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Language control mechanisms differ for native languages: Neuromagnetic evidence from trilingual language switching

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ABSTRACT

How does the brain process and control languages that are learned at a different age, when proficiency in all these languages is high? Early acquired strong languages are likely to have higher baseline activation levels than later learned less-dominant languages. However, it is still largely unknown how the activation levels of these different languages are controlled, and how interference from an irrelevant language is prevented. In this magnetoencephalography (MEG) study on language switching during auditory perception, early Finnish-Swedish bilinguals (N = 18) who mastered English with high proficiency after childhood were presented with spoken words in each of the three languages, while performing a simple semantic categorisation task. Switches from the later learned English to either of the native languages resulted in increased neural activation in the superior temporal gyrus (STG) 400–600 ms after word onset (N400m response), whereas such increase was not detected for switches from native languages to English or between the native languages. In an earlier time window of 350–450 ms, English non-switch trials showed higher activation levels in the inferior frontal gyrus (IFG), pointing to ongoing inhibition of the native languages during the use of English. Taken together, these asymmetric switch costs suggest that native languages are suppressed during the use of a non-native language, despite the receptive nature of the language task. This effect seems to be driven mostly by age of acquisition or language exposure, rather than proficiency. Our results indicate that mechanisms of control between two native languages differ from those of a later learned language, as upbringing in an early bilingual environment has likely promoted automatiation of language control specifically for the native languages.

1. Introduction

In daily life, bilingual speakers carry out a complex task of which they may not even be aware: they select and manage their languages without apparent trouble. Bilingual speakers adapt to their conversational partners depending on the conversational setting, which could be a single- or dual-language context, or even a language environment characterised by frequent switching between languages (Green and Abutalebi, 2013). Experimental evidence from many domains of language processing has indicated that lexical access is language non-selective (for a review, see Kroll et al., 2006). The integrative nature of the bilingual lexicon underscores the need for cognitive control over its various languages, to prevent unwanted interference from languages that are not in use.

Language inhibition has often been proposed as a means to prevent such interference. During the use of a non-dominant language, characterised by lower activation levels, lexical representations of the stronger language are assumedly inhibited. In contrast, such suppression is not assumed for a non-dominant language, as its lower activation levels result in less interference during the use of a more dominant language (Inhibitory Control model, Green, 1998). An important factor that affects language control mechanisms is language proficiency, suggesting that control networks are particularly recruited when a weaker second language (L2) is processed (e.g. Abutalebi and Green, 2007).

Evidence for inhibitory control processes has been presented by several behavioural language switching studies, in which asymmetric switch costs during language production were reported. In these

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studies, switches to a dominant language elicited longer reaction times than switches to a less dominant language (Jackson et al., 2001; Meuter and Allport, 1999; Philipp et al., 2007; Tarłowski et al., 2013). After the use of a weaker language, it is assumedly more costly to reactivate the previously suppressed language than to produce a language that has not undergone such suppression. Asymmetric costs have therefore commonly been taken as evidence for an inhibitory control system working to facilitate the use of the relevant language in a given situation (for alternative theoretical accounts see, e.g. Finkbeiner et al., 2006; Philipp et al., 2007; Runnqvist et al., 2012; Verhoef et al., 2009).

A study using functional magnetic resonance imaging (fMRI) during a production task in trilinguals revealed activation of the right inferior frontal gyrus (rIFG) and the pre-supplementary motor area (pre-SMA), neural regions related to domain-general inhibition, after switches to L2 and L3 (De Bruin et al., 2014). This suggests active inhibition of L1 during the use of weaker languages. Such inhibitory processes were not seen when switching to L1, thus supporting claims made by the Inhibitory Control model. Other studies on language production found differential activity in areas related to cognitive control for less proficient languages compared to L1 as well, indicating that the language control network is distinctively engaged according to the relative strength of the language (for a review, see Abutalebi, 2008).

Studies on language control mechanisms during language production increase our knowledge on bilingual language processing and control. However, considerably less is known about control mechanisms at play during language comprehension. In language production, lexical items of the target language are actively selected, whereas the receptive bottom-up driven nature of language comprehension arguably does not recruit similar cognitive processes. The few behavioural studies on language switching in receptive tasks often produced symmetric switching costs in reaction times, or no switching costs at all (Macizo et al., 2012; Thomas and Allport, 2000; Von Studnitz and Green, 2002), supporting the notion that active inhibition may not be necessary. Yet, several studies, especially those utilising brain measures, also suggest otherwise. For example, an event-related potential (ERP) study found that an L1 context prior to the experiment, resulted in L1-related N400 priming during the first half of the experiment, and slowed adjustment to an L2 lexical decision task (Elston-Güttler and Gunter, 2008). This suggests that bilingual speakers need time to tune into the current language context. The language network and its lexical representations may undergo inhibition or facilitation according to the language in use.

