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When two are better than one: Bilateral mesial temporal lobe contributions associated with better vocabulary skills in children and adolescents

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ABSTRACT

This study considered the involvement of the mesial temporal lobe (MTL) in language and verbal memory functions in healthy children and adolescents. We investigated 30 healthy, right-handed children and adolescents, aged 7–16, with a fMRI language paradigm and a comprehensive cognitive test battery. We found significant MTL activations during language fMRI in all participants; 63% of them had left lateralized MTL activations, 20% exhibited right MTL lateralization, and 17% showed bilateral MTL involvement during the fMRI language paradigm. Group analyses demonstrated a strong negative correlation between the lateralization of MTL activations and language functions. Specifically, children with less lateralized MTL activation showed significantly better vocabulary skills. These findings suggest that the mesial temporal lobes of both hemispheres play an important role in language functioning, even in right-handers. Our results furthermore show that bilateral mesial temporal lobe involvement is advantageous for vocabulary skills in healthy, right-handed children and adolescents.

1. Introduction

The mesial temporal lobe (MTL) is traditionally considered critical for episodic memory functions, yet its contribution to language processing is a recent finding. Our work and others demonstrate with functional magnetic resonance imaging (fMRI) that the MTL plays a role in vocabulary and verbal fluency in healthy right- and left-handed adults (Alessio et al., 2006; Bartha et al., 2003; Bonelli et al., 2011; Tomaszewki Farias, Harrington, Broomand, & Seyal, 2005). Clinical evidence suggests that focal lesions in the left, but also in the right MTL induce linguistic deficits, especially in naming and category fluency (Bartha-Doering & Trinka, 2014; Bartha, Benke, Bauer, & Trinka, 2005; Bartha et al., 2004; Gabrieli, Cohen, & Corkin, 1988; Powell et al., 2008; Sabsevitz et al., 2003). Furthermore, it has been shown that left hippocampal pathology affects language reorganization in adults and children (Hamberger et al., 2007; Liegeois et al., 2004).

These findings underscore the role of the MTL in naming and word retrieval, though its involvement in broader language skills is not yet fully understood. The hippocampal formations have long been known for their role in relational binding and in online information processing in memorization (Eichenbaum, Yonelinas, & Ranganath, 2007). Duff and colleagues have proposed that these processes are not only important for episodic memory, but also support the language processing system in rapid access of information and integration of contextual information (Duff & Brown-Schmidt, 2012; Kurczek, Brown-Schmidt, & Duff, 2013). This hypothesis is supported by findings in patients with hippocampal amnesia that have deficits in establishing, recovering, maintaining, and the use of relational memory representations in conversation (Duff, Gupta, Hengst, Tranel, & Cohen, 2011; Duff, Hengst, Tranel, & Cohen, 2008).

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The lateralization of language is of clinical and theoretical relevance. The degree of language lateralization represents a prognostic factor of language deficits after unilateral brain lesions (Jansen et al., 2006; Knecht et al., 2002). The determination of language lateralization is also important for the preoperative investigation of epilepsy patients, as the risk of postoperative language and memory deficits is related to preoperative language lateralization (Bell, Davies, Haltiner, & Walters, 2000; Bonelli et al., 2012; Sabsevitz et al., 2003). Furthermore, disorders like autism (Kleinhans, Muller, Cohen, & Courchesne, 2008; Knaus et al., 2010), specific language impairment (Badcock, Bishop, Hardiman, Barry, & Watkins, 2012; de Guibert et al., 2011), and dyslexia (Heim, Eulitz, & Elbert, 2003) have been linked to abnormal language lateralization.

For the recognition and understanding of atypical language lateralization patterns in children and adolescents with neurological diseases, knowledge about language lateralization in healthy children and its possible impact on language functioning is important. Some studies in healthy children and adolescents show a correlation between better linguistic abilities and greater left lateralization of language regions (Everts et al., 2009; Groen, Whitehouse, Badcock, & Bishop, 2012). However, not all studies find that increased lateralization is associated with better performance; rather some studies suggest that the relationship between language lateralization and language functioning in healthy children may be task and region dependent (Berl et al., 2010; Berl et al., 2014; Lidzba, Schwilling, Grodd, Krageloh-Mann, & Wilke, 2011).

Accordingly, the relevance of laterality for MTL involvement in language processing is unknown. Clinical studies in adults reported linguistic deficits in both left and right temporal lobe epilepsy patients (Bartha-Doering & Trinka, 2014). However, a significant association of left hippocampal activations during a language fMRI task with naming performance has been shown in healthy participants, and in patients before and after epilepsy surgery (Bartha, Marien, et al., 2005; Bonelli et al., 2011). Moreover, better naming correlated with larger activation in the remaining left posterior hippocampus following epilepsy surgery (Bonelli et al., 2012). Few studies have been conducted with children. Recently, Sepeta et al. (2016) demonstrated MTL activation during an auditory description definition task not only in healthy adults, but also in the majority of healthy children, thus underlining the role of MTL in language early in development. Yet, the developmental finding was that activation in the MTL was more bilateral in children than in adults. Thus, there may be developmental differences in the role of left and right MTL, respectively, in neural language organization. However, these authors did not examine how language laterality in the MTL is associated with language performance.

