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Research report

Structural plasticity in the language system related to increased second language proficiency

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ABSTRACT

While functional changes linked to second language learning have been subject to extensive investigation, the issue of learning-dependent structural plasticity in the fields of bilingualism and language comprehension has so far received less notice. In the present study we used voxel-based morphometry to monitor structural changes occurring within five months of second language learning. Native English-speaking exchange students learning German in Switzerland were examined once at the beginning of their stay and once about five months later, when their German language skills had significantly increased. We show that structural changes in the left inferior frontal gyrus are correlated with the increase in second language proficiency as measured by a paper-and-pencil language test. Contrary to the increase in proficiency and grey matter, the absolute values of grey matter density and second language proficiency did not correlate (neither on first nor on second measurement). This indicates that the individual amount of learning is reflected in brain structure changes, regardless of absolute proficiency.

1. Introduction

A substantial amount of research on second language comprehension has demonstrated that increasing second language proficiency is linked to functional changes in language-related brain regions (e.g., Yetkin et al., 1996; Chee et al., 2000, 2001; Sakai et al., 2004; Perani and Abutalebi, 2005; Tatsuno and Sakai, 2005; Stein et al., 2006). Concerning semantic and syntactic processing, literature shows that low proficient bilinguals activate additional, mainly prefrontal, brain regions for the processing of the second language (e.g., Chee et al., 2001; Tatsuno and Sakai, 2005; Stein et al., 2006) while they show less left temporal activity (e.g., Perani et al., 1998). These differences disappear, or are at least diminished, with increasing second language proficiency (e.g., Perani et al., 1998; Tatsuno and Sakai, 2005; Stein et al., 2006, 2009).

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Whether and how changes in brain structure accompany an increase in second language proficiency has until now not been sufficiently investigated.

The work of Golestani et al. investigated the ability to learn the differentiation of foreign speech sound and reported increased white matter density anterior of the parieto-occipital sulcus (Golestani et al., 2002, 2007) and in left Heschels gyrus (Golestani et al., 2007) of fast learners when compared to slow learners. Their findings thus demonstrate a connection between brain anatomy and language abilities in the phonological domain. Mechelli et al. (2004) used a global measure of overall second language proficiency and showed that grey matter density in the left gyrus supramarginalis correlated with achieved second language proficiency. In the same region, grey matter density was found to correlate with vocabulary knowledge in monolingual adolescents but not adults (Richardson et al., 2010; Lee et al., 2007). Cross-sectional studies however did not allow to estimate the timescale on which the observed language-related grey matter alterations occurred and to clearly separate effects of genetic predisposition or increased density before learning from experience-induced structural plasticity. It was therefore emphasized that – similar to research in other domains (e.g., Draganski et al., 2004; Boyke et al., 2008) – longitudinal studies are necessary to further clarify the role of experience-dependent structural plasticity in language acquisition, including second language learning (Sakai, 2005; Richardson and Price, 2009).

The present study now uses a longitudinal approach to examine learning-related structural changes induced by five months of second language learning: Ten native English-speaking exchange students learning German in Switzerland were examined once at the beginning of their stay (day 1) and a second time about five months later, when their second language proficiency had significantly increased (day 2). On both days, the subjects' brain structure was measured with magnetic resonance imaging (MRI) on a Siemens 1.5 Tesla Scanner and their German language proficiency was assessed using two written language test (thus omitting). The relation between changes in language proficiency (as assessed by the language tests) and changes in brain structure was then examined using voxel-based morphometry (VBM). VBM yields voxelwise indices of cortical grey matter density, thus allowing objective investigation of subtle changes in grey matter (Ashburner and Friston, 2000; Good et al., 2001); It has been successfully applied before to investigate experience-dependent changes in brain structure (e.g., Draganski et al., 2004). The swiss cantonal ethics committee approved the study and written informed consent was given by each participant.

As mentioned above, functional studies have mainly indicated prefrontal and temporal cortices as regions where brain activation changes occur when second language proficiency in the semantic and syntactic domain increases (e.g., Perani et al., 1998; Tatsuno and Sakai, 2005; Stein et al., 2009). Following the same line of investigation, with the exception that we concentrate on structural changes, we therefore expect to find structural changes in prefrontal and temporal regions as well.

2. Methods

2.1. *Subjects & timing of first and second measurements*

Ten native English-speaking exchange students learning German in Switzerland participated in the study (3 male, 7 female; mean age 17.5 years, range: 16–18.5 years, all right-handed, countries of origin: Australia, Canada, USA). They were recruited via the exchange organization (rotary youth exchange) at the very beginning of their stay in Switzerland. Before coming to Switzerland, 6 of our subjects had no exposure to the German language, 3 subjects had started learning German by themselves (using books) between two and five months before their arrival in Switzerland, a single subject had attended German classes in high school for the last 4 years. After arrival in Switzerland, all of them attended during 3 weeks an intense German language course organized by the exchange organization. In all cases, first measurement (day 1) was after this initial language course. As the subjects with prior exposure to the German language (especially the subject with the history of German classes in high school) were by no means outliers concerning their language skills or their grey matter density on day 1, all subjects were included in the analyses.

Subjects were invited back for second measurement (day 2) about 5 months after first measurement (days between first and second measurement: mean: 166 days, range: 133–224 days).

2.2. *Assessment of German language proficiency*

As described earlier (Stein et al., 2006), German language proficiency was measured using two tests: The first measure (test 1) was a multiple choice test developed by "inlingua" language schools (www.inlingua.com). It consisted of 100 cloze sentences where the subjects had to fill in blanks by picking the correct answer from four possible options. To answer correctly, syntactic as well as semantic knowledge was needed. This test was applied on day 1 and day 2. The second measure (test 2) was a vocabulary test, where subjects were asked to write down the English equivalents of 40 German nouns. This test served as a measure of semantic single word knowledge in the second language. Two versions of this vocabulary test were created. Half of the subjects had version 1 on day 1 and version 2 on day 2, the other half of the subjects had the order reversed.

As both measures were correlated (see also Section 3.1), the percentage of correct answers from both tests was averaged for each subject, yielding one single (more robust) language proficiency score per day. To assess changes in language proficiency, language proficiency scores on day 1 were subtracted from language proficiency scores on day 2 [Δ(*Lang.Test*)].

2.3. *Magnetic resonance (MR) data*

2.3.1. *MR acquisition*

All images were acquired using a 1.5 Tesla whole-body MRI system (Siemens Vision, Erlangen, Germany) equipped with a standard radio-frequency head coil. Anatomical images on day 1 and day 2 were acquired using a 3D T1-weighted