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## Individual variability and neuroplastic changes

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An important proposal in the insightful Keynote Article by Baum and Titone is that the field of bilingualism research needs to attend more closely to intersubject variability in order to understand the nature of neuroplastic changes in the brains of bilingual speakers as they age. I agree. Understanding such variability and its drivers (such as the contexts of language use that Baum and Titone nicely comment on in the Montreal milieu) will help us develop theoretical accounts of the cognitive control processes recruited in bilingual speakers and establish how adaptive changes to these processes mediate the effects of normal aging; yield protective effects against neurodegenerative disease, such as Alzheimer disease; and modulate language recovery poststroke in bilingual speakers. In this commentary I explore some aspects of this variability and commend, in line with the views expressed in the Keynote Article, the value of relating behavioral indices to whole brain structural magnetic resonance imaging for enriching our understanding of experience-dependent changes. Allied to tractography studies, such research can help us develop a rich picture of the major drivers of neuroplastic changes.

I start on a pragmatic note. Experience-dependent effects modify preexisting differences, and so it would seem that longitudinal studies must represent a gold standard for any effort aimed at creating a causal account of the relationship between bilingual experience and neuroplastic changes. The argument goes like this: cross-sectional studies showing that one group of individuals displays increased grey matter or increased functional connectivity between one or more neural regions might after all reflect preexisting differences. Further, those most adept at speaking a given language or speaking more than one language for preexisting structural or connectivity reasons may seek out relevant domains for exercising their skills and so enhance preexisting differences. The riposte has been that children do not choose to be born into particular linguistic communities, as Baum and Titone note. Nonetheless, longitudinal studies do allow us to chart changes over time that take account of initial brain differences. However, we can make progress using cross-sectional studies if we grant a normal distribution of preexisting differences for bilingual speakers in the various behavioral ecologies or interactional contexts in which they participate. The primary need then is to characterize the recurrent patterns of conversational exchange in these contexts as effectively as we can.

The basic argument is that different recurrent patterns of conversational exchange impose different demands on the processes of language control. These different demands lead to adaptive changes in the control processes with structural consequences for the regions involved in the cognitive control of language and their white matter connectivity (Green & Abutalebi, 2013). To be more concrete, when bilingual speakers use one language at home and another at work, there are demands to maintain the language in use and to control between language interference in order to maintain fluency. Such single-language contexts place demands on frontal regions and circuits. In a dual-language context, where a speaker uses a different language to different addressees, there is a demand both

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to minimize between-language interference and to secure effective switching between languages. The control demands in such a context load on frontoparietal and subcortical structures and circuits together with a frontothalamic circuit involved in the detection of salient environmental cues. In addition to these two contexts, we can distinguish the different demands imposed by different code-switching contexts (Green & Wei, 2014). A dense-code switching context allows speakers the free use of expressions from either language in a kind of dynamic bricolage that may load on frontocerebellar circuits implicated in morphosyntactic processing. In other code-switching contexts, speakers may alternate from one language to another between utterances or insert words or phrases from one language into another. In such contexts, switching into the other language is licensed for pragmatic or momentary processing reasons and so the control process is one in which the control of interference from that language is suspended, again implicating frontosubcortical circuits contingent on the communicative intention. The different code-switching contexts reflect differences in the social status of the languages in question (e.g., Muysken, 2000). Close examination of the actual patterns of language use as a part of the neuroscientific understanding of brain changes will then exert an integrative effect: it will help draw together the sociolinguistic and neurolinguistic traditions.

This characterization of the different interactional contexts is a first step. A full characterization will enable a multivariate profile of the speaker. Such a profile can then be correlated with whole-brain structural magnetic resonance imaging and connectivity data (i.e., statistical analysis of the network data; see García-Pentón, Fernández, Iturria-Medina, Gillon-Dowens, & Carreiras, 2014). Consistent demands will induce adaptive changes. The parameters of such a profile remain to be determined. Individuals will vary in the extensiveness of exchanges within these different contexts and may differ in the range of contexts in which they participate. The precise communicative demands of a given type of exchange may also differ. In some circumstances, speakers and hearers work together to secure the goal of the exchange (Clark, 1996), but in other contexts the primary responsibility may lie with the speaker (e.g., in certain safety critical circumstances).

Different domains of language use may play a crucial role in shaping plastic changes. In some workplaces (e.g., reception areas of hotels) the names of objects and procedures will be well known in both languages. Speaking in one language rather than another requires the control of lexical interference. In other circumstances (e.g., an operating theatre) objects and procedures may be known and used in just one language. Vocabulary knowledge restricted to one language not only reduces demands on regions associated with the representation of vocabulary (e.g., left and right posterior supramarginal gyri) but also reduces demands on the processes of language control as there is no direct lexical interference.

Typical conversations are multimodal and arise in concrete physical circumstances in which a shared physical world is available to both parties. Neuroscientific research has yet to address the multimodal nature of bilingual interactions. In face-to-face interactions, the immediate environment may reduce demands on certain types of language control. For example, the control demands for a bilingual speaker in selecting a relevant word in order to refer to an object may be reduced when the speaker can point to the designated object visible to the addressee. In contrast, if pointing or other gestural devices are minimal, the speaker and

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addressee must select among competing object names (e.g., at the lemma level). The addressee must also potentially exert greater control of oculomotor processes in order to fixate the correct target. Mercier, Pivneva, and Titone (2014) show that these two kinds of control processes dissociate.

My purpose has been to sketch out some of the sources of interactional variance that an effective profile of language use in bilingual speakers might cover. There is a related requirement. We need to know how individual profiles relate to standard clinical markers (e.g., letter and semantic fluency tests) and cognitive control tests. If long-term experience affects performance on these tests then such decontextualized tests offer a proxy for such experience. In addition, we are then in position to see which aspects of the profile explain additional variability in the structural and connectivity data and so develop further standardized tests. In short, the effort to produce a meaningful characterization of language use in bilingual speakers may lead to more efficient and ecologically valid clinical instruments pertinent to language control that are globally applicable.

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## Commentary on Baum and Titone

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Baum and Titone address several issues related to bilingual advantages in executive control that are often overlooked in this literature but warrant further consideration and empirical investigation. We limit our comments to two issues: the problem of establishing the directional relationship between bilingualism and executive control and the problem of decomposing executive control.

Baum and Titone acknowledge the challenges inherent in establishing a clear directional relationship between bilingualism and cognitive advantages. As the

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