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Functional connectivity changes in second language vocabulary learning

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ABSTRACT

Functional connectivity changes in the language network (Price, 2010), and in a control network involved in second language (L2) processing (Abutalebi & Green, 2007) were examined in a group of Persian (L1) speakers learning French (L2) words. Measures of network integration that characterize the global integrative state of a network (Marrelec, Bellec et al., 2008) were gathered, in the shallow and consolidation phases of L2 vocabulary learning. Functional connectivity remained unchanged across learning phases for L1, whereas total, between- and within-network integration levels decreased as proficiency for L2 increased.

The results of this study provide the first functional connectivity evidence regarding the dynamic role of the language processing and cognitive control networks in L2 learning (Abutalebi, Cappa, & Perani, 2005; Altarriba & Heredia, 2008; Leonard et al., 2011; Parker-Jones et al., 2011). Thus, increased proficiency results in a higher degree of automaticity and lower cognitive effort (Segalowitz & Hulstijn, 2005).

1. Introduction

Although some parts of the human brain (e.g., Broca's and Wernicke's areas) have long been known to be responsible for language processing, it is now believed that language production and comprehension, like many other complex behaviors, are also supported by non-specific circuits. In other words, the language system is viewed as a dynamic system (Liberman, 2000, 2003), subserved by a number of regions, which contribute differently according to processing demands. Over the last 20 years, functional neuroimaging studies have focused on determining which brain areas are involved in language production and comprehension.

In a recent review of 100 fMRI studies on speech comprehension and production, Price (2010) lists the areas that showed significant activation in a variety of language comprehension and production tasks, at the word and sentence levels. This review shows that areas involved in language comprehension include the superior temporal gyri bilaterally, the middle and the inferior temporal cortices, the left angular gyrus and pars orbitalis, the superior temporal sulci bilaterally, the inferior frontal regions, the posterior planum temporale, and the ventral supramarginal gyrus. As for language production, the left middle frontal cortex, the left anterior insula, the left putamen, the pre-SMA (Supplementary motor area), the SMA, the motor cortex, the anterior cingulate and the bilateral head of the caudate nuclei are also involved. This review neatly summarizes our understanding of the neurobiology of the language system; however, despite the behavioral, psycholinguistic and neurolinguistic evidence accumulated in recent decades, much remains to be studied about the details of language and the brain.

Specifically with regard to bilingual people, neurocognitive studies on bilingualism have frequently focused on the neural basis of second language processing, as a function of age of acquisition (e.g., Baker & Trofimovich, 2005; ; Bosch & Sebastián-Gallés, 2003; De Diego Balaguer, Sebastian-Galles, Diaz, & Rodriguez-Fornells, 2005; Doiz & Lasagabaster, 2004; Fabbro, 2001a or Fabbro, 2001b?; Paradis, 2001; Sebastián-Gallés, Echeverría, & Bosch, 2005; Silverberg & Samuel, 2004), and proficiency attained (Chee, Tan, & Thiel, 1999; Perani et al., 1998; Yetkin, Yetkin, Haughton, & Cox, 1996). The results are controversial. Thus, some authors claim that the age of L2 acquisition determines functional organization of L1 and L2 in the brain (Kim, Relkin, Lee, & Hirsch, 1997), whereas others claim that language proficiency is more important than age of acquisition (Perani et al., 1998; Yetkin et al., 1996). Specifically, according to some authors (Chee et al., 1999; Klein, Milner, Zatorre, Meyer, & Evans, 1995 or Klein, Zatorre, Milner, Meyer, & Evans, 1995?; Perani et al., 1996, 1998), first (L1) and second (L2) languages are supported by common brain areas.

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Conversely, Kim et al. (1997) argue that this only holds true of early L2 learners.

More recently, it has been argued that the puzzle might be solved by taking proficiency into account. Thus, according to Abutalebi and Green (2007), there is sufficient evidence that both L1 and L2 are represented and processed in the same network (Abutalebi & Green, 2007; Chee et al., 1999; Klein, Milner, et al., 1995 or Klein, Zatorre, et al., 1995?; Perani et al., 1996, 1998), and that different degrees of activation in the left prefrontal areas for L2 (e.g., Crinion et al., 2006; Frenck-Mestre, 2005; Rodriguez-Fornells, 2005; Raboyeau, Marcotte, Adrover-Roig, & Ansaldo, 2010) can be accounted for by different proficiency levels (Abutalebi & Green, 2007). More specifically, it has been suggested that functional integration between different areas involved in language and cognitive control should vary as proficiency increases (Abutalebi & Green, 2007). Furthermore, Abutalebi and Green point to the need for longitudinal studies to examine changes in connectivity patterns among different regions of interest (ROIs), or a better understanding of changes that may occur during the acquisition of L2.

