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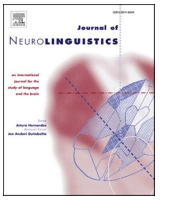

Research paper

Brain, mind and linguistic processing insights into the dynamic nature of bilingualism and its outcome effects

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Beyond its ubiquity and utility in all that we do, language is perhaps the most essential characterizing trait differentiating humans from all other sentient beings. As such, studying the acquisition, processing and neurological/cognitive effects of housing language in the mind affords opportunities to better understand fundamental characteristics implicated in multiple domains of cognitive science, such as the manifestation and working of language itself, human cognition, brain plasticity and the role experience plays in shaping relevant competencies. While there is no question that studying how monolinguals acquire and process their native languages provides key insights into the aforementioned domains, comprehensive understanding can never be ultimately achieved in the absence of considering what bilingualism brings to bear on these same queries. Why should this be so?

Knowing more than one language represents the default linguistic reality across the globe—over 50% of the world population is at least bilingual, if not multilingual (Grosjean, 2019; Romaine, 1995). Therefore, understanding language and its knock-on effects within the mind/brain from the perspective of the global minority, so-called monolinguals, constitutes an inherent fallacy compromising any meaningful generalizability *a priori*. Whether from a linguistic perspective that places more emphasis on describing and explicating how language comes to be, is mentally represented and processed or a more neuroscience perspective that capitalizes on language to reveal what brain areas and neural networks are implicated in complex cognitive processes, without evidence from bilinguals we could only ever have (less than) half of the story. Indeed, studies examining the acquisition and processing of language in various types of bilinguals document both similarities and differences between them (e.g., Desmet & Duyck, 2007; Meisel, 2004, 2011; Kaan, 2014; Slabakova, 2016; Kupisch & Rothman, 2018). Given that bilinguals are not the sum total of two monolinguals in a single mind, such discoveries are not surprising, nor do they speak to the superiority of one state over the other. They merely highlight that despite sharing much overlap at multiple levels, including underlying mechanisms, they are unique instantiations of the same fundamentally human reflexes.

Bilingualism itself constitutes a crucial natural laboratory for language and cognitive science research. Studies related to cross-linguistic influence in bilingual acquisition and processing over more than fifty years, to cite one of numerous examples, highlight not only the relative (yet constrained) porosity of language and its intimate relationship to domain general cognition, but more

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impressively the principally economic nature of the human mind more generally. The presence of more than one language in a single mind is likely to have multifarious consequences well beyond the domains of language representation, processing and use. Minimally, the management of two systems that compete for finite cognitive resources introduces layers of convolution that stress whatever underlying mechanisms are implicated for language (acquisition, processing, maintenance and contextual use) in all learners, monolingual and bilingual alike. Despite intention or contextual need, research shows that all known language systems are simultaneously active (e.g. Green & Abutalebi, 2013; Jared & Kroll, 2001; Marian & Spivey, 2003; Kroll, Bobb, Misra, & Guo, 2008; Schwartz & Kroll, 2006; Spivey & Marian, 1999). Although potentially costly at the cognitive level, to fulfill the remit of bilingualism simultaneous activation makes perfect sense. Just as one could not expect a car that has been left inactive in subzero temperatures to immediately take off at full throttle by turning the ignition key (if at all without warming up), it would be untenable for bilinguals to be able to switch, as (often unpredictable) shifts in context require, between languages if the language(s) in disuse at any moment were completely disengaged. Alternatively, keeping the other language system(s) at a low level of idling activation enables smooth transitions as necessary.

As one might expect, successful management of simultaneous activation does not come for free. As stated above, it taxes executive and language control, including the brain areas and neural networks that support them, and places demands on finite attentional resources and their allocation. What are the consequences of this? Research suggests that over time this cognitively demanding mental juggling could result in rather positive secondary effects, such as relative gains in executive functions performance, volumetric changes to the brain in areas related to executive and language control and/or increased efficiency in task performance (i.e. less network recruitment) with or without accompanying behavioral (speed) effects (see Pliatsikas, 2019 for a review). Indeed, active engagement with bilingualism might constitute a lifestyle enrichment factor—like other activities that tax/engage cognitive functions such as sustained exercise (Yaffe et al., 2009; Sanchez-Lopez et al., 2018)— related to cognitive and brain reserve accrual over time (Stern, 2012). If on the right track, accrual of cognitive and brain reserves would explain findings that suggest bilingualism can afford compensatory protection against the onset of symptoms of cognitive aging, especially in neurodegeneration with dementia/Alzheimer's (see Abutalebi et al., 2014, 2015a,b; Anderson, Hawrylewicz, & Grundy, 2020; Bak, 2016; Bialystok, Craik, & Freedman, 2007; Craik, Bialystok, & Freedman, 2010) or even with other neurocognitive degenerative diseases (see Voits, Pliatsikas, Robson, & Rothman, 2020 for a review). All of the aforementioned possibilities are captured under the umbrella of the so-called "bilingual advantage" position.

As is well known, in recent years the generalizability of the "bilingual advantage" has been contested (e.g. Lehtonen et al., 2018; Nichols, Wild, Stojanoski, Battista, & Owen, 2020; Paap, Johnson, & Sawi, 2015). It is fair to highlight issues of replication in executive function tasks across bilingual studies, a potential bias/tendency towards not publishing null results and issues with statistical power in particular studies. However, it is important to note that replication issues across bilingual studies is to be expected. This is true not least because bilingualism is not a categorical variable, despite often being treated as if it were, and differences between so-called monolinguals and bilinguals in any given study are not equally defined or assessed, if clearly definitive at all (DeLuca, Rothman, Bialystok, & Pliatsikas, 2019; Luk & Bialystok, 2013, see Bice & Kroll, 2019 for evidence showing that amid so-called *monolinguals* increased cognitive plasticity unfolds as a function of increased exposure to more linguistic diversity in the environment).

Context is always important. And so, it is germane to highlight that it had already been noted in the earliest of relevant studies that behavioral effects in executive function performance is not seen in all bilingual individuals or even aggregates of bilinguals of particular ages (i.e. young adults, see Bialystok, Craik, Klein, & Viswanathan, 2004; see Bialystok, 2016, 2017 for discussion). As such, it is not surprising that many studies do not find supportive evidence of bilingual effects, not least since the most studied age group comprise young adults. Equally, it is prudent to keep in mind that the entire body of research that comprise the evidence base *for*, *neutral to, inconclusive of* or *against* bilingual effects on neurocognition largely fits within the confines of the last two decades. Taken together, it is premature to conclude much of anything definitive on the basis of available data (Leivada, Westergaard, Duñabeitia, & Rothman, 2020). Instead, what challenging data represent is an opportunity to test the parameters of the original observation itself.

In a recent meta-analysis examining 167 studies, Grundy (2020) identified several potential factors that could constitute confounds of comparability across studies, including how bilingualism is defined, verbal demands of the tasks, ceiling/floor performance and outlier removal procedures, among others. Crucially, Grundy's meta-analysis clearly shows that bilinguals outperform monolinguals on executive functions tasks significantly more often than chance, refuting claims of a type 1 error at play within the field as a whole. In line with recent calls by several researchers, the conclusion to which Grundy's analysis leads is that a shift in focus and questions is warranted. The question is not if indeed there are potential differences between monolinguals and bilinguals, but under what circumstances and conditions do differences emerge. In other words, what bilingual experiences, opportunities for engagement and in what proportions thereof are bilingual effects on neurocognition more likely to result (and why)? As is typical of any seismic shift in research focus, such as the one pursuing the role bilingualism might have in shaping domain general cognition and neuroplasticity has had, refinement and greater precision as the field becomes more nuanced and experienced in the object of study is a natural progression.

In summary, as the linguistic, psycholinguistic and neurocognitive study of bilingualism have matured over the last decades, a significant amount of research points in the same direction across these interrelated fields: diverse language experiences (from age and quantity and quality of input/intake exposure to individual engagement at various levels with language use across multiple axioms, and much more) has distinct consequences on mental representations of language, linguistic performance, language processing and domain general adaptations to the mind (cognition) and brain (neural anatomy and functional connectivity). The exact effects of diverse language experience, however, are surely more nuanced than we currently understand and/or are able to measure. Thus, at present, they are not yet well understood. This special issue brings together papers engaged in earnest and sophisticated attempts at making strides towards beginning to fill this gap. As such, it is a collection of studies addressing the contemporary issues and debates

surrounding bi-/multilingualism and the brain/mind, thereby providing a unique window into bilingual processing.

In what follows, we briefly summarize each of the studies that comprise this special issue. Each study stands alone as an example of well-conducted and meaningful research, focusing on specific questions that motivate the empirical work undertaken in the context of partially overlapping subfields. Nevertheless, reading these studies in the context of the special issue has added value. Together they combine to offer significant evidence from adjacent subfields that underscores the complexity of bilingualism, the reach that bilingualism can have as well as the need to be more nuanced in how we measure, treat and ultimately conceive the spectrum of bilingual experiences. The articles roughly fall into three macro groups (presented in that order), namely *brain*, *mind* and *language processing*.

The *first group* (Brain) includes papers that are related to what extent language experience factors in the bilingual continuum, such as age of acquisition (AoA), proficiency, immersion in the L2 environment, age of second language acquisition (L2AoA), as well as inhibitory control and code-switching have an effect on the human brain structurally (gray and white matter) and functionally. Looking at the effects of bilingualism on the human brain, DeLuca, Segaert, Mazaheri, and Krott (2020) offers a review and comparison of existing models of neurocognitive adaptations from bilingualism to date (Abutalebi & Green, 2016; Stocco, Lebiere, & Anderson, 2010; Grundy, Anderson, & Bialystok, 2017; Pliatsikas, 2019) and propose a novel, predictive framework. Their Unifying the Bilingual Experience Trajectories (UBET) model seeks to map the relationship between the various neurocognitive adaptations and different trajectories of bilingual experience. UBET focuses on intensity and diversity of language switching, language use, relative duration and proficiency of bilingual experience. Predictions stemming from the interactions between different bilingual experience factors and relationships in measurable neurocognitive and anatomical brain adaptations have been put forward (for both MRI and brain oscillations in EEG). This new framework provides a theoretical background and, crucially, clear predictions for future empirical studies on a large scale that hones in precisely on individual differences in outcomes across groups and individuals.

Luk, Mesite, and Leon Guerrero (2020) investigated whether the age of second language acquisition (L2AoA) and the onset age of the second most proficient language (pL2AoA) can be considered as a sensitive measure (i.e., experience factors) that modulates and correlates with fractional anisotropy in white matter. Their results show that both L2AoA and pL2AoA negatively correlated significantly with fractional anisotropy in the corpus callosum, suggesting that these two factors can modulate white matter in multilingual young adults. While the previous study addressed white matter changes in relation to bilingualism experience, Rossi, Dussias, Diaz, van Hell, and Newman (2021) were interested in the neural control mechanisms at play during habitual code-switching. Their goal was to investigate if and to what extent the comprehension of code-switched sentences modulates the putative control network. They found that relative to non-code-switched sentences, code-switched sentences engage areas generally involved in cognitive control, such as the pre-SMA, the anterior cingulate cortex and so on. Moreover, the fact that significant activation was found in the cerebellum when processing sentences containing code-switches at the noun-phrase boundary might suggest that habitual code-switchers activate a larger control network to adapt inhibitory control processes according to task demands.

Wang et al. (2020) were interested in how L2 learning experience shapes the bilingual brain, by using a combination of structural, functional and resting state methodologies. The results revealed increased GMV in an extensive network in higher-proficiency bilinguals only, which correlated with the functional changes. FMRI data of the L2 picture naming task, compared with L1 processing, exhibited more neural activation in both cognitive and language control areas, and this increase was positively correlated with L2 proficiency. Finally, the rs-MRI data showed positive correlations between the amplitude of low-frequency fluctuation (ALFF) and participants' L2 proficiency. This was found in brain areas within the salience network and cognitive control, suggesting a cognitive flexibility associated with the L2 learning experience. Addressing similar questions, Grundy, Pavlenko, and Bialystok (2020) used a new approach to investigate the domain-general cognitive outcomes of bilingualism to look at the role of attention disengagement by means of EEG/ERPs. By creating a continuous measure of bilingualism across their sample, they observed that greater bilingual experience and proficiency were associated with the magnitude of the inhibition effect. Namely, "more bilingual individuals" showed larger and earlier inhibition effects. The study represents a next step in the understanding of facilitation in the inhibition paradigm and demonstrates how bilingualism modulates domain-general attention networks in the brain.

Taken together, the studies in the first group point in the direction of bilingualism induced brain changes, in both structure and function. Not only that, they do so while highlighting, if not emphasizing, the need and value of deconstructing the binary monolith of treating bilingualism as a categorical variable (and monolingualism for that matter). In line with current trends in the bilingualism and (neuro)cognition literature seeking to unpack bilingualism as the continuum of experiences it entails (e.g. Bialystok, 2017; DeLuca et al., 2019; Gullifer & Titone, 2020), the present studies underscore how approaching bilingualism as a continuous variable achieves greater ecological validity while serving as a useful methodological tool for clarifying the mechanisms at play, the conditions under which they are engaged and the thresholds of engagement under which bilingualism is more and less likely to induce effects.

The *second group* (Mind) includes papers that are related to how bilinguals manage and use their languages and how the mind regulates the cognitive mechanisms behind it, such as focused attention, inhibition and other executive functions (EFs). Ning, Hayakawa, Bertolotti, and Marian (2020) used behavioral and neural methods to investigate how language influences cognition in adult bilinguals, showing that bilingual experience can influence perceived semantic associations. They propose that bilinguals' denser and more interconnected phonological, orthographic and lexical systems may change the links between semantic concepts. Such an account is consistent with connectionist models of language (e.g., Caramazza, 1997; Dell, 1986; Levelt, Roelofs, & Meyer, 1999; McClelland & Rumelhart, 1981) that allow for phonological and lexical influences on conceptual representations, with implications for models of bilingual language processing. Previous studies (Bialystok, 2009; Struys, Duyck, & Woumans, 2018) showed that bilinguals seem to perform better in tasks requiring executive control due to their constant juggling of two languages, pointing towards a potential for a bilingualism effect. In Patra, Bose, and Marinis (2021), the authors investigated the relationship between increased lexical competition and executive control processes in adult bilinguals. They used a blocked-cyclic naming task and assessed participants on three measures of EFs (inhibitory control, mental-set shifting and working memory). The results showed that bilinguals had a

significantly smaller inhibitory context effect, more semantic facilitation, and better inhibitory control and shifting abilities than the monolinguals, but similar working memory span. To our knowledge, this is the first study to find that bilinguals are less affected by semantic context manipulation compared to monolinguals, showing that even in a challenging linguistic task with increased lexical competition, bilinguals can perform better than monolinguals.

Kubota, Chevalier, and Sorace (2020) investigate the degree of relative language proficiency and exposure influence on EFs in a novel group of bilinguals, namely returnee children. Returnees are children who are either born in a country different from their parents native homeland or move to a new country in early childhood, often due to temporal career needs, and return to their homeland later after a significant amount of time living abroad (Flores, 2010, 2017). Although rarely studied, returnees are of particular interest because their unique context of shifting language exposure allows researchers to address questions of how the moving target of opportunities to engage in a bilingual setting affects EF over time, especially after they return to a monolingual dominant environment. Kubota et al.'s results showed that the amount of reduction of L2 exposure (difference in L2 exposure before vs. after moving back to the L1 country) correlated with children's abilities in the EF tasks. These findings suggest that, in children, the loss of access to the L2 has consequences for the EF development, i.e. less active bilingualism is associated with smaller EF's effects in development. Luque and Morgan-Short (2021) addressed the question of CC as a way to provide a multidimensional perspective on developing bilingualism by means of multiple behavioral measures (Flanker Task, Automated Continuous Performance Task). Their results indicate a significant relationship between CC abilities and overall L2 proficiency. A significant relationship between speed of processing and overall L2 proficiency was also found. The results of this study provide critical new insights into the underlying cognitive mechanisms that may contribute to adult learners becoming bilingual.

A final study in this group, which has important implications for all studies of bilingualism, but especially for those working on revealing the conditions and parameters of the contexts and experiences resulting in neurocognitive effects of bilingualism is the Tiv, Gullifer, Feng, and Titone (2020) study. They used a novel application of Network Science to investigate the interactions of bilingual language usage in Montreal bilinguals across different communicative contexts in their dominant (French) vs. non-dominant language (English). They found that all communicative contexts produce a unique pattern in which conversational topics are discussed, but only work and social contexts emerged as being significantly distinct from other contexts in both network size and strength. Their study is the first to use Network Science as a tool to characterize and quantify the complex relationship between bilingualism and social language use in an attempt to better understand the role of individual differences on bilingualism and cognition. In light of the lively discussion in recent years related to the extent to which bilingualism truly has knock-on effects for the mind and brain, studies like Tiv et al. (2020) are crucial to provide researchers the means to tease apart the complexities and dynamic nature of how and under what conditions opportunities for bilingual engagement combine to result in meaningful mind/brain adaptations.

Similar to what the first group of papers underscored at the (anatomical) brain level, the papers in the second group provide a multidimensional perspective on bilingualism in an effort to unravel the complex relationship between bilingual experiences (with language: its structure, contact with it and its usage) and outcomes. In this case, they do so at the level of mind (cognition). In doing so, they offer new insights into the underlying cognitive mechanisms that (may) influence the bilingual experience and, in reverse, how experiences of bilingualism affect domain general cognition.

The final and *third group* relates to language processing, with two main sub-topics crossed: (i) how different domains of language are processed, such as morphosyntax, phonology and semantics within (ii) different types of bilingual populations (e.g., heritage speakers, late bilinguals, third language acquisition), including bilinguals with language disorders (e.g., aphasia). In one of the very first studies to specifically investigate heritage speakers (HSs) using online EEG methodology, Bice & Kroll, (in press) examined the variation between the non-dominant L1 (their heritage (minority) language acquired at home) and their now dominant 2L1 or child acquired L2 (the majority societal language of the environment in which they grew up) and compared it to variation found in monolingual L1 processing. Within the same set of participants, the authors compared the individual variation in N400 and P600 responses to subject-verb agreement violations in both L1 and L2 processing. EEG data analysis showed that both proficient HSs and monolinguals had similar processing patterns, as seen in their N400 and P600 components. They also conducted individual difference analyses between the variation in ERPs with WM and proficiency. These analyses showed that language processing in bilinguals was more similar to monolingual language processing as proficiency in each language increased; in contrast, WM was the primary factor driving variability in monolingual language processing. Their findings suggest that individual differences in language processing are the product of an interplay between proficiency and WM across languages, further modulated by language dominance. Studies that employ online methods, especially ones that capture more automatic processes and are thus vulnerable to affective factors known to condition heritage bilingual performances on behavioral tasks (Polinsky, 2018), embody an important methodological step forward with epistemological consequences. Not only are online processing measures complementary to behavioral tasks, they permit a level of granularity needed for understanding heritage language bilingualism better and provide missing evidence needed to unpack the true nature and degree as well as significance of so called differences heritage language bilinguals display from other sets of native speakers (Bayram, Rothman, Di Pisa, & Slabakova, in press; Kupisch & Rothman, 2018).

Zawiszewski and Laka (2020) employed EEG to investigate how adult high proficiency Spanish-Basque and Basque-Spanish bilinguals processed noun morphology in both Basque and Spanish. Crucially, they examined conditions that differ with respect to whether only the L1 or both the L1 and the L2 instantiate a given grammatical property. In general, non-native speakers exhibited a smaller P600 and produced more errors for violations than native speakers when processing accusative, dative and allative morphology in Spanish and ergative and allative in Basque. All in all, these findings provide evidence that also for early and proficient bilinguals L1 grammar has a deep impact on the way L2 is processed.

In the first paper published designed to test third language linguistic transfer models using EEG, González Alonso et al. (2020) sought to investigate what the factors are that lead to the (eventual) transfer selection between an L1 or L2 in an additive multilingual

acquisition context via measuring neuro-electrical correlates within a mini-artificial language exposure/learning paradigm. Two artificial languages (ALs) were created. Native speakers of Spanish proficient in L2 English (and living in the UK in immersion) were tested. The speakers were matched and divided into two groups based on which of the two ALs they were trained on. The ALs were lexically based on English and Spanish, yet both exhibited a novel morphological (nominal) agreement paradigm similar to Spanish. The authors based their predictions for performance outcomes based on those articulated for EEG signatures in Rothman, Alemán Bañón, & González Alonso (2015) corresponding to these three models of L3 transfer: the Typological Primacy Model (Rothman, 2011, 2015; Rothman, González Alonso, & Puig-Mayenco, 2019), the L2 Status Factor (Bardel & Falk, 2007; Falk & Bardel, 2011) and the Cumulative Enhancement Model (Flynn, Foley, & Vinnitskaya, 2004). The results did not match the specific predictions for ERP components (P600 and/or N400). However, an early positivity was found albeit only in the group exposed to Mini-Spanish. The authors interpret the appearance of this P300-like component as evidence for an indicative precursor for transfer, that is, a signature demonstrating differential attention being placed by one group only given the typological similarity of the AL, when based on the Spanish grammar.

Calabria, Grunden, Iaia, and Garca-Sánchez (2020) investigated the underlying mechanisms of lexical retrieval in two languages when modulated by phonological context in bilinguals with aphasia. Focusing on facilitation/interference effects of phonological similarity during a lexical retrieval task, they examined such effects through two lenses: bilingualism (dominant vs. non-dominant language) and language deficit (aphasia vs. healthy controls). The authors measured reaction times, word duration, and accuracy in naming during a phonologically blocked cyclic naming task in each of their languages. The results showed that accuracy was negatively impacted in both languages for patients with aphasia, while this was not observed in controls, and that performance in both groups was similar across their two languages. They showed that lexical retrieval mechanisms work within each language in a very similar way, suggesting that phonological processing operates in a language-independent manner.

On the whole, the studies of the third group report critical findings to understand the underlying mechanism of L2 and L3 language processing (and acquisition) in different populations. Crucially, they offer some novelty in terms of design pathways to acknowledge, investigate and deal properly with bilingualism through the lens of its experiential nature.

Taken all together, the studies in this special issue combine to form a collection of well-orchestrated papers that open up new insights and directions for research committed to ecological validity in bilingual language processing, cognitive control, and the underlying neurocognitive bases of the bilingual brain and mind and how these areas crosscut each other. Notwithstanding the narrower value for particular theories, specific questions and discrete debates that each paper brings to bear individually, the collection stands out as generally informative and most valuable as a whole. This is true precisely because the breath of topics, methods and domains of inquiry ultimately touch upon and provide converging evidence for a similar truism: understanding bilingualism and all its sub-questions requires an approach that treats it for the spectrum it is. The days of dichotomous handling and monolithic assumptions regarding bilingualism are over. This collection of papers combines with other work in recent years to highlight how and why results from bilingual empirical research cannot begin to be generalized in the absence of confronting the dynamic and multifarious nature of the experiences that condition how languages come to be represented, processed and used much less drive potential knock-on effects to the mind and brain from the linguistic competition of more than one system in the same individual.

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