Various psycholinguistic models reflect the debate on whether bilingual receptive access is fully non-selective or (partly) selective depending on language-specific cues in the language context. In the domain of visual word recognition, the Bilingual Interactive Activation Plus Model (BIA+; Dijkstra and van Heuven, 2002) specifies the bilingual lexicon as fully integrated for the different languages. In this view, top-down processes do not affect the activation state of the words of different languages. This is in contrast to its predecessor, the BIA, which implies that inhibition takes place via the language node belonging to the language not in use (Dijkstra et al., 1998). In bilingual speech perception, in turn, the Bilingual Interactive Activation Model of Lexical Access (BIMOLA; Grosjean, 1988; Léwy and Grosjean, 2008) assumes that the two language networks of a bilingual speaker are independent, yet share many connections. When a bilingual speaker is required to use only one language in a given situation (monolingual mode), one network is strongly activated while the other is subject to inhibitory influences, consequently receiving only weak activation. Feature-, phoneme- and word-based input present in the interactional context can thus enable more language-selective processes. In this respect, the BIMOLA is similar to the IC model (Green, 1998) although both models were developed to explain processing in different language domains, i.e., production compared to perception.

One of the few studies that specifically addressed the auditory modality in language control processes, is an MEG study by Pellikka et al. (2015), reporting an asymmetric switching cost to spoken native and non-native words in bilateral temporal activation (N400m responses). These results suggest that effects of L1 inhibition can be observed during language reception using time-sensitive neuroimaging. Previous visual ERP studies have showed N400 modulations in response to language switches as well (e.g. Van der Meij et al., 2011; Ruigendijk et al., 2015). The N400 response has been related to semantic processing and word recognition, and is independent of presentation in the visual or auditory domain (for a review, see Lau et al., 2008).

Further evidence for cognitive control during auditory language comprehension comes from an fMRI study on language switching in auditory perception, which reported increased signals in the caudate nucleus and anterior cingulate after switching into the weaker language, areas related to cognitive and executive control (Abutalebi et al., 2007). Furthermore, an fMRI study that investigated switching between L1 and L2 during a phonological judgment task, reported greater activation for the right prefrontal cortex (PFC), the left superior temporal/supramarginal gyrus (STG/SMG), anterior cingulate cortex (ACC), left IFG, and left caudate nucleus after switches to L2, whereas such increased activity was not found for switches to L1 (Hosoda et al., 2012).

Age of acquisition (AoA) is known to have a pervasive effect on language processing, especially concerning phonology (e.g. Piske et al., 2002) and grammar (for a review, see DeKeyser, 2005). A possible reason for the effect of AoA on language processing is the originally proposed 'critical period' for language acquisition (Lenneberg, 1967), later regarded as a 'sensitive period', after which language acquisition becomes more effortful. Late bilinguals, defined by a later AoA, have shown extended activation of neural regions related to phonological and syntactic processing in their L2, recruiting additional neural resources to process the language (e.g. Consonni et al., 2013; Hernandez and Meschyan, 2006; Perani et al., 2003; Wartenburger et al., 2003), possibly pointing towards more effortful L2 processing. The recruitment of distinct memory networks in early vs. late language acquisition has additionally been proposed as a means to explain the impact of AoA on language processing (Ullman, 2001). Yet, convergence of neural networks underlying the processing of early vs. late languages has been reported as well (for a review, see Abutalebi, 2008).

However, few studies have specifically addressed the effect of AoA on language control processes even if AoA could arguably have an impact on language control via lifelong language exposure. For example, long-term cognitive plasticity caused by AoA or language exposure may cause less dependence on controlled processing, evidenced by a decrease in left prefrontal activity (Perani et al., 2003). A study by Abutalebi et al. (2007) found engagement of prefrontal structures related to language control specifically for a language that had received less exposure across the lifespan. Furthermore, Pellikka et al. (2015) found evidence for inhibition of L1 during language comprehension, although L2 proficiency was comparably high. The participants in this study were highly proficient in their L2 but had a clear difference in the AoA of their languages, with L2 acquired after the age of 9. This points to AoA as an important driver of control mechanisms. In contrast, previous behavioural studies typically found symmetric switch costs in case of high language proficiency, even when AoA differed (Costa and Santesteban, 2004).The exact effect of proficiency and AoA on language control is still unclear.

It has been suggested that early bilingualism enhances cognitive control functions (e.g., Luk et al., 2011), possibly leading to an advantage in executive functions. Experience with language environments where language control is frequently needed, especially early in life, may train these functions. The situations and tasks that recruit language control are, however, not well known. Better understanding of language control mechanisms is likely to shed light on the bilingual training hypothesis as well. The current study focuses on the role of AoA in neural correlates of switching during auditory language comprehension, and addresses the yet unanswered question of how language control is manifested between early acquired, balanced native