric lateralization than purely receptive tasks only (Staudt et al., 2001). Both have been shown to be useful for the assessment of language lateralization in children using fMRI (Wilke, Lidzba, et al., 2006) and adults using MEG (Ressel et al., 2006).

2. Materials and methods

2.1. Subjects

Twenty-two healthy, right-handed children participated in this study (10 girls and 12 boys, age range 7–16 years, mean: 10.5 ± 2.52). Handedness was strongly right-lateralized with an average score of 0.78 ± 0.17 in the Edinburgh Handedness Inventory (EHI, range 0.47–1; Oldfield, 1971). Neuropsychological testing using the age-appropriate version of the Wechsler Intelligence Scale (WISC-III) revealed an average full-scale IQ of 113.32 ± 10.12, range 91–129; verbal IQ was 115.32 ± 13.95, range 85–147. We recruited participants from the community by means of advertisements. No participant had a history of neurological or psychiatric disorders and all participants were native German speakers. All parents gave their informed, written consent and all subjects assented to participate. This study was approved by the Ethics Committee of Tübingen University in accordance with the declaration of Helsinki.

2.2. Stimuli and tasks

Tasks were based on previous local fMRI-studies (Wilke, Lidzba, et al., 2006) and adapted for MEG (Ressel et al., 2006). Tasks were presented in random order. Stimuli were presented with a custom-built, in-house presentation software.

2.2.1. Verb-generation (VG)

In the experimental condition, 100 concrete German nouns meeting the following criteria were selected: common words, high familiarity for children, one to two syllables, duration ranging from 450 to 700 ms. Subjects were instructed to generate verbs matching the noun (e.g., horse → ride, Fig. 1) and say them outloud immediately after hearing the noun. An error was recorded each time that the participant failed to generate a verb matching the noun. In addition, participants' vocal reactions were recorded to form a measure of reaction time. The control condition consisted of two sorts of beeps with a duration of 600 ms. Each beep was presented 50 times. One beep consisted of a constant tone (200 Hz) and the second beep changed in frequency (from 200 to 500 Hz) after 500 ms. Subjects were instructed to respond only to the changing beep by lifting both index fingers out of a light barrier. An error was recorded each time that the participant responded to the constant beep or failed to respond to

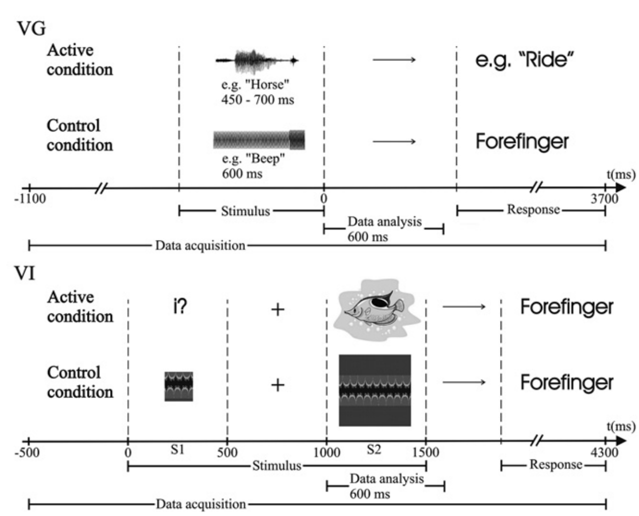

Fig. 1. Task design and stimuli used in the Verb-generation (VG) and in the Vowel-identification (VI) task.