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How much bilingual experience is needed to affect executive control?

doi:10.1017/S0142716414000265

A wealth of research on experience-related plasticity has shown that specific experiences, such as musical training (Herholz & Zatorre, 2012) or juggling (Draganski et al., 2004), can modify brain function and structure and induce long-term changes in cognitive behavior throughout the life span. In their comprehensive Keynote Article, Baum and Titone focus on the neural and cognitive implications of lifelong experience with multiple languages. They discuss empirical studies on bilingualism, executive control, and aging to enhance our understanding of the frequently observed executive control advantages in bilinguals and how lifelong bilingualism may contribute to the development of cognitive reserve and buffer age-related declines in executive control functions. In reframing these issues in terms of neuroplasticity, Baum and Titone propose to "embrace the inherent individual variability among bilinguals in all its glory" and identify key issues related to individual variability to pave the way to new avenues of research. We fully concur with Baum and Titone's general recommendation to embrace variability among bilinguals to advance our understanding of bilingualism, aging, and neuroplasticity, but we would like to particularly highlight the importance of the earlier stages of second language (L2) learning and the emergence of executive control advantages, a topic we believe has been understudied in this domain. How much bilingual experience is needed to affect executive control?

As Baum and Titone's review shows, bilingual children and younger and older adults often perform better on a wide range of executive control tasks than their monolingual peers, although some studies did not observe such cognitive advantages. The presumed source for this executive control advantage is the bilinguals' lifelong experience using executive control functions to manage two language systems that, as research has abundantly shown, are both active even when only one language is used. The body of evidence demonstrating

executive control advantages in bilinguals is largely based on highly proficient or even "balanced" bilinguals with extensive experience in controlling their two language systems. This raises the question to what extent the observed cognitive advantages are restricted to highly proficient bilinguals and, more generally, how much experience with multiple languages is needed to induce cognitive and neural changes in executive control.

An emerging body of literature has observed that limited L2 training can lead to observable changes in the cognitive and neural correlates of linguistic processing (e.g., McLaughlin, Osterhout, & Kim, 2004; Stein et al., 2009), but few studies have examined to what extent limited L2 training affects processing in the nonlinguistic domain of executive control. In a recent study, we examined executive control (through the Simon task and the attentional networks task) in four groups of 5- to 8-year-old children: monolinguals, L2 learners, bilinguals, and trilinguals (Poarch & Van Hell, 2012). The rationale for the study was to explore executive functions in groups of children with varying language backgrounds and in this way extend previous research usually conducted with monolinguals and bilinguals only. All four groups of children grew up in Germany and performed similarly on the German language test. The L2 learners, bilinguals, and trilinguals all attended a German–English immersion school, and the monolinguals attended a German-only school. The bilingual children were raised with German and English at home and were equally proficient in German and English, and the trilingual children had either German or English and an L2 at home and German and English at school. The L2 learners spoke German at home and spoke English only at school, for about 1 year at the time of testing. It appeared that the bilingual and trilingual children performed better on the executive function tasks than the monolingual children. It is interesting that the L2 learners' performance fell in between that of the bilinguals/trilinguals and the monolinguals, indicating that brief L2 learning can already affect executive control functions. It also suggests that enhanced executive control seemed to be slowly emerging in the L2 learners but without yet reaching the performance levels of the bilinguals and trilinguals. Further evidence that increased experience with multiple languages gradually affects executive control has been observed in Grade 2 to 5 children in a primary school immersion program (Bialystok & Barac, 2012) as well as in more proficient adult bilinguals with varying levels of L2 proficiency (Fernandez, Tartar, Padron, & Acosta, 2013; Khare, Verma, Kar, Srinivasan, & Brysbaert, 2013; Luk, De Sa, & Bialystok, 2011; Segalowitz & Frenkiel-Fishman, 2005).

How much L2 experience is needed to incur structural changes in the brain, and does this affect executive control? A functional magnetic resonance imaging study by Stein et al. (2012; see also Stein et al., 2009) suggests that even limited L2 training incurs changes in neural structures recruited for language processing. Native English speaking exchange students learning German in Germany were tested at the beginning of their program and 5 months into their program. Voxel-based morphology showed that an increase in grey matter density in the left-inferior frontal gyrus and the left anterior temporal lobe correlated with an increase in L2 proficiency, suggesting that even a brief L2 training induces experience-related structural neural changes in areas subserving semantic and syntactic language

processing. An intriguing question is to what extent limited experience in controlling two language systems also incurs changes in a different, nonverbal domain. Does brief linguistic training also affect neural structures subserving nonverbal executive control? If so, are language experience-related effects on executive function gradual, so that a monotonic relationship will be observed between executive control and L2 proficiency, or is there a critical threshold level of L2 experience needed before any effects on executive control emerge that remain relatively stable as the amount of L2 experience increases? Moreover, is there any age-related variability in the amount of L2 experience needed to affect executive control? Specifically, if neural plasticity changes across the life span, the amount of L2 experience necessary to impact executive function may differ for children and younger and older adults.

A final point we would like to add to the research agenda proposed by Baum and Titone pertains to the duration of L2 training effects on executive function. If L2 learners do reap cognitive advantages from relatively brief experiences handling two languages, do these experiences need to be recent or do early experiences leave long-lasting footprints (even in the absence of recent experience)? Research on musical training has shown that moderate amounts of formal music training as children (about 3 years or more) induced neural changes (i.e., more robust brain stem responses to sound) in adulthood, long after training had stopped (e.g., Skoe & Kraus, 2012; White-Schwoch, Carr, Anderson, Strait, & Kraus, 2013). Likewise, even moderate and time-limited exposure to a certain language during childhood can lead to later facilitation of relearning that language as adults (e.g., Au, Oh, Knightly, Jun, & Romo, 2008; Oh, Jun, Knightly, & Au, 2003; but see Pallier et al., 2003), although effects of relearning seem to depend on age and were no longer detectable in relearners aged 40 or older (Bowers, Mattys, & Gage, 2009). Would these brief and early linguistic experiences (and the possible structural neural changes) cross domains and affect executive functioning well beyond the initial L2 learning experience, or is executive functioning only affected (if at all) by recent L2 training experiences?

In closing, we buttress Baum and Titone's proposal to embrace individual variability among bilinguals. However, we think it is crucial to add the emergence of enhanced executive control to the future research agenda to gain more insight into how much experience with multiple languages is needed to affect executive function and, more generally, gain insight into the timing, gradience, decay, and cross-domain generalizability of experience-related neural plasticity.

ACKNOWLEDGMENTS

The preparation of this commentary was supported by NSF Grants BCS-0955090, OISE-0968369, and BCS-1349110.

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