In the present study, we investigated the association between MTL activation during an auditory description definition task and language competence in healthy children and adolescents. We hypothesized that, similar to lateralization of classical language areas, stronger lateralized activation of the MTL will be associated with better language performance in healthy children and adolescents.

2. Methods

2.1. Participants

Thirty healthy children and adolescents, aged 7–16 years (mean 10.27, sd 2.80), participated in the study. All participants (12 girls, 18 boys) were native, monolingual German speakers with no history of neurological disease and no clinical evidence of neurological dysfunction or developmental delay. No study participant was on medication. All children and adolescents had normal or corrected-to-normal vision and normal hearing. All participants were right-handed, Edinburgh Handedness Inventory EHI (Oldfield, 1971) ranging from +50 to +100 (mean 93.33, sd 12.95). Participants were recruited by flier distribution at the Medical University Vienna and received a 30 € voucher for a book store. The study was approved by the Ethics Committee of the Medical University Vienna in accordance with the Helsinki Declaration of 1975.

2.2. Data acquisition

2.2.1. Neuropsychological examinations

All participants underwent standardized cognitive assessment. Expressive vocabulary was investigated with the Wortschatz- und Wortfindungstest WWT (Glück, 2011). This test provides information about expressive vocabulary in different lexical categories including nouns, verbs, and adverbs/adjectives. Immediate auditory attention, short-term, and working memory was measured by digit span forward and backwards tasks of the Hamburger-Wechsler-Intelligenztest für Kinder IV (Petermann & Petermann, 2008). Verbal learning was assessed using the Verbaler Lern- und Merkfähigkeitstest (Helmstaedter, Lendt, & Lux, 2001), the German version of the Auditory Verbal Learning Test (Lezak, 1995). This test provides scores for verbal learning curve, verbal short-term recall after distraction, verbal long-term recall, and verbal recognition. Semantic verbal fluency was evaluated with the Regensburger Wortflüssigkeitstest (Aschenbrenner, Tucha, & Lange, 2001) which requires the participant to name, within two minutes, as many words as possible in the category of animals (Regensburger Wortflüssigkeitstest, RWT).

In order to gain information about non-linguistic cognitive functioning, a perceptual reasoning index was measured with the subtests block design, matrix reasoning, and picture completion of the Hamburg-Wechsler Intelligenztest für Kinder HAWIK IV (Petermann & Petermann, 2008), the German equivalent of the Wechsler Intelligence Scale for Children.

Raw scores of cognitive tests were transformed into age adjusted percentiles for each cognitive test. For the WWT vocabulary norms are only available from 6 to 10;11 years of age. For the ten adolescents aged 11–16, we therefore decided to transform the WWT raw scores into percentiles based on the 10;11 year old children with the risk of an overestimation of percentile rank results in the elder participants. We therefore included analyses for the WWT results without the ten adolescents aged 11–16 yielding a sample of n = 20 (marked in the analyses with n = 20).

2.2.2. fMRI paradigm

During fMRI assessment, the German version of an auditory description definition task was applied. This paradigm reliably lateralizes language and elicits mesial temporal lobe activation in healthy children (Balsamo, Xu, & Gaillard, 2006; Berl et al., 2014; Gaillard et al., 2007; Sepeta et al., 2016; You et al., 2011). During this task, participants listened via headphones to a definition of an object followed by a noun. Participants were instructed to press a button each time they judged that the description did not match the noun. For instance, “A long yellow fruit is a banana.” (true response) or “Something you sit on is a spaghetti.” (not true). Seventy percent of items were correct targets, matching pairs were pseudo-randomly distributed. This paradigm requires comprehension of a phrase, vocabulary knowledge, semantic recall, and a semantic decision. During the control condition, participants listened to verbal stimuli presented in reverse speech. The participants were instructed to press a button each time he/she heard a tone following the auditory string. The baseline was designed to control for first and second order auditory processing, attention, and motor response, while engaging the broad language processing network on an individual basis (You et al., 2011). Task performance was evaluated by the overall percentage accuracy for the language task and the control task separately.

Target nouns were selected according to linguistic criteria including word frequency, word length, and word complexity and were well balanced within five semantic categories. Three age appropriate levels of difficulty were available (7–9 years old, 10–12 years old, 13–16 years