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Executive function predicts artificial language learning ☆

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ABSTRACT

Previous research suggests executive function (EF) advantages among bilinguals compared to monolingual peers, and these advantages are generally attributed to experience controlling two linguistic systems. However, the possibility that the relationship between bilingualism and EF might be bidirectional has not been widely considered; while experience with two languages might improve EF, better EF skills might also facilitate language learning. In the current studies, we tested whether adults' and preschool children's EF abilities predicted success in learning a novel artificial language. After controlling for working memory and English receptive vocabulary, adults' artificial language performance was predicted by their inhibitory control ability (Study 1) and children's performance was predicted by their attentional monitoring and shifting ability (Study 2). These findings provide preliminary evidence suggesting that EF processes may be employed during initial stages of language learning, particularly vocabulary acquisition, and support the possibility of a bidirectional relationship between EF and language acquisition.

Introduction

Acquiring and speaking two languages places additional cognitive control demands on multilingual speakers compared to individuals who speak a single language. Evidence from previous research suggests that non-linguistic cognitive control skills are advantaged in bilingual individuals when compared to their monolingual peers. Cognitive advantages of bilingualism have been widely reported among children (Bialystok, 1999; Bialystok & Martin, 2004; Carlson & Meltzoff, 2008; Yoshida, Tran, Benitez, & Kuwabara, 2011) and adults (Bialystok, Craik, & Freedman, 2007; Bialystok, Craik, Klein, & Viswanathan, 2004; Bialystok, Craik, & Luk, 2008; Costa, Hernandez, & Sebastiàn-Gallès, 2008; Costa, Hernández, Costa-Faidella, & Sebastiàn-Gallès, 2009; Prior & MacWhinney, 2010) who are proficient in two language systems. Among the specific skills reportedly advantaged among bilinguals are inhibitory control (Carlson & Meltzoff, 2008), cognitive flexibility (Ibrahim, Shoshani, Prior, & Share, 2013), attentional shifting (Prior & MacWhinney, 2010) and attentional monitoring (Costa et al., 2009; Kapa & Colombo, 2013). Such higher-order cognitive skills that control attention, thought, and behavior are collectively referred to as *executive function* (EF).

Miyake, Friedman, Emerson, Witzki, and Howerter (2000) identified three components of EF that are related but separable. Inhibitory control reflects one's ability to deliberately inhibit or prevent prepotent/automatic responses. Shifting is the ability to switch attention between tasks, operations, or stimulus properties. Attentional monitoring, which is part of the process of *updating* (Miyake et al., 2000), captures the ability to monitor the environment for changes in stimuli/task demands and alter

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responding accordingly. Although these EF skills are also necessary for monolingual language use (Paap & Greenberg, 2013), the additional cognitive demands of bilingualism are assumed to result in greater use of these skills, which in turn leads to bilingual advantages even on non-linguistic tasks (Green, 1998). Previous studies have reported bilingual advantages for each of these EF components.

Researchers hypothesize that the EF advantages of bilingualism are the result of bilinguals continually practicing domain-general EF processes while controlling two language systems. For example, during lexical access, bilinguals must maintain separation between their two languages (see Bialystok & Craik, 2010 for review) in order to correctly access the target language and avoid accessing the non-target language. Both behavioral (Marian & Spivey, 2009a, 2009b; Poulisse, 2000; Schwartz & Kroll, 2006) and neuroimaging evidence (Abutalebi et al., 2007; Christoffels, Firk, & Schiller, 2007; Hoshino & Thierry, 2011; Jeong et al., 2007; Marian, Spivey, & Hirsch, 2003; Misra, Guo, Bobb, & Kroll, 2012; van Heuven, Schriefers, Dijkstra, & Hagoort, 2008) suggests that when speaking or listening to one of their languages, bilinguals' other languages are simultaneously activated. Therefore, it is hypothesized that bilinguals use cognitive control processes to maintain control over their two languages. Bilinguals likely employ domain-general inhibitory control (Green, 1998; Kroll, Bobb, Misra, & Guo, 2008; Meuter, 2005) to prevent lexical access in the non-target language, which in turn leads to improvements in these control mechanisms even when tested using nonlinguistic measures.

Additionally, bilinguals may use attentional monitoring to determine which of their languages they should use based on the language used by their interlocutors (Costa et al., 2009; Crinion et al., 2006; Soveri, Rodriguez-Fornells, & Laine, 2011). Finally, bilinguals may rely on attentional shifting when it is necessary to switch between their two languages (Abutalebi & Green, 2008; Costa & Santesteban, 2004; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Jackson, Swainson, Cunnington, & Jackson, 2001; Meuter & Allport, 1999; Prior & Gollan, 2011; Thomas & Allport, 2000) due to either code switching or changing between communication partners.

It should be noted, however, that other research does not support a bilingual advantage in non-linguistic control processes (see Hilchey & Klein, 2011 for review). For example, Paap and Greenberg (2013) found no differences in performance between bilinguals and monolinguals on three measures of inhibitory control – an antisaccade task, a Simon task, and a flanker task – nor was there a bilingual advantage on an attentional switching task. Likewise, Kousaie and Phillips (2012) reported no bilingual advantage on a battery of inhibitory control tasks, and Hernandéz, Martin, Barceló, and Costa (2013) found that bilinguals and monolinguals performed equally on switching tasks. Duñabeitia et al. (2013) also reported that a comparison between a large sample of bilingual and monolingual children revealed equal inhibition abilities between these two groups. Thus, although frequently reported, bilingual advantages in non-linguistic cognitive control are not without well-documented exceptions.

When bilingual cognitive advantages are found, it is typically assumed that bilingual experience leads to better EF performance. However, little attention has been given to the reverse causal possibility. It is theoretically possible that the additional cognitive demands of bilingualism may be less challenging to individuals who are already equipped with strong EF skills. For example, an individual may be more successful at learning to produce a novel label for an object if she can use inhibitory control to suppress the prepotent response of labeling the object in her native language. Therefore, individual differences in EF abilities may affect how easily an L2 can be acquired and controlled. In other words, individuals with better EF abilities may be more likely to become proficient, balanced bilinguals.

Evidence of the role of EF in language control comes from research comparing the language control abilities of bilinguals who differ in levels of EF. Indeed, among bilinguals, individuals with better EF abilities demonstrate less difficulty controlling their two languages. Festman, Rodriguez-Fornells, and Munte (2010) reported that bilingual adults who were better able to avoid interference from their non-target language during a bilingual picture naming task (*non-switchers*) outperformed *switchers* (i.e., those participants who made more non-target language errors) on a battery of non-linguistic EF tasks. Additional evidence of the role of EF in L2 production comes from neuroimaging research. Hernandez and Meschyan (2006) reported that when covertly naming pictures in their weaker L2, there was a significant activation increase in participants' dorsolateral prefrontal cortex and anterior cingulate gyrus, which are brain regions that have been shown to be significantly activated during task-switching and inhibition tasks. These fMRI findings led Hernandez and Meschyan (2006) to conclude that bilingual participants were likely engaging in similar EF processes while producing their non-dominant L2.

Furthermore, the possibility that individual differences in EF abilities are related to language control abilities is consistent with studies of monolingual participants suggesting that individuals with better cognitive control are more successful at processing ambiguous sentences (see Novick, Trueswell, & Thompson-Schill, 2005, for review). For example, in a recent study, Novick, Hussey, Teubner-Rhodes, Harbison, and Bunting (2014) found that improvements in non-linguistic cognitive control abilities, specifically conflict-resolution, through a training program also led to improved ability to avoid misinterpretation of ambiguous garden-path sentences.

A similar relationship exists between EF ability and L2 learning. Linck, Kroll, and Sunderman (2009) examined individuals' access to their L1 after 3 months of an L2 immersion experience. These adult learners were found to have reduced access to their L1 as evidenced by a decreased interference effect of L1 translation distractors in a judgment task that required participants to rate whether a pair of L1 and L2 words were translation equivalents. Additionally, L2 immersion experience resulted in reduced performance on an L1 fluency task. These findings led Linck et al. (2009) to conclude that L2 learners were inhibiting access to their L1 in order to successfully acquire