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Experience-Based Individual Differences Modulate Language, Mind and Brain Outcomes in Multilinguals

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Being able to speak and/or understand multiple languages is a ubiquitous human behavior. Over the past decades in particular, an increasing amount of research has investigated the acquisition, processing, and use of multiple languages as well as how variation therein associates with differential cognitive performance, brain functions and structures (see Bialystok 2016, 2017; De Houwer, 2021; Fricke et al. 2019; Grundy & Timmer, 2017; Kroll & Bialystok, 2013; Li & Dong, 2020; Sulpizio et al., 2020 for reviews). Taken together, this research strongly suggests that these behavioral and neural consequences reflect individual differences in how one adapts to her environment through multilingualism. Paying homage to the reality of language diversities around the world, we have opted to use herein the term multilingualism, as opposed to simply bilingualism, given that linguistic experiences can, and often do, extend beyond managing only two languages on a daily basis. The present special issue presents a collection of 15 papers examining the linguistic, cognitive and neural consequences of multilingualism, using innovative approaches to characterize relevant experiences.

Research focusing on the psycholinguistics of multilingualism has long shown behavioral differences in overall developmental timing, sequencing, ultimate attainment in language acquisition as well as cross-linguistic influence in language management and processing (e.g., see Bullock & Toribio, 2009; De Houwer, 2016; Kaushanskaya & Marian, 2007; Rothman et al., 2019 for reviews). Though individual differences are observed among monolinguals, within-group behavioral variation tends to be more pronounced in multilingual populations. For many domains of grammatical knowledge, use and processing (including lexical, phonological, morphosyntactic), monolingual and multilingual individuals can overlap to a significant degree. This is to be expected since regardless of speaker type (i.e., educated monolinguals, under-literate monolinguals, bidialectal speakers, heritage language bilinguals, second language learners, trilinguals), individuals within any given type are bound to fall on a scale of relevant experiences with and exposure to language no matter how many languages are involved. That is, linguistic outcomes in both monolinguals and multilinguals are related to quantity and quality of exposure to their language(s), opportunities for more diverse contexts of language(s) usage, as well as individual differences in cognitive capacities. For multilinguals in particular, the typological/structural relationship between the languages may also play a role leading to differences in linguistic outcomes. Differences in these same variables are not isolated to individual differences within group type. Rather, they conspire to account for observable trends of differences between monolinguals and multilinguals at the aggregate level. In our view, this is probably the case because, on average, the range of variation in how relevant variables present within an aggregated group are more likely to be similarly constrained than across types (we return to this below). Yet, even though group comparisons are often used to demonstrate differences between monolinguals and multilinguals, it is important to underscore the fact that they share common experiences in language acquisition and usage that have similar outcome consequences.

Despite clear individual differences in both monolinguals and multilinguals, there are, as referenced above, (important) observable trends that pertain to speaker type. To cite merely one example, age of acquisition does seem to have reliable effects for the acquisition of phonological systems. Such observations are perfectly compatible with individual difference approaches, because speaker category membership can impart a greater likelihood that (some) contributing variables to individual differences are more and less prominent across individuals of a particular type. While group differences are meaningful, especially for specific questions, understanding the potentially clandestine individual variation hidden within aggregated comparisons is at least equally important and useful for other theoretical questions. Despite differences at the group and individual levels, there is clear support from research that multiple languages can be acquired, simultaneously or consecutively, and that the learning and presence of more than one language in the same mind does not confer any insurmountable burden for their effective use and processing (De Houwer, 2021; DeLuca et al., 2019a; Rothman & Slabakova, 2018; Malovrh & Benati, 2020).