Functional integration between brain areas can be studied by means of functional connectivity analysis. Functional connectivity allows us to understand how brain areas involved in the processing of specific tasks operate within a system, and how different systems interact within a specific task; functional connectivity has also been related to information flow in the neural system (Anders, Heinzle, Weiskopf, Ethofer, & Haynes, 2011; Babiloni et al., 2005; Ramnani, Behrens, Penny, & Matthews, 2004; Shinkareva, Gudkov, & Wang, 2010). Functional connectivity changes are expressed in terms of functional integration, a measure that characterizes the global integrative state of a network (Marrelec et al., 2008). This approach allows one to examine the dynamic links between the language and control networks involved in L2 vocabulary learning, as proficiency in L2 picture naming increases.

Studies of functional connectivity first appeared rather recently. A few authors have examined the functional connectivity of language networks in healthy monolinguals performing language comprehension tasks (Leff et al., 2008; Van de Ven, Esposito, & Christoffels, 2009; Warren, Crinion, Lambon Ralph, & Wise, 2009) and language production tasks (Bitan et al., 2005; Just, Cherkassky, Keller, & Minshew 2004; van de Ven et al., 2009), whereas others have focused on people with aphasia (Abutalebi, Rosa, Tettamanti, Green, & Cappa, 2009; Marcotte, Perlbarg, Marrelec, Benali, & Ansaldo, 2012; Sonty et al., 2007). Studies of functional connectivity in bilinguals are scarce (Dodel et al., 2005; Majerus et al., 2008; Prat, Keller, & Just, 2007; Veroude, Norris, Shumskaya, Gullberg, & Indefrey, 2010). To date, no study has examined the functional connectivity profiles associated with L2 vocabulary learning.

Prat et al. (2007) examined functional connectivity profiles as a function of processing demands in a group of monolinguals who performed a reading task. Based on an fMRI test, subjects were divided into two groups, with either high or low working memory capacity. The results showed greater efficiency, increased adaptability and greater synchronization of the language network for the high-capacity readers, whereas low-capacity readers showed either no reliable differentiation, or a decrease in functional connectivity with increasing demands.

Studies with bilingual populations have mostly focused on the impact of cognitive load (i.e., task difficulty and cognitive capacity) on functional connectivity within the language processing network. Specifically, Dodel et al. (2005) focused on the syntactic processing level, and showed that differences in syntactic proficiency in L2 were associated with differences in the functional connectivity patterns in low- and high-proficiency L2 speakers. The authors used a condition-dependent functional interaction approach, a psychophysiological interaction technique introduced by Friston et al. (1997). This approach allows one to compare two conditions by computing a weighted correlation between the time courses of each pair of regions from a set of pre-determined ROIs. The authors reported that differences observed within these networks were correlated with TOEFL scores, reflecting low or high syntactic proficiency. Hence, this study provides evidence for links between functional connectivity and proficiency at the syntactic level of L2 processing.

In another study, Majerus et al. (2008) examined the links between short-term memory (STM) capacity and bilingual language achievement, in two groups of German–French bilinguals differing in L2 proficiency. They focused on connectivity between the left intra-parietal sulcus and bilateral superior temporal and temporo-parietal areas. Compared to the high-proficient group, the low-proficient group showed enhanced functional connectivity between the latter areas, which the authors interpreted as evidence of poorer storage and learning capacity for verbal sequences in that group.

One shortcoming of these studies is that L2 proficiency (high and low) is measured in different groups of participants, and thus a number of individual factors across groups could influence the connectivity patterns observed. Longitudinal studies with a single group of participants are better suited to measuring proficiency effects and their neurofunctional correlates (Abutalebi & Green, 2007). Moreover, by examining the functional connectivity patterns of networks that are known to contribute to L2 learning, a better understanding of the dynamic roles of the language and cognitive control systems can be achieved.

The aim of the present study is to describe the functional connectivity patterns that characterize L2 vocabulary learning in a group of Persian (L1) speakers who learnt French (L2). The language processing network described by Price (2010) and the control network described by Abutalebi and Green (2007) were identified with a ROI approach. The functional connectivity patterns of these two regions were described at two points in time during the process of learning L2 vocabulary: the shallow phase and the consolidation phase. These patterns were compared to those of the mother tongue, which was tested at both points. No changes in L1 functional connectivity patterns were expected.

Furthermore, in line with the psycholinguistic literature on L2 learning, and with previous functional connectivity studies on motor learning, reading and syntactic processing tasks, it was expected that functional connectivity levels would decrease with increased proficiency. Moreover, in accordance with Abutalebi and Green (2007), it was expected that higher proficiency would result in less effortful, and thus more automatic, processing, reflected in decreased functional integration between the language and control networks.

2. Experimental design

This was a longitudinal group study, with repeated behavioral, fMRI and functional connectivity measures at two points in time: (a) the shallow phase: after one week of computerized training and a 35% success rate in naming trained items; and (b) the consolidation phase: following 30 days of training and attaining a 100% success rate in naming trained items. Participants completed a pre-experimental assessment of bilingualism and cognitive status before inclusion.

2.1. Participants

A group of 12 native Persian speakers, aged between 26 and 66 (6 females and 6 males), with no history of neurological or neuropsychological disorders, participated in our study. All participants