Capturing the variation in language experience to understand language processing and learning

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A goal of early research on language processing was to characterize what is universal about language. Much of the past research focused on native speakers because the native language has been considered as providing privileged truths about acquisition, comprehension, and production. Populations or circumstances that deviated from these idealized norms were of interest but not regarded as essential to our understanding of language. In the past two decades, there has been a marked change in our understanding of how variation in language experience may inform the central and enduring questions about language. There is now evidence for significant plasticity in language learning beyond early childhood, and variation in language experience has been shown to influence both language learning and processing. In this paper, we feature what we take to be the most exciting recent new discoveries suggesting that variation in language experience provides a lens into the linguistic, cognitive, and neural mechanisms that enable language processing.

Keywords: language variation, bilingualism, second language learning, language development, language processing

1. Introduction

Traditionally, the goal of psycholinguistics was to provide an account of how language is learned, understood, and spoken. During the earliest months of infancy, babies tune to the speech of their environment so that by the end of the first year of life, they have become experts in the language that surrounds them (e.g. Kuhl, 2004; Werker & Tees, 1984). That initial trajectory appears to establish the course of language development, with constraints in the ability to fully acquire

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the phonology and grammar for those who are exposed to a second language (L2) after early childhood (Flege, Yeni-Komshian, & Liu, 1999; Iverson et al. 2003). On this account, the native or first acquired language (L1) takes precedence in establishing the foundation for language processes and language learning across the lifespan. When individuals are exposed to an L2, by virtue of choice or necessity, it is the L1 that has been hypothesized to be the source of transfer to the L2, with the success of learning outcomes determined by the structural relations between the two languages and by the age at which the L2 is acquired (e.g. MacWhinney, 2005; Pienemann, Di Biase, Kawaguchi, & Håkansson, 2005).

In the last two decades, there has been a shift of focus, with the observation that the variation in how language is experienced may not only illuminate the mechanisms that enable language learning and language processing across the lifespan (Fricke, Zirnstein, Navarro-Torres, & Kroll, 2019; Kroll, Takahesu Tabori, & Mech, 2017; Pierce, Chen, Delcenserie, Genesee, & Klein, 2015; Zirnstein, Bice, & Kroll, 2019), but may also require a revision of the traditional view concerning the role of the native language. Many people learn and use two or more languages in different contexts and cultures. Some speak two languages, while others speak or read one language and sign the other. Many people speak more than one language but only some have literacy skills in both languages. Some acquire a single language from birth and continue to live in a context where that language is the dominant[1] and majority language. Others immigrate, often faced with the task of learning a new community language quickly as adults. In homes where the language spoken is not the dominant language of community, children are later immersed into the majority language when they enter school. These heritage speakers of a home language are in fact the most representative bilinguals in the United States (American Academy of Arts and Sciences, 2017), typically becoming dominant in the majority language despite the fact that it is technically their second acquired language. For those who speak the majority language but use a non-standard dialect, the experience may resemble that of heritage speakers when being immersed in and required to use the standard form. In cases in which there is a prolonged break in exposure to the native language, there may be attrition of the L1. Yet others may be diagnosed with a language disorder early in life or as a result of brain injury later in life. There are many examples of language variation,

1. In this paper we use *dominant language* to refer to the language an individual uses as primary although it may not be the language that was first acquired as the native language. For many individuals, the native and dominant languages will be the same. For many others, the dominant language will change as they shift the contexts in which they live and work. Although the dominant language is likely to become an individual's most proficient language, it is possible to be highly proficient in multiple languages, with variation in the form of that proficiency over languages.

and it is