Similar issues (and opportunities) related to understanding and unpacking individual level contributing variables within linguistic acquisition and processing also pertain to the study of the cognitive neuroscience of multilingualism. As is well known at this point, much research on cognitive control of languages has demonstrated that multiple languages are simultaneously active in a multilingual's mind, reinforcing top-down control processes based on bottom-up monitoring of language use (e.g., Spivey & Marian, 1999; Jared & Kroll, 2001; Marian & Spivey, 2003; Schwartz & Kroll, 2006; Kroll et al., 2008; Green & Abutalebi, 2013). As a result, multilingualism requires language control in relation to the contexts of language use (Abutalebi & Green, 2016) and engages attentional mechanisms to manage the contextually irrelevant language(s), shifting the focus of attention to the language needed at hand (Bialystok & Craik, 2022). This persistent, life-long, language management experience requires substantial and continuous recruitment of executive functions. In turn, it has been argued that this experience can fine-tune cognitive skills and brain networks (Bialystok et al., 2012) to make them more efficient in switching, inhibition, monitoring and directing attention. Crucially, multilingual experience is argued to directly and fundamentally rely on domain-general processes related to attention and the underlying neural architecture (Bialystok, 2017; Bialystok & Craik, 2022; Pliatsikas, 2020; Pliatsikas & Luk, 2016).

Many relevant structural MRI studies show functional and structural brain differences in multilinguals, often relative to monolinguals, in topographical regions that are highly implicated in language processing/control, memory and other executive functions (e.g., De

Baene, et al., 2015; Li, et al., 2014; Rossi et al., 2021). fMRI studies show increased efficiency in neural recruitment during task performance in multilinguals, even when there are no measurable behavioral differences (e.g., Abutalebi et al., 2012; DeLuca et al., 2020). Neuroimaging is not dependent on behavioral effects alone, a significant asset since there are non-trivial issues with granularity and test-retest reliability for many of the common cognitive behavioral tasks (e.g., Paap & Sawi, 2016; Soveri et al., 2018). This heightened sensitivity of neuroimaging methods to language experience enables the neurocognitive investigation of multilingualism as a spectrum rather than a single category. Indeed, recent neuroimaging work demonstrates how more active multilingualism (increased exposure, domains of use, proxies for social use and networking, etc.) correlates with individual-level neuroanatomical variation or more efficient functional connectivity (e.g., Li et al., 2014; Dash et al., 2019; DeLuca et al., 2019a; DeLuca & Voits, 2022; Luk et al., 2021; Sulpizio et al., 2020).

Given the correlations between degree of multilingual engagement and linguistic and neurocognitive outcomes, it would seem that group comparisons between multilinguals and monolinguals are not (always) reliable across studies, much less *a priori* necessary or appropriate at all. The default nature of monolingualism as the benchmark of comparison is problematic for scientific and social reasons. On the scientific side, monolingual language experience is not monolithic. That is, it is not devoid of individual level variation, and this reality can have important consequences. For example, ambient exposure to language for so-called monolingual cohorts has been shown to affect learning a new language (Bice & Kroll, 2019). Therefore, it is not unreasonable to expect that greater monolingual experience with ambient linguistic diversity as compared to those with less, little or none will matter for the neurocognitive baseline data used in studies comparing them to multilinguals. Yet, monolinguals, typically considered as a control population, are—unwittingly—presented as if they are monolithic with little regard to their own within-group variability. Whether or not such baselines are warranted for other reasons aside, this reality alone should give us cause for concern. Variability in exposure to linguistic diversity in monolinguals either being ignored or research practice leaving the implied impression that any given monolingual group is functionally equivalent to those in other studies can add significant noise to the intended signal – to identify between-group difference relative to multilinguals. As is true of similar assumptions about multilingual groups across studies (Grundy 2020; Leivada et al. 2021; Surrain & Luk, 2019), this reality hazes the general picture of what we seek to better understand by compromising cross-study comparability. Insofar as basic assumptions for data comparability are confounded, this reality questions the basis upon which conclusions can be meaningfully made, especially in the context of meta-analyses and/or systematic reviews.

For decades now, the comparative fallacy of multilinguals to monolinguals has been discussed and cautioned against in psycholinguistic research (e.g., Bley-Vroman, 1993; Grosjean, 1998; Ortega, 2013). Moreover, comparing to monolingual controls subverts the global linguistic reality of the world, where over 50% of people live in bilingual contexts (De Houwer, 2021) and where some languages simply do not have any monolingual speakers given their historical and geographical situations (Romaine, 1995). In this vein, dichotomous (binary) categorization of monolinguals vs. multilinguals, which varies across studies, is woefully insufficient to capture complexity in all contexts, perhaps more so as a function of increasing numbers of languages in the mix. As recent empirical and epistemological work has demonstrated, including the articles in this special issue, one of the most pressing challenges for the field is to identify a consistent way to qualify and quantify degree of multilingualism across different social and individual contexts (see Leivada et al. 2021 for discussion).

The articles that comprise this special issue, individually and collectively, shift the question from *whether* multilingualism confers effects on language, mind, and brain to *what the necessary conditions and experiences of multilingualism* are that potentially contribute to cognitive and brain plasticity. Framing the question in this way accomplishes several objectives. Firstly, it forces us to engage with the reality that multilingualism is not a categorical variable, but rather a constellation of overlapping, continuous and multi-dimensional spectra. Secondly, identifying variation in diverse language experience that correlates with linguistic and cognitive performances, brain functioning, structure and connectivity enrichens our current understanding of how language is represented in and interacts with the mind and brain. Thus, the papers in this special issue collectively combine to move several interconnected research fields forward to better understand the multifarious relationships that multilingualism has, as an experience-dependent mechanism, for linguistically related neuroplasticity.

The special issue is comprised of 15 original articles: two theoretical perspective pieces, one meta-analysis, and 12 original empirical papers using fNIRS, eye-tracking, task- and resting-state functional neuroimaging techniques (EEG and fMRI) and structural MRI methods. Echoing our call to attend to the nuance of multilingualism as a complex life experience, *Navarro-Torres et al.* (2022) advocate for considering cognitive research on multilingualism as a discovery process, attending to the justification of sample size yet not devaluing findings from rigorously designed studies with smaller subject pools with carefully matched samples. Importantly, the authors point out that valid and meaningful interpretation of behavioral and neuroimaging consequences of multilingualism relies on detailed characterization of the samples' language experiences as well as parameters of limitations in generalizing results to all multilinguals. Using an analogy of ecosystem, *Claussenius-Kalman et al.* (2021) stress the importance of attending to a bilingual's cognitive ecosystem and present a framework to consider the non-linear relationship between multilingual experience and outcomes. The framework calls for an emergentist perspective that accounts for developmental trajectories, a dimension that has not been the focus of sufficient investigation in multilingualism to date. To illustrate the impact of diversity across samples, *Stankovic et al.* (2022) reported a meta-analysis of the foreign language effect in decision-making involving moral dilemmas, showing that language proficiency plays a modulating role for making these decisions. Their findings showcase the diversity of at least one dimension of multilingual experiences modulate findings on a cognitive outcome, specifically moral reasoning.

While we strongly advocate for considering multilingualism beyond a categorical variable, the resources involved in collecting data that allow examining multilingualism as multi-dimensional spectra are considerably more demanding than those involved in comparing groups. In this special issue, four empirical studies adopt enriched group comparisons to illustrate the utility of comparing samples with different language experiences. By constructing person-centered connectivity models, *Arrendondo et al.* (2022) contrasted findings from standard analyses for fNIRS data in an Attentional Network Task (ANT) completed by English monolingual and Spanish-English bilingual children. In adults, *Chung-Fat-Yim et al.* (2021) examined EEG components when English monolingual and Chinese-English multilingual young adults completed a flanker task in three language context blocks: English single-language, Chinese single-language, and Chinese-English mixed-language. Multilinguals showed significantly lower mean amplitude for the P2 component compared to their monolingual peers only in the Chinese-English mixed-language blocks. However, context block differences obtained only for monolinguals in the amplitude domain of the P3. Two other empirical studies also showed differential brain responses in ERPs: between early/late bilinguals and monolinguals in a prospective memory paradigm (López-

Rojas et al., 2021) and between monolingual and bilingual participants situated on opposite ends of a continuum of latent variables (Calvo & Bialystok, 2021). These enriched group differences demonstrate the possibility of harnessing multilingualism as a multidimensional spectrum to augment more traditional group comparisons.

A set of five papers probed the associations between variations in neuroimaging outcomes or eye movements and multilingual experience. *Dash et al.* (2022) utilized a principal component approach to extract subjective and objective measures of second language acquisition experience among French-English bilingual participants in Montréal, Canada. These subjective and objective measures modulated the correlations between resting-state functional connectivity with 20 seed regions in all three attention networks (alerting, orienting, and executive control). Similarly, *Li et al.* (2021) examined resting-state functional connectivity and signal variability while further considering the diversity of language usage through an entropy measure (Gullifer & Titone, 2018) among a group of linguistically diverse young adults in Singapore. A significant positive correlation was observed between the weighted entropy measure and latent brain scores, suggesting that increased entropy in language usage was related to stronger representation of the executive control network. Also using resting-state data, but via EEG oscillatory dynamics, *Pereira Soares et al.* (2021) reported that onset age of second language acquisition had an inverse relationship with high beta and gamma power frequency among bilingual participants in Norway and in Germany. Notably, coherence maps of different band power connecting localized regions were modulated by onset age of second language acquisition, self-rated proficiency in the societal language, and non-societal language exposure at home and in community. The converging findings from these functional studies were that complexity of language usage modulates brain functional measures in both MRI and EEG. Yet, whether these studies' findings can be generalized across different language communities is yet to be determined. In addition to functional connectivity, yet another paper by *Fedeli et al.* (2021), using a network neuroscience framework, showed that multilingual experiences correlated with the connectome of brain structural components. Moreover, using eye-tracking, *Marian et al.* (2021a) showed that while retrieval of visual memory improves with shared phonological or semantic features with the target, effects of phonological competition were attenuated by greater dual language immersion and effects of semantic competition were reduced by greater dual language proficiency. As a cohort, the findings in this subset of papers underscores the need and utility of considering multilingual experiences as continua.

The remaining three papers in this special issue provide unique contributions to prompting the "next questions" in how we understand multilingualism and cognitive or brain consequences, namely longitudinal designs in a second language learning context (Liu et al., 2021), whether exposure to different dialects is similar to multilingualism (Di Dona et al., 2022), and cognitive variables that contribute to learning an artificial language among monolinguals (Marian et al., 2021b), all of which provide crucial insights into how understanding individual differences in cognitive abilities and/or relevant experiences may contribute to the development of interactive multilingual language systems.

Concluding remarks

Newly emerging questions from the 15 papers comprising this special issue, as well as many pre-existing ones reinforced in them, are important to enrich our understanding of multilingualism, not least, by probing into the nuance and quality of its experiences as well as the behavioral and neural consequences of them. Indeed, the majority of the present studies involved young adults; only one study involved children. This alone highlights another critical point: the investigation of multilingualism needs to better diversify age groupings in order to evaluate how multilingual experience interacts with development and aging. The studies included in this special issue feature empirical studies involving samples from eight unique countries (Canada, United States, Spain, Singapore, Norway, Germany, China, and Italy). For studies targeting the interactional experiences of multilinguals, information about the social contexts where and how languages are used is likely to be highly relevant to inform the characterization of multilingualism (Tiv & Titone, 2022). Echoing *Claussenius-Kalman et al.* (2021) and *Navarro-Torres et al.* (2021) from this special issue alone, the prospects of understanding how diverse language experiences shape behavior, cognition, brain functions and structures ought to consider the ecology and contexts where languages are used as a communicative tool. As demonstrated in this collection of empirical studies, new approaches in characterizing multilingualism will continue to propel our fields beyond simple group comparisons, increasing ecological and social justice validities for understanding multilingualism in a global perspective of the 21st century.

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