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The potential roles of multilingualism and language structural distance in neurocognitive adaptation to language experience

Abstract

A growing body of research shows that individual differences in bilingual language experience variably contribute to neurocognitive adaptations. The trends in this work are beginning to show a specificity of adaptations to the nature and degree of bilingual experiences (e.g., duration of use, language switching, context, and intensity of engagement, etc.). However, several other factors exist which likely would further influence these bilingualism-induced neural and cognitive adaptations. Two such factors may play a modulatory role but are currently under-researched in this field. The first is how such adaptations are affected by the addition of a third or more language and the second is the role of language structural distance in shaping neurocognitive adaptation trajectories. Regarding the role of multilingualism, previous research suggests differences in neurocognitive adaptation to multiple languages over two, although results are mixed. It is possible that, like bilingualism, individual differences in engagement with a third (or more) language might also variably condition neurocognitive adaptation, but this remains an unanswered empirical question. Regarding the role of language structural distance, there are plausible reasons to predict that the relative distance in language pairings would condition the nature or trajectory of bilingualism-induced adaptations, but this is also an understudied topic. I review the existing literature covering these factors, discuss the potential mechanisms of adaptation to each, and propose some potential ways of incorporating these factors in future research.

Introduction

Over the past few decades, a growing body of research has shown that speaking more than one language has potential implications for adaptations across several aspects of neurocognition (Bialystok et al., 2012). Moreover, bilingualism is a dynamic and complex experience with a number of facets that may determine how the mind/brain may be required to manage the languages one speaks (DeLuca et al., 2020; Luk & Bialystok, 2013), which in turn would determine the nature and degree of adaptation. As research begins to incorporate further factors that may modulate how bilingualism affects neurocognitive outcomes (language use/exposure patterns, duration of bilingual experience, etc.), the inclusion of these factors would benefit from cross-talk within and across disciplines. Herein we will focus on two example factors: the role of multilingualism (specifically, competence in more than two languages) and language structural distance (the degree of structural overlap between two languages or varieties). Despite potentially compelling reasons to assess their contributions, both are currently under-researched in the field of bilingualism and neurocognition. Furthermore, there are several potential theoretical and methodological considerations to take in the inclusion of these factors in this body of research.

The present paper will first provide an overview of the relevant mechanisms of bilingual language control and what this entails for neurocognitive adaptations, inclusive of effects of individual differences in bilingual experience and developments in the field, going forward. The available data on effects of multilingualism and relative language distance are then reviewed and some suggestions for how to ideally include these factors in future research are discussed.

Background: bilingual experience and neurocognition

To better contextualize the potential modulatory roles of multilingualism and language structural distance on bilingualism-induced neurocognitive adaptation, it is worth briefly discussing the mechanisms for which bilingual experience is argued to affect neurocognitive outcomes. The languages one speaks are argued to form active and competing mental representations, which must constantly be managed to facilitate successful communication, by actively selecting the target language and/or inhibiting the contextually inappropriate one(s) (Dijkstra & van Heuven, 2002; Green, 1998; Kroll et al., 2012). Both of these cognitive processes related to language control are demanding; thus, several neurocognitive adaptations occur to allow the brain to handle these demands optimally and efficiently (Li et al., 2014; Pliatsikas, 2019).

Crucially, the brain networks/cognitive processes used to facilitate language control overlap at least partially with domain-general cognitive control processes (e.g., Anderson et al., 2018; Coderre et al., 2016). Thus, the neurocognitive adaptations that occur for handling the cognitive demands associated with language control are argued to, in turn, affect domain-general cognitive control and its neural substrates (Li et al., 2014). Indeed, a substantial body of research in the past two decades has shown bilingual experience to affect both domain-general cognitive processes including attentional control and types of memory, and adaptations in brain structure and function (Bialystok, 2017; Pliatsikas, 2019; Pliatsikas & Luk, 2016). These effects have been shown to manifest as adaptations (typically increases) in grey matter volume in cortical and subcortical structures implicated in language-/executive control (Burgaleta et al., 2016; Grogan et al., 2009; Mechelli et al., 2004; Pliatsikas et al., 2017);

changes in white matter microstructure in tracts connecting these language- and cognitive control regions (Luk et al., 2011; Mohades et al., 2015; Pliatsikas et al., 2015; Singh et al., 2018), brain recruitment patterns in cognitive control tasks indicating increased efficiency (Abutalebi et al., 2012; Calvo & Bialystok, 2021; Carter et al., 2023; Kousaie & Phillips, 2017; Morales et al., 2015), and changes (often increases) in task performance on tasks measuring aspects of executive function and memory (Costa et al., 2008; Stasenko et al., 2017).

However, inconsistencies exist between studies examining bilingualism effects on neurocognition, in terms of the nature of the effect on brain structure and function (García-Pentón et al., 2016; Pliatsikas & Luk, 2016) and how or even if these effects consistently emerge at the level of behavior or task performance (Donnelly et al., 2015; Grundy, 2020; Lehtonen et al., 2018; Leivada et al., 2021; Paap et al., 2015). This inconsistency, particularly in the literature examining behavioral effects, has led to debate over the reliability of the domain-general neurocognitive effects of bilingualism (Paap et al., 2019).

These inconsistencies between studies are not necessarily problematic, though, provided there is some underlying systematicity to them. Bilingualism is not homogeneous; rather it is a dynamic and complex experience (Bak, 2016; Luk & Bialystok, 2013). In recent years, a growing body of literature has argued that examining bilingualism as a unitary phenomenon, particularly comparing bilinguals to monolinguals as a control group, can provide misleading results (see for discussion Rothman et al., 2022); examining individual differences in (bilingual) language experience may provide the systematicity to some of the above mentioned inconsistencies (de Bruin, 2019; Leivada et al., 2021). As language control demands are what is argued to shape bilingualism-induced neurocognitive adaptations, the degree of engagement in bilingual experiences is likely to condition the nature and degree of adaptation.

Indeed, several theoretical models have made proposals for a specificity of neural and/or cognitive adaptations to bilingual experience (Abutalebi & Green, 2016; DeLuca et al., 2020; Grundy et al., 2017; Pliatsikas, 2020; Salig et al., 2021; Stocco et al., 2014). Some models propose that degree of engagement within specific communicative contexts (where one or multiple languages are available for use) will determine the nature and degree (respectively) of neural adaptations, reflecting an optimization of the underlying system to handle the specific control demands (e.g., Abutalebi & Green, 2016; Calabria et al., 2018; Salig et al., 2021). Other models and frameworks outline a trajectory of adaptation over time, from initially adapting maximal efficacy at handling increased control demands associated with bilingual experience shifting towards increased efficiency at handling the same demands with prolonged bilingual experience (Grundy et al., 2017; Pliatsikas, 2020; Stocco et al., 2014). Other models propose a set of language experiences and map a specificity of cognitive demands and adaptation patterns associated with them (e.g., DeLuca et al., 2020).

A growing body of literature supports both several of the predictions of the above models, and the notion that bilingualism-induced adaptations in domain-general neurocognition are calibrated to specific aspects of that experience including contexts of language exposure, intensity of engagement with one's languages, duration of bilingual experience, nature and degree of switching between languages, among others (see e.g., (Barbu et al., 2020; Beatty-Martínez et al., 2020, 2021; Bice et al., 2020; Carter et al., 2023; Chung-Fat-Yim et al., 2020; Dash et al., 2019; DeLuca et al., 2019; Gallo et al., 2023; Gullifer et al., 2018, 2023; Gullifer & Titone, 2021; Hartanto & Yang, 2016, 2020; Hofweber et al., 2020; Kałamała et al., 2022; Korenar et al., 2023; Kuhl et al., 2016; Luk et al., 2020; Luo et al., 2019; Marin-Marin et al., 2022; Navarro et al., 2022; Nichols & Joanisse, 2016; Pereira Soares et al., 2021, 2022; Rossi et al., 2017; Sorge et al., 2017; Sulpizio et al., 2020; Wagner et al., 2023;

Yamasaki et al., 2018; Yang et al., 2023). Across these studies some trends have begun to emerge. Notably, increased intensity of use of one's languages, and frequent and controlled code switching seem to correspond to adaptations towards maximal efficacy at handling language control demands; alternatively, prolonged duration of bilingual experience corresponds to adaptations towards increased efficiency of handling existing control demands (see for review DeLuca et al., 2020).

Further modulatory factors affecting bilingualism-induced neurocognitive adaptations

Of course, the field of research is relatively young and much remains to be understood regarding the potential variables pertaining to bilingual experience that condition neurocognitive adaptations. Several new directions have since been taken in the field examining other modulatory variables, some of which condition the nature of language experience and use of specific individuals. While a full discussion of these factors is beyond the purview of this paper, it is worth noting them here. Newer theoretical proposals and empirical evidence outline a potential modulatory role of (broader) social networks (Kałamała et al., 2023; Navarro et al., 2022; Titone & Tiv, 2023; Tiv et al., 2020, 2022), the specific cultural and social contexts of individuals (Tran et al., 2019; Treffers-Daller et al., 2020; Xie et al., 2022), and contexts of conversation/interaction one engages in (Beatty-Martínez et al., 2020; Yang et al., 2023). In particular, these proposals explore how these contexts and networks might dictate the engagement patterns of individuals, thus constraining how bilingual experiences manifest, and in turn what adaptations may be required to handle the associated control demands. Other work has shown effects of indirect exposure to language diversity and potential implications for cognitive processes, for example in aspects of subsequent language acquisition (Bice & Kroll, 2019). Calls have also been made to expand beyond the typical Western, Educated, Industrialized, Rich, and Democratic (WEIRD) demographic subject pool that occupies the majority of research on bilingual effects on neurocognition (Blasi et al., 2022; Kutlu & Hayes-Harb, 2023); in so doing expanding equity and representation in research and generalizability of results.

Each of the above directions is informative for our understanding of both the language- and domain-general outcomes of bilingual experience. Several other factors also require further examination, given their potentially indirect or modulatory effect on language experience-induced neurocognitive outcomes. In what follows, we will unpack on two understudied examples of these which warrant further exploration: multilingual experience and language structural distance.

The role of multilingualism

A logical question that follows from the role of bilingualism on shaping neurocognition is how these domain-general/control adaptations might shift (if at all) when a third (or more) language is acquired, specifically if additional control demands are also imposed by the additional language. Mechanistically, the language control demands inherent to multilingualism are highly similar to those of bilingualism: existing work shows multilingual language engagement makes use of the same cognitive processes to facilitate language control (Linck et al., 2012; Schwieter & Ferreira, 2013). Given these shared control mechanisms, and based on the above adaptation patterns for bilingual experience, several predictions can be proposed for the effects of the addition of a third (or more) language, in terms of the associated language control demands this would impose and neurocognitive adaptations to them:

1) More languages entail more options (languages) to inhibit, and/or more potential opportunities to exercise the activation/inhibition mechanisms, especially if degree of engagement in the languages stays constant. This would likely result in greater cognitive

demands being placed on the language/executive control system and thus require further neurocognitive adaptation.

2) The number of languages one speaks (thus competing systems) may not be the decisive factor in determining the relevant control demands. The languages would only serve to provide more potential opportunities for engagement of the language/cognitive control systems. In other words, speaking more than two languages could, in principle, provide a greater number of conversational situations where at least two of the languages one speaks would be available/have the potential need for use (e.g., Green & Abutalebi, 2013) and thus more often require language control. In other words, the degree of adaptation would largely come down to how the systems are engaged, not the number of languages (beyond two) that one actually speaks.

3) It is also possible that the trajectory of adaptations to multilingualism are highly similar to bilingualism, but shorter-lived. That is, the same, or highly similar, neurocognitive adaptations would occur for multilingual- as for bilingual experience, and follow a similar pattern or trajectory over time (Grundy et al., 2017; Pliatsikas, 2020). However, these adaptations are likely to occur over a more contracted timeframe, given that the neural architecture used to handle these has already been optimized for this before (Pliatsikas, 2020).

Of the research that has examined neurocognitive effects of multilingualism, the vast majority compares groups of multilinguals to monolinguals (Abutalebi et al., 2013; Jafari et al., 2023; Jouravlev et al., 2021; Yee et al., 2023), which problematizes direct comparisons of multilinguals to bilinguals. However, it is worth noting that the regions implicated in this work overlap to a large extent to those affected by bilingual experience and the adaptations (largely) seem to reflect a greater degree of adaptation towards efficiency of language control. For example, Jouravlev and colleagues showed polyglots (who spoke 5 or more languages) have a reduced activation strength within the networks recruited for language activity, interpreted as a more efficient system for language processing (Jouravlev et al., 2021). Abutalebi and colleagues showed multilinguals to have increased activation- and higher grey matter volume in the left putamen, a structure implicated in language control and production (Abutalebi et al., 2013).

The relevant literature examining effects of multilingualism (as a departure from bilingualism) is quite limited. Of the existing literature, evidence for any behavioral adaptations for multilingualism over bilingualism in cognitive control do not seem to reliably appear. The very few studies that do examine relevant adaptations in brain structure, however, seem to show adaptations to the acquisition and use of a third or more language (see for review Yee et al., 2023).

Regarding brain structure adaptations, a study by Grogan and colleagues (2012) examined cortical grey matter volume between bi- and trilingual participants, and found trilinguals had increased grey matter density, compared to bilinguals, in the right posterior supramarginal gyrus, a region frequently associated with vocabulary production (Richardson et al., 2010). Conversely, the majority studies examining cognitive outcomes of bi-/multilingualism have predominantly reported no significant effects of exposure to a third or more language over exposure to two languages (e.g., Chung-Fat-Yim et al., 2020; Poarch & van Hell, 2012; but see Madrazo & Bernardo, 2018). Poarch and van Hell (2012) examined effects of multilingualism on varying aspects of executive control in children, via the attentional network task (ANT), specifically comparing second language (L2) learners (limited bilingual experience) with bilinguals (more extensive amount of experience) and multilinguals (who spoke three languages). Both bilinguals and multilinguals outperformed the L2 learners, but themselves did not significantly differ in performance. Chung-Fat Yim et al. (2020) examined effects of bi-/multilingualism on task performance in a flanker task. Bilingual and multilingual experience were found to contribute to flanker task performance over monolinguals. However, multilingual (beyond bilingual) experience did not further affect task performance, indicating little behavioral contributions of multilingualism to inhibitory control performance. A notable exception, however, is seen in work by Madrazo and Bernardo (2018) who found Chabacano-Filipino-English trilinguals outperformed Filipino-English bilinguals on tests of executive function.

Taken together, the evidence comparing (at the aggregate level) bilinguals to multilinguals supports aspects of the second and third predictions, namely that the cognitive control system (which has been optimized to handle two languages) is unlikely to encounter sufficient demands by the addition of a third language to show reliable behavioral effects. However, the brain may further adapt to handle any additional control/processing requirements more efficiently.

Individual differences in multilingual experience are key to successfully unpacking and assessing how multilingual experiences should (above and beyond bilingual experience) affect neurocognitive adaptations (Festman, 2021). It should also be noted, however, that the majority of research conducted so far has not examined individual differences in (multilingual) language experience and how the presence of a third or more language influences the trajectory of adaptation seen in bilingual experience. The work that does examine individual differences in multilingual experience does show a calibration of neurocognitive effects to the nature and degree of experience, much akin to the existing literature on bilingual experiences. Two example studies report that age of acquisition (AoA) of at least one of the languages multilinguals speak has implications for brain structure adaptations in language processing and control regions. Work by Kaiser and colleagues (2015) shows some structural differences as a function of timing of the AoA of the L2 within multilinguals. Specifically, earlier acquired L2s corresponded to reduced grey matter volume in several cortical regions involved in language processing and control (Kaiser et al., 2015). Similarly, Hämäläinen et al. (2017) examined effects of L2 AoA on white matter microstructure in multilinguals, dividing between early-acquired (L2 AoA < 5) and later-acquired (learned L2 only after starting school). Multilinguals with earlier AoAs were found to show increased white matter integrity in several tracts related to language processing including the left arcuate fasciculus whereas later bilinguals exhibited adaptations within the bilateral IFOF. Hervais-Adelman and colleagues (2018) examined the volume and morphology of several subcortical structures implicated in language control including the caudate nucleus, putamen, pallidum, and thalamus. A continuous measure of multilingual experience was also calculated using weighted scores combining the duration of use (via AoA) of each language the study participants spoke and their respective proficiencies of each of those languages. The volume of the bilateral caudate and morphology (i.e., shape, via a vertex analysis) of the right caudate significantly correlated with the degree of multilingual experience where greater degrees of multilingual engagement were associated with larger volumes and significant local expansions. Taken together, the patterns of results from the available studies seem to support the third prediction discussed above, that is a similar adaptation trajectory for multilingualism as for bilingualism (DeLuca et al., 2020; Grundy et al., 2017; Pliatsikas, 2020), at least for brain structure.

Despite some interesting trends shown for effects of multilingual experience, other factors known to be decisive in bilingual experience such as the degree of engagement in each of the languages and the nature and degree of switching between the languages remains understudied. Interpreters are a unique case of one more extreme end of the multilingual control spectrum which serve as a useful indicator of how intensive engagement with multiple languages may manifest in terms of language control demands and neurocognitive adaptations (see e.g., Becker et al., 2016; Hervais-Adelman et al., 2015; Hervais-Adelman & Babcock, 2020; Pliatsikas, 2020). Evidence from work covering interpreters and individual differences in multilingual experience seems to largely align with evidence for polyglots- namely, adaptations at the neural and cognitive levels towards greater efficiency in handling language control demands (DeLuca et al., 2020; Grundy et al., 2017; Pliasikas, 2020).

Incorporating multilingual experience in future research

The complexity of multilingual experience entails that several factors need to be taken into consideration (see for discussion Festman, 2021) in future research. As discussed above, individual differences in multilingual experience also calibrate the nature and degree of language/cognitive control demands. However, given the complexity and increased potential for engagement in situations requiring varying language controls, methods of both recording and quantifying aspects and degrees of multilingual experience need to develop to adequately capture meaningful individual differences. To that end, some methods for capturing and quantifying multilingual experience have shown considerable promise, including adapting questionnaires to suit a multilingual reality of participants and deriving specific measures to account for cumulative experience with all ones languages (e.g., Fyndanis et al., 2023; Hervais-Adelman et al., 2018). Regarding such measures, language entropy may be an ideal tool to better understand the relative proportions of use of each of the languages a multilingual speaks and/or the degree of integration of each of these languages within and across disparate contexts (see e.g., Gullifer et al., 2018; Gullifer & Titone, 2020). Scores of multilingual experience diversity (MLD), which is based on language entropy, have been adopted within the Language History Questionnaire 3 (LHQ 3.0; Li et al., 2020). Others have adapted existing questionnaires to more accurately capture cumulative patterns of engagement across multiple languages (Fyndanis et al., 2023). Furthermore, examining and quantifying the larger socio-communicative contexts in which multilingual individuals exist (Beatty-Martínez et al., 2020; Titone & Tiv, 2023; Tiv et al., 2022) has also shown considerable promise for quantifying multilingual experience and the control demands this will entail.

In addition to the tools described above, empirical work would ideally be run with populations and cohorts that allow us to tap into different aspects of multilingual experience (e.g., simultaneous vs sequential multilingualism, different societal availabilities of language, etc.). This runs in parallel for calls for the field to expand the scope of research to a broader set of sociolinguistic contexts (Blasi et al., 2022); in addition to creating more equitable representation in participant samples, doing so will also provide the necessary diversity needed to answer the above questions. The continued use of both neuroimaging and behavioral measures will allow us to map the overall nature and trajectory of adaptation to multilingual experience.

The role of language structural distance

Given the mechanisms of inhibition and selection during bilingual language use, it is reasonable to predict that structural distance between languages could modulate language control requirements (and thus adaptations), although this remains under-researched. Recall that, for purposes of discussion, I define language structural distance as the degree of overlap between two languages or varieties, in terms of different features of the languages, e.g., vocabulary, functional morphology, syntactic structure, etc. (see e.g., Putnam et al., 2018; Rothman et al., 2019; Westergaard et al., 2017).

It would be logical to specifically predict that languages which are structurally closer will have more overlap across different features and thus provide more potential for competition at varying levels (e.g., lexis, syntax, etc.) in language production and processing (see for discussion Antoniou & Wright, 2017; Lee, 2022). This, in turn, would result in greater demands on the language/executive control system and thus show more robust bilingual effects. However, the way in which language structural distance might affect language-/cognitive control demands is conceptually complex and (among other factors) is potentially dependent on how languages differ, structurally, for example in terms of which features differ (see for discussion Lee, 2022), or at what point in the process of the acquisition trajectory one is (Antoniou & Wright, 2017). Furthermore, the degree to which this effect obtains and how it might interact with, or modulate the effects of, other bilingual experiential factors remains an open empirical question given the relatively small body of work that has directly examined these relationships to date.

Some research seems to show a modulatory effect of structural distance between languages on bilingual neurocognitive adaptations but the results from the present body of work are mixed (Bialystok et al., 2005; Coderre & van Heuven, 2014; Morrison & Taler, 2023; Perovic et al., 2023; Radman et al., 2021; Yamasaki et al., 2018). Some studies find closely related languages to confer stronger cognitive effects (particularly at the level of neural recruitment to handle control demands on-task) than those considered more structurally distant (e.g., Radman et al., 2021), although these effects are somewhat mixed depending on how linguistic distance is quantified and what outcomes are measured (Coderre & van Heuven, 2014; Morrison & Taler, 2023). Other work finds no differences between languages of differing structural proximities, in terms of measurable neurocognitive adaptations, across different populations and ages (e.g., Antoniou et al., 2016; Sörman et al., 2019; Von Grebmer Zu Wolfsthurn et al., 2022), while other work still shows the opposite pattern, with bilinguals with more structurally distant languages showing stronger neurocognitive effects (e.g., Bialystok et al., 2005). Evidence for effects of language structural distance on neuroanatomical outcomes is more fleeting: currently no research exists which directly examines how language structural distance modulates brain structure adaptations to bilingual experience.

Radman and colleagues (2021) compared Persian-English (distant language pairing) with French-English bilinguals (closer language pairing) in a picture naming task and switching task. The French-English bilinguals were found to show lower switch costs, but increased brain recruitment patterns to the Persian-English participants, which is interpreted as a stronger involvement of control systems. Morrison and Taler (2022) compared monolingual, French-English (closer language pairing) and Arabic-English (more distant language pairing) bilingual groups in two working memory tasks, a delayed match sample- and n-back task, while EEG was recorded. No behavioral differences were observed between groups for either task, however brain recruitment strategies differed across groups in the two tasks. In the delayed matching task, monolinguals displayed larger N2 amplitudes than both bilingual groups (who did not differ), whereas French-English bilinguals displayed larger P3b amplitudes than monolinguals. French-English bilinguals also displayed larger P3B components than the Arabic-English bilinguals and monolinguals. Von Grebmer Zu Wolfsthurn and colleagues (2022) showed no differences in task performance on a Stroop paradigm between Italian-Spanish bilinguals (closer language pairing) and Dutch-Spanish bilinguals (considered the more distant language pairing). Conversely, Bialystok and colleagues (2005) found Chinese-English bilinguals (more distant language pairing) to show reduced brain recruitment and faster reaction times than French-English bilinguals (closer language pairing) and native-English speaking monolinguals. Similarly, Perovic and colleagues (2023) found Hungarian-Serbian bilinguals (more distant language pairing) outperformed Slovak-Serbian bilinguals (closer language pairing) and Serbian monolinguals on a series of executive function tasks.

In order to understand the effects of language structural distance, more closely related varieties should also be included in research, including dialectal varieties of a language. While no consistent delineation between dialects and languages currently exists, we will restrict discussion to regional varieties of a language, for example of Norwegian (Lundquist & Vangsnes, 2018) or British English (Melinger, 2021). While considerable overlap is likely to exist between such varieties of a language in terms of their structural distance, a growing body of work indicates that these are processed as separate systems (see e.g., Kirk et al., 2018; Lundquist & Vangsnes, 2018). How this separation manifests across studies with regard to performance on domain general cognitive control tasks, however, is not consistent (see e.g., Kirk et al., 2014; Ross & Melinger, 2017). Poarch and colleagues (2019) show data indicating greater degree of engagement in both standard German and Swabian (dialect) showed increased task performance on two inhibition tasks. Ross and Melinger (2017) compared bilingual, bidialectal (English-Scots) and functionally monolingual participants on several cognitive control tasks including a Simon and Flanker task and a version of the Berg Card-Sorting task. No differences in task performance were found between the bidialectal and monolingual groups. Bilingual participants were found to outperform the other groups but only for accuracy rates in the Simon task. No group difference was found for the Berg Card-Sorting task. Kirk et al. (2014) compared bilinguals, bidialectals, and monolinguals on a Simon task. Here no group differences were found in task performance which is interpreted as a lack of a clear effect of bidialectalism on task performance.

Taken together, an initial examination of the body of literature examining a modulatory role of language distance on bilingualism-induced neurocognitive adaptations would indicate that there is an inconsistent effect of this factor. However, several issues need to be considered and addressed in future research before any concrete conclusions can be drawn. The first issue is that the existing literature (with few exceptions) has examined language distance via comparing specific language pairs and has not consistently quantified how each of these languages are distinct. For example, one can make an argument that, for example, Italian and Spanish are structurally more similar than German and Spanish. However, the structural distance of each pairing is currently not quantifiable, making comparability between the majority of literature in the field at present difficult. The second issue is that, with scarce exceptions (e.g., Poarch et al., 2019; Yamasaki et al., 2018) the available body of evidence examining neurocognition largely does not consider individual differences in language experience (e.g., AoA, degree of engagement with languages, nature and degree of switching, etc.) or for that matter how language structural distance might *moderate* the neurocognitive effects of one or more of these experiences. Moreover, the lack of consideration of individual difference patterns between groups could be artificially boosting or masking any role that language structural distance might play in the trajectory of neurocognitive adaptation to bilingual experience. That is, for example, studies finding effects for more closely related languages could potentially be seeing effects of differences in engagement patterns which happen to coincide with the grouping variable of language pairing. Alternatively, those studies showing no effect may, for instance, simply have groups of speakers whose language use patterns are cancelling out any effect of language distance, when viewed in the aggregate.

Some ways forward and calls for trans-disciplinarity

As alluded to above, one of the primary obstacles to incorporating language structural distance is the lack of comprehensive and unified method in quantifying language structural distance or proximity. Some promising attempts have already been made to quantify language structural distance; for example using adaptations of Levenshtein distance, a measure based on lexical overlap between languages (Feleke et al., 2020; Wichmann et al., 2010), or via the calculations stemming from language scores on proficiency measures during language training (Chiswick & Miller, 2005). In the literature on multilingual language acquisition, proposals have been made for hierarchies of language structural proximity as engaged with during acquisition and processing (Rothman, 2015; Rothman et al., 2015). However, no study to date has developed a systematic method quantifying language structural distance that both takes into account multiple specific features of language and relates disparate languages to each other, to map how this factor modulates control demands across different degrees of separation. Such an endeavor is monumental and requires insights and expertise from across a variety of related disciplines to accomplish.

This lack of a comprehensive method to capture and quantify language structural proximity would thus benefit from cross-talk between related disciplines. Bringing together insights from acquisition, language typology, dialectology, and others would aid in a better understand and develop methods of doing this. Collaboration between these fields and the field of bilingualism and cognition (acquisition, processing, language typology) is essential for progress going forward in this line of research towards a more comprehensive understanding what modulatory effects language structural distance play on the neurocognitive effects of bilingual language experience. Empirically, more studies can include such a unified measure of language distance across broader ranges of language pairings (Blasi et al., 2022; Kutlu & Hayes-Harb, 2023) to understand in what contexts, to what degree, and/or how this affects outcomes of bi-/multilingual experience. Here, collaboration with other disciplines, including sociolinguists, is also key to adequately capture and quantity the nature and degree of bi-/multilingual experiences that differ across individuals and groups.

Conclusions

As the field progresses towards a more holistic understanding of the multifaceted nature of the effects bi-/multilingual language experience on neurocognitive outcomes, new factors and variables will need to be incorporated at the levels of both empiricism and theory. The present paper has focused on two currently under-researched factors among these, the role of multilingualism (as a departure from bilingualism) and language structural distance, outlining some challenges and avenues to their incorporation along with other factors in (bilingual) language experience. By incorporating insights from various methods within and across disciplines we can more faithfully and accurately capture and understand the role each plays in conditioning neurocognitive adaptations to bilingual experience.

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