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Converging diversity to unity: Commentary on *The neuroanatomy of bilingualism*

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Converging diversity to unity: Commentary on *The neuroanatomy of bilingualism*

Research in bilingualism has received tremendous scholarly and public attention in the recent decade. Advancements in neuroimaging techniques allowed researchers to ask questions about how multiple languages are represented in the brain (for a review, see Buchweitz & Prat, 2013) and how brain structural differences are associated with bilingual experience or second language acquisition (for reviews, see Li, Legault, & Litcofsky, 2014; Stein, Winkler, Kaiser & Dierks, 2014). The review paper by García-Pentón and colleagues (2015) focuses on the *differences* in neuroanatomy of individuals growing up with bilingual or monolingual experience. This target commentary is timely and provides a comprehensive overview of the current state of neuroanatomy of bilingualism, along with other reviews published in 2014 (Baum & Titone, 2014; Costa & Sebastián-Gallés, 2014; Li, Legault, & Litcofsky, 2014; Stein, Winkler, Kaiser & Dierks, 2014). While literature review is the stated focus of the paper, García-Pentón and colleagues (2015) included the additional goal to suggest that brain structural differences could potentially illuminate the debate on bilingual advantage in behavior. This additional goal is somewhat distracting the review from the aim of providing "methodological recommendations to follow in future studies with the aim of providing a methodological framework that will help the field to progress." (p. 5). Oversimplification of a complex question to a binary answer does little to progress. Besides, the available neuroimaging literature does not provide direct evidence linking bilingualism-induced changes to brain structure to a cognitive advantage, and when this is suggested, it usually is speculative at best (for example, see Olulade et al., 2015). Converging diversity to unity in the field may offer a constructive plan to interpret the hazy view and unite collaborative effort to advance our understanding of how a prevalent life experience shapes human brain and cognition.

In this commentary, we will focus on the two directions that García-Pentón and colleagues (2015) have identified as sources of the hazy view in the neuroanatomy of bilingualism: (1) diversity of sample characteristics; and (2) diversity in methodological issues. In addition to pointing out these sources of variation, we will include recommendations to interpret and incorporate these sources of variation. Then, we will end this commentary with a suggestion particular to the research community interested in bilingualism and neuroplasticity. We hope that this commentary will supplement García-Pentón and colleagues' (2015) target article and provide a converging framework.

Sources of diversity

In the target review article, García-Pentón and colleagues (2015) pointed out that one source of the variation in neuroanatomical findings is associated with bilingual experience, inherent in studies conducted globally. This issue is prevalent in bilingual research due to the natural variation of social contexts supporting/suppressing bilingualism. To complicate matter further, bilingualism covers multiple quantifiable dimensions, such as functional usage (Luk & Bialystok, 2013), second language (L2) proficiency (Tse & Altarriba, 2012), and onset age of L2 acquisition (Kaiser, Eppenberger, Smieskova, Borgwardt, Kuenzli, et al., 2015; Wei, Joshi, Zhang, Mel, Manis, et a., 2015) or onset age of bilingual usage (Luk, De Sa, & Bialystok, 2011). In addition to the quantifiable dimensions, qualitative differences in bilingual experience possibly interact with the quantifiable measures. García-Pentón and colleagues (2015) have acknowledged this complexity as a source of variation in results comparing brain structures in monolinguals and bilinguals. It is understandable that the diversity in quantitative and qualitative dimensions of bilingualism contributes to the inconsistent results across studies. However, it is not reasonable to expect uniformity when the construct of interest is inherently diverse.

One tangible suggestion to harness this diversity is to recommend researchers to collect and report relevant information of the bilingual, as well as monolingual, participants. Potential candidates of participant characteristics include self-reported functional usage on a daily basis, L2 proficiency using standardized measures, and L2 acquisition history. There are a few accessible instruments available for researchers to adopt and include in respective studies (e.g., *Language History Questionnaire, LHQ 2.0,* Li, Zhang, Tsai, & Puls, 2013; *Language Experience* *and Proficiency Questionnaire, LEAP-Q,* Marian, Blumenfeld, & Kaushanskaya, 2007). Moreover, if monolinguals are included as a comparative sample, it is also crucial to provide language usage and characteristics of these individuals beyond just labeling them as monolinguals, outlining the contrasting group differences. Here, the social context where these two group of participants are exposed to and interact with on a daily basis is vital to judge whether the groups are comparable across studies. To provide substantial information about participants' sociolinguistic environment as well as their language usage is critical to identify the dimensions of bilingualism most relevant to brain structural changes.

A second source of variation acknowledged by García-Pentón and colleagues (2015) is the variation in methodologies. The effort in compiling and summarizing existing studies in the literature has been admirable. Furthermore, García-Pentón and colleagues discussed the diversity of methods extensively, already providing meaningful guidelines on common data analytic outcomes for accumulative research synthesis. We agree that there is more diversity in methods analyzing gray matter relative to white matter. This is mostly due to the fact that these methods have been available for a longer period of time, and also because the T1 images that are normally used for grey matter analysis are routinely acquired for functional studies, whereas the DTI images usually have to be specifically planned. Aside from the diversity of methodology, including the variety in the scanning equipment, the analytic outcomes are different for studies examining between-group differences on gray matter: density (Mechelli et al., 2004), volume (Pliatsikas, Johnstone, & Marinis, 2014), and cortical thickness (Klein, Mok, Chen, & Watkins, 2014) have all been reported. Using voxel-based morphometry (VBM) methods over 400 participants, Winkler, Kochunov, Blangero, Almasy, Zilles, et al., (2009) had demonstrated that gray matter volume was related to cortical surface area, but less so with cortical thickness. Indeed, correlations between cortical surface area and cortical thickness were weak and did not reach statistical significance. In order to clear the indeed hazy view of grey matter findings, Garcia-Pentón and colleagues call for a certain set of standards to be applied. A quick glance at

Table 1 from Garcia-Pentón et al. reveals that there is a trend towards standardizing the scanning and analysis protocols in the field (e.g. optimized VBM analysis on modulated images, comparable voxel sizes, 3T scanners), meaning that an increasing amount of studies will eventually be utilizable in meta-analyses. Additionally, García-Pentón and colleagues have provided three actionable directives for future researchers to consider: correction of multiple comparisons, interpretation of uncorrected results, and recommendation to perform a whole-brain analysis prior to reporting region-of-interest analysis. These directives should be adopted by future research to develop a sustainable field to allow research synthesis at a meta-analytic level.

The third source of variation that has not been described in the target article concerns whether we should simply compare findings in studies or take a critical evaluation of nuances in studies. Take an example, Luk, Bialystok, Craik, & Grady (2011) and Pliatsikas, Moschopoulou, & Saddy (2015) reported comparable results in which older and younger bilinguals had *higher* fractional anisotropy (FA) in various white matter structures. Contrary, Gold et al. (2013) and Cummine & Boliek (2013) reported *lower* FAs in white matter regions when comparing bilingual and monolingual older and younger individuals respectively. At a glance, these studies seem to provide a hazy view because the results are contradictory. However, careful interpretation comparing the characteristics of the studies (the how) instead of comparing the findings (the what) may illuminate this hazy view.

First, a major difference between Luk et al. (2011) and Gold et al. (2013) is in the age of the participants. Luk et al. have recruited participants who were around the age of 70 at the time of participation, whereas the participants in Gold et al.'s study were about 10 years younger. Using a longitudinal design, Sexton, Walhovd, Storsve, Tamnes, Westlye, et al. (2014) have demonstrated that decrease in fractional anisotropy (FA) began in the fifth decade of life and had accelerated decrease thereafter. This decrease in FA was accompanied by increased axial, radial, and mean diffusivity. Furthermore, age-related acceleration of change (decrease in FA, increase in diffusivities) was most pronounced in frontal and parietal regions, relative to occipital and temporal regions. In addition to the age differences, Gold et al. (2013) have elaborated in the discussion that the regions with lower FA in bilinguals were part of the memory system rather than the fronto-parietal executive system as reported in Luk et al. (2011). Along the lines of participant diversity in bilingual characteristics that García-Pentón and colleagues (2015) had identified, *nuances* in each study that may contribute to a hazy view in *findings* may actually embed signals to. Therefore, critical evaluation of results in light of characteristics in studies may contribute to illuminating the hazy view.

In Pliatsikas et al. (2015) and Cummine & Boliek (2013), both studies recruited young adults, with monolingual English-speaking and bilingual experience. Similar to Luk et al. (2011) and Gold et al. (2014), these two studies reported seemingly contradicting findings. While Pliatsikas et al. (2015) showed higher FA in white matter structures similar to those reported in Luk et al. (2011), the reported higher FA in monolinguals compared to bilinguals in Cummine & Boliek (2013) involve regions that largely do not overlap with those reported in Pliatsikas et al. (2015). What are the nuances in difference between these two studies? First, monolinguals actually had higher mean diffusivity in regions similar to those reported in Pliatsikas et al. (2015) where bilinguals had higher FA. If only FA findings were considered, the picture is not only hazy, but also partially obstructed. Secondly, Pliatsikas et al. (2015) recruited a group of bilinguals who had immersive experience with a wide age range of L2 age of acquisition and first languages, mostly through schooling (supplemental table S1). These participants had self-reported proficiency and were tested objectively using an English language test. The monolingual English speakers had significantly higher English proficiency compared to the bilinguals, but the two groups had similar backward digit performances. Bilingual participants in Cummine & Boliek (2013) spoke Chinese as their first language and they had formal instruction in English introduced after the age of 5. They also reported that they "remained fluent in both languages" (p.596), without further elaboration on how their fluency was assessed. Monolingual participants, despite the self-reported single language proficiency in English reading and writing, also reported “a certain amount of exposure to a second language” (e.g., learning French in high-school, understanding native tongue of relatives, etc.). No further information about the participants was given in the methods. Again, García-Pentón and colleagues’ (2015) argument was demonstrated that language experience and usage should be compared. When interpretations only involve *findings* across studies, agnostic to *nuances*, it is less likely to have a luminous picture. The current challenge at hand is how we can harness the diversity to achieve unity?

Harnessing diversity to achieve unity

The short answers to harnessing diversity to achieve unity are (1) more research is needed; and (2) a theoretical model is necessary. The first answer is evident in the surge of research involving “bilinguals” (broadly defined) that is ongoing and published (Kroll & Bialystok, 2013). As García-Pentón and colleagues’ (2015) have eloquently pointed out, diversity in research findings forms a hazy view. Although it is not likely (and there is no reason to) we could constraint parameters that are signatures of bilingualism, clearer and systematic reports of participant characteristics are warranted. Therefore, we recommend reporting detailed information about the participants, such as onset age of L2 acquisition, onset age of bilingual usage, L2 proficiency (at word level and beyond), mode of L2 acquisition, command of additional languages, and most importantly, daily functional usage of multiple languages. Notably, these variables are quantifiable and are usually collected through self-reports. To supplement this quantifiable information, qualitative description of the community where participants live should also be reported so readers can understand the interaction between the participants and the environment. Indeed, bilingual experience is interactional, complete and full description of the social situation that is relevant to bilingualism will facilitate researchers to understand the contexts of bilingual usage. In short, when more research is deemed necessary, future research would benefit from systematic reports of individual and community description.

In addition, examining the longitudinal impact of bilingual experience in brain changes is essential to recognize the experience-dependent mechanism associated diverse language experience.

The second short answer for harnessing the diversity observed in studies concerning the neuroanatomy of bilingualism is a theoretical model. Abutalebi and Green (2013) have proposed the Adaptive Control Hypothesis (ACH), which highlights the need to consider characteristics concerning both the individual and the community s/he resides in order to examine the level of interaction with multiple languages in bilingual participants. The ACH has set the stage for highlighting the importance of the interactional context of bilingualism. Supplementing the current ACH and along the lines that García-Pentón and colleagues (2015) have proposed, we suggest that the predictions of ACH can be extended to include which underlying white matter structures supporting the functional neural network involved in bilingual language control. Understanding complex human behavior, such as plasticity in brain functions and structures, multi-modal integration of data is essential. A closer look at the current hazy view of emerging research may indeed shed light on what defines bilingual experience. Achieving unity requires converging diversity from disperse theoretical underpinnings and empirical evidence. A hazy view may be a precursor for a clear picture. The transformation requires collaborative effort from researchers studying bilingualism around the world.

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