Neuroscience 300 (2015) 474–492

FLUENCY-DEPENDENT CORTICAL ACTIVATION ASSOCIATED WITH SPEECH PRODUCTION AND COMPREHENSION IN SECOND LANGUAGE LEARNERS

K. SHIMADA, [a,b,c,d] **M. HIROTANI,** [a,e*] **H. YOKOKAWA,** [f] **H. YOSHIDA,** [g] **K. MAKITA,** [a,b] **M. YAMAZAKI-MURASE,** [a,c] **H. C. TANABE** [a,b,h] **AND N. SADATO** [a,b,d]

[a] *Division of Cerebral Integration, Department of Cerebral Research, National Institute for Physiological Sciences (NIPS), Aichi, Japan*

[b] *Department of Physiological Sciences, The Graduate University for Advanced Studies (Sokendai), Aichi, Japan*

[c] *Research Center for Child Mental Development, University of Fukui, Fukui, Japan*

[d] *Biomedical Imaging Research Center (BIRC), University of Fukui, Fukui, Japan*

[e] *School of Linguistics and Language Studies, and Institute of Cognitive Science, Carleton University, Ottawa, Canada*

[f] *School of Languages and Communication, Kobe University, Kobe, Japan*

[g] *Department of English Education, Osaka Kyoiku University, Osaka, Japan*

[h] *Division of Psychology, Department of Social and Human Environment, Graduate School of Environmental Studies, Nagoya University, Nagoya, Japan*

Abstract—This functional magnetic resonance imaging (fMRI) study investigated the brain regions underlying language task performance in adult second language (L2) learners. Specifically, we identified brain regions where the level of activation was associated with L2 fluency levels. Thirty Japanese-speaking adults participated in the study. All participants were L2 learners of English and had achieved varying levels of fluency, as determined by a standardized L2 English proficiency test, the Versant English Test (Pearson Education Inc., 2011). When participants performed the oral sentence building task from the production tasks administered, the dorsal part of the left inferior frontal gyrus (dIFG) showed activation patterns that differed depending on the L2 fluency levels: The more fluent the participants were, the more dIFG activation decreased. This decreased activation of the dIFG might reflect the increased automaticity of a syntactic building process. In contrast, when participants performed an oral story comprehension task, the left posterior superior temporal gyrus (pSTG) showed increased activation with higher fluency levels. This suggests that the learners with higher L2 fluency were actively engaged in post-syntactic integration processing supported by the left pSTG. These data imply that L2 fluency predicts neural resource allocation during language comprehension tasks as well as in production tasks. This study sheds light on the neural underpinnings of L2 learning by identifying the brain regions recruited during different language tasks across different modalities (production vs. comprehension). © 2015 The Authors. Published by Elsevier Ltd. on behalf of IBRO. This is an open access article under the CC BY license (http://creativecommons.org/licenses/by/4.0/).

Key words: functional MRI, inferior frontal gyrus, listening comprehension, oral production, second language learning, superior temporal gyrus.

INTRODUCTION

There are numerous challenges associated with the learning of a second (or foreign) language (L2). To become a proficient L2 speaker, one must master a considerable amount of linguistic knowledge (e.g., new vocabulary, grammatical structures, and speech sounds). While it is clear that knowledge of the target L2 is crucial, this alone does not make for a proficient L2 speaker. In speaking and listening situations that demand "fluency", various processes and procedures are invoked that, in turn, call upon and make use of this requisite linguistic knowledge. The purpose of this paper is to investigate the brain areas that show increased activation when L2 speakers engage in different language tasks, tasks that make use of the aforementioned linguistic knowledge, in both production and comprehension. Specifically, we are interested in identifying the brain areas of the L2 speakers that modulate as a function of the speaker's fluency level (i.e., oral proficiency) (see below for the discussion of L2 fluency). Furthermore, assuming that some specific brain areas are identified as playing a crucial role based on the L2 speakers' fluency level, we are interested in investigating the differences in the activation patterns in the production and comprehension domains.

*Correspondence to: M. Hirotani, School of Linguistics and Language Studies, and Institute of Cognitive Science, Carleton University, 236 Paterson Hall, 1125 Colonel By Drive, Ottawa, Ontario K1S 5B6 Canada. Tel: +1-613-520-2600x2805; fax: +1-613-520-6641.
E-mail address: masako.hirotani@carleton.ca (M. Hirotani).

Abbreviations: ANOVA, analysis of variance; BA, Brodmann area; BS, Build Sentence; CEFR, Common European Framework of Reference; CS, Comprehend Story; dIFG, dorsal part of the left inferior frontal gyrus; ERP, event-related potential; fMRI, functional magnetic resonance imaging; L1, first language; L2, second language; pSTG, posterior part of superior temporal gyrus; VET, Versant English Test.

http://dx.doi.org/10.1016/j.neuroscience.2015.05.045
0306-4522/

As previously mentioned, fluency is the chief L2 proficiency measure in which we are interested. L2 fluency is often characterized by the level of spontaneous oral proficiency in speech production, including factors such as the speaking speed for words and segments within words, and the response time to conversation partners (Lennon, 1990; Schmidt, 1992; Chambers, 1997). In short, L2 fluency can be interpreted to be part of L2 proficiency targeting oral production and listening comprehension. This is the definition of the term ''L2 fluency'' we will adopt in this paper. Of course, there is an on-going debate in the literature as to what should count as L2 fluency in adult language learning, and what achieving fluency entails (see Housen and Kuiken, 2009 for an overview). There is no doubt that L2 fluency interacts with and is closely related to factors such as L2 learning environment, L2 speakers' motivation and aptitude toward learning the language, and their overall communication skills (e.g., Segalowitz, 1997; Skehan, 1998; Saville-Troike, 2006). Setting aside issues around L2 fluency or L2 proficiency in general, it is important to ask how L2 fluency is related to different language tasks in both production and comprehension. Addressing such a question becomes even more important in a context in which attaining sufficient L2 fluency is not easy, i.e., Japanese speakers learning English (e.g., Ojima et al., 2011). To our knowledge, systematic investigation looking into the relationship between L2 fluency and two different modalities, production and comprehension, using a functional magnetic resonance imaging (fMRI) technique, has not been done for Japanese-speaking L2 learning.

How can L2 learners obtain fluency in L2? We propose that L2 fluency is achieved largely by attaining automaticity in predicting what comes next (or what is to be uttered next by the speaker's conversation partner) during L2 production (Segalowitz, 2010; Lim and Godfroid, 2014). Automaticity in L2 not only results in the rapid and smooth production of words or sentences, but also reduces the overall amount of effort required on the part of L2 learners as it increases; this, in turn, allows more fluent L2 learners to allocate more resources to later and more complex integration stages of language comprehension and other tasks (for an overview of L2 research on memory resources, see Robinson, 2008; see also Koda, 2005; Schmalhofer and Perfetti, 2007; Grabe and Stoller, 2011). Thus, based on the aforementioned view, it can be concluded that L2 fluency crucially depends on cognitive resource management.

With respect to our proposal regarding L2 fluency (see above), some issues need to be discussed. First, we assume a specific configuration of the language system, one important to our perspective on the requirements for fluency. We adopt the view that the production system is part of the comprehension system for both first language (L1) and L2 speakers. This assumption is based on the work originally conducted in the field of L1 production and comprehension, and more recently, extended to the L2 domain. It has been proposed that successful verbal communication between two people is facilitated by the listener's ability to predict upcoming language input (i.e., what the communication partner is going to say next) (e.g., Natale, 1975; Giles and Coupland, 1991; Schober, 1993; Gregory and Webster, 1996; Garrod and Pickering, 2004; Pickering and Garrod, 2004; Garrod and Pickering, 2009; Menenti et al., 2012). Previous evidence suggests that making successful predictions about what comes next in a sentence requires the activation of the listeners' speech production system (for an overview, see Guenther et al., 2006; Pickering and Garrod, 2007, 2013). This is because the production system is used to rehearse the incoming language data, putting them in a form suitable for analysis, a necessary part of making predictions. All of these processes occur covertly and automatically. Importantly, such automaticity applies to all levels of linguistic knowledge, starting with phonemes, and moving to words, and then to sentences (Altmann and Kamide, 1999; Kamide et al., 2003; DeLong et al., 2005; Lau et al., 2006; Staub and Clifton, 2006; Pickering and Garrod, 2007, 2013; Garrod et al., 2014). Previous research demonstrates that L2 learners are likely to go through the same process when they engage in L2 verbal communication (e.g., Tettamanti et al., 2002; Musso et al., 2003). Recent findings support the view that L2 learners have the same or similar configurations of their L2 systems as L1 speakers (see e.g., Morgan-Short et al., 2012; Batterink and Neville, 2013).

It should be noted, however, that the production system may be intrinsically different from the comprehension system. It is well known that different behavioral effects appear in those different domains, and hence, different language production and comprehension principles designed to different levels of linguistic representation, have been proposed. For example, in the L1 domain, it has been proposed that the mechanism of phoneme articulation is ultimately driven by our motor control system (e.g., Levelt, 1989, 2001), while phoneme perception is often linked to word (or lexical) recognition and is assumed to be carried out in a parallel fashion. Furthermore, different stages of phonation are supported by different brain areas (for details, see Ackermann and Riecker, 2004, 2010). It is widely accepted that phoneme perception is controlled by our perception of articulatory gestures (Liberman et al., 1967; Liberman and Mattingly, 1985). At the level of sentence comprehension, a number of proposals have been made, some arguing for parallel processing (e.g., Marslen-Wilson and Tyler, 1980; McClelland and Rumelhart, 1981) and others for serial processing (e.g., Frazier and Fodor, 1978). More recently, underspecified models such as the ''good enough parser'' have been proposed (Ferreira et al., 2002; Ferreira and Patson, 2007). Accordingly, it has been proposed that the neural underpinnings for production and comprehension are (partially) different (Damasio and Geschwind, 1984; Grodzinsky, 2000; Gernsbacher and Kaschak, 2003). The same situation occurs in the L2 domain. Restricting ourselves to adult L2 studies, beginning L2 speakers almost always show an asymmetry between L2 production and comprehension (Abutalebi et al., 2001, 2005). Some studies show that the age of acquisition plays a key role in phoneme pronunciation (e.g., Bongaerts, 1999; Flege,