Journal of Neurolinguistics 40 (2016) 1–14

Contents lists available at ScienceDirect

Journal of Neurolinguistics

journal homepage: www.elsevier.com/locate/jneuroling

Research paper

What to do if we have nothing to rely on: Late bilinguals process L2 grammatical features like L1 natives

Hao Yan [a, b, c, *, 1], Yu Mei Zhang [d, 1], Min Xu [a], Hong Yan Chen [e], Yong Hui Wang [f, **]

[a] Neuroimaging Laboratory, School of Biomedical Engineering, Shenzhen University Health Science Center, Shenzhen 518060, China
[b] Key Laboratory of Optoelectronic Devices and Systems of Ministry of Education and Guangdong Province, College of Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, China
[c] Departments of Psychology and Linguistics, Xidian University, Xi'an 710071, China
[d] Department of Neurology, Beijing Tiantan Hospital, Capital Medical University, China National Clinical Research Center for Neurological Diseases, Stroke Centre, Beijing Institute for Brain Disorders, and Beijing Key Laboratory of Translational Medicine for Cerebrovascular Disease, Beijing 100050, China
[e] Department of Radiology, Beijing Tiantan Hospital, Capital Medical University, Beijing 100050, China
[f] School of Psychology, Shaanxi Normal University, Xi'an 710062, China

ARTICLE INFO

Article history:
Received 23 December 2015
Received in revised form 13 April 2016
Accepted 13 April 2016
Available online 27 April 2016

Keywords:
Language features
English past tense
Late Chinese-English bilinguals
Event-related fMRI

ABSTRACT

It is predicted that bilinguals rely on their first language (L1) to process the second language (L2). However, it remains largely unknown as to how the brain processes unique grammatical features of L2. To answer this question, we explored how Chinese-English bilinguals recognized English inflected verbs that are lacking in Chinese. By using a semantic consistency judgment task, we found that highly proficient late bilinguals processed dichotomic regular and irregular inflections the way English monolinguals did. Behaviorally, regular past tense verbs significantly primed recognition of verb stems, but irregulars did not enhance recognition of their simple forms. Brain imaging results showed that, in contrast to irregulars, late bilinguals additionally employed the procedural memory system of the inferior frontal gyrus (IFG), superior temporal gyrus (STG), middle temporal gyrus (MTG), supramarginal gyrus (SMG), cerebellum, and basal ganglia (BG) to process regulars. Such a differential brain activity pattern elicited by L2 syntax and semantics was distinctive from the way Chinese-English bilinguals processed their L1 syntax and semantics, which supported Ullman's declarative/procedural model. Native-like brain activity elicited by L2 grammatical features suggested that unique language features were processed through specialized neural substrates by late bilinguals either. Meanwhile, we also found that late bilingual learners with a high L2 proficiency still employed the cognitive control system (the BA47 and dorsal lateral prefrontal cortex, DLPFC) more heavily to process L2 syntax than L2 semantics. It supported the sensorimotor/emergentist (S/E) model which emphasized that cognitive control must be involved in L2 processing, and ran contrary to the fade-away prediction of the cognitive control process of the Convergent Hypothesis.

* Corresponding author. Neuroimaging Laboratory, Shenzhen University Health Science Center, Shenzhen, 518060, China.
** Corresponding author.
E-mail addresses: yanhao@xidian.edu.cn (H. Yan), wyonghui@snnu.edu.cn (Y.H. Wang).
[1] The authors contribute equally to this work.

http://dx.doi.org/10.1016/j.jneuroling.2016.04.002
0911-6044/

1. Introduction

1.1. Theoretical rationales of L2 processing

It is becoming clear that the acquisition age of a second language (L2) affects neural activities during language processing (Dehaene et al., 1997; Frenck-Mestre, Anton, Roth, Vaid, & Viallet, 2005; Friederici, Steinhauer, & Pfeifer, 2002; Klein, Watkins, Zatorre, & Milner, 2006; Mahendra, Plante, Magloire, Milman, & Trouard, 2003; Perani et al., 2003; Weber-Fox & Neville, 2001; Wartenburger et al., 2003).

In particular, there are three theoretical frameworks that have been offered to account for age of acquisition (AoA) effects in bilingual learners. The sensorimotor/emergentist (S/E) model (Hernandez, Li, & MacWhinney, 2005; MacWhinney, 2004) proposes that linguistic information which is learned earlier in life is dependent upon sensorimotor analysis and recruits phono-articulatory brain regions (Hernandez & Li, 2007), but later learned information preferentially enrolls brain areas underlying semantic and executive cognitive control (Hernandez, Hoffman, & Kotz, 2007). To be specific, Waldron and Hernandez (2013) claimed that early-learned information is preferentially processed in brain regions such as the putamen, anterior insula, inferior frontal gyrus, and motor cortices; later acquired linguistic information is mediated through regions involved in executive functioning, such as dorsolateral prefrontal cortex (DLPFC), and other frontal regions such as anterior inferior frontal gyrus (BA47). It postulates that late bilingual learners have already formed a consolidated and entrenched linguistic system in place, and they would employ direct lexical memory access strategy to a greater degree with special reliance on executive cognitive control and working memory circuits. Similarly, the Convergence Hypothesis (Abutalebi, 2008; Abutalebi & Green, 2007) predicts that late bilinguals utilize similar regions and networks of L1 to perform tasks in L2, but with additional reliance on cognitive control due to unmatched language proficiency.

Generally, these two models can be categorized as the "single network hypothesis" (Abutalebi & Green, 2007), which proposes that adult individuals use their first language (L1) as a reference when processing L2 (Waldron & Hernandez, 2013). They share the opinion that late bilingual learners would display a greater extent of brain activity in regions implementing cognitive control and L1 processing. The disparities of the two theories can be summarized as the S/E model highlights different cognitive control mechanisms in early and late bilinguals, and the Convergence Hypothesis predicts a gradual fade-away of cognitive control. However, the two theories both neglected how late bilingual learners processed L2 grammatical features.

Different from a strong assumption that L2 must rely on L1, the declarative/procedural (D/P) model provided an alternative explanation for the AoA effects. The D/P model is based on the claim that language depends on a memorized "mental lexicon" and a computational "mental grammar" (Chomsky, 1965; de Saussure, 1959; Pinker, 1994). The mental lexicon is defined as a repository of stored information, including arbitrary sound-meaning pairings, word-specific information of grammatical properties, and words' unpredictable morphosyntactic forms. As for the rules of grammar which are characterized by language regularities, Ullman (2001b) defines them as what underlie mental operations that manipulate words and abstract representations to construct phrase, sentences, and complex words, such as "walked". According to the D/P model, the declarative memory system underlies the mental lexicon, whereas the procedural memory system subserves aspects of the mental grammar (Ullman, 2014).

Under the D/P model of L2, the grammatical/procedural system is less available than lexical/declarative memory at later ages, especially after puberty (Ullman, 2001a, 2004). Fortunately, the availability of the lexical/declarative system allows it to compensate for the dysfunctional grammatical/procedural system, as some of the same or similar types of knowledge can be acquired by both systems. Therefore, adult L2 learners rely more heavily on declarative memory, not only for storing idiosyncratic lexical knowledge but also for memorizing complex forms and "rules" typically in a pedagogical context at the beginning. Since declarative memory provides a database from which grammatical rules can gradually and implicitly be abstracted by the procedural memory system, rule governed aspects of grammar should gradually rely on native like aspects of grammatical processing at higher levels (at least to some extent). Even though L2 bilinguals may not attain native-like language proficiency, native-like neural mechanism underlying L2 grammar can be finally achieved (Bowden, Steinhauer, Sanz, & Ullman, 2013).

Although Ullman's theory provides a possible explanation about how late bilinguals process unique features of L2, its validity has not been demonstrated with neuroimaging evidence. In addition, the D/P model overlooked the role of cognitive control in L2 processing, which contradicted the observation that both early and late bilinguals utilize the cognitive control network differently or more efficiently than monolinguals (Abutalebi et al., 2012; Bradley, King, & Hernandez, 2013; Marian, Chabal, Bartolotti, Bradley, & Hernandez, 2014).

To supplement the neurocognitive theory of L2 processing, it was quite worthy probing that (1) what to do when late bilinguals process unique L2 features which are lacking in L1, (2) and what is the role of cognitive control and semantics in processing unique L2 grammatical features. Given that syntax, especially morphosyntax, is more sensitive to AoA than semantics (Hernandez & Li, 2007), the current study planned to adopt tasks of English regular/irregular inflected verbs with late bilinguals. Since language similarity plays a role in the nature of neural activity (De Diego Balaguer, Costa, Sebastian-Galles, Juncadella, & Caramazza, 2004), the AoA effect should be more obvious between languages that are in stark contrast. The Chinese language lacks in grammatical morphology, as subject-verb agreement in Chinese sentences is not required (Chen, Shu, Liu, Zhao, & Li, 2007). It thus embodied profound implications if determining what brain areas Chinese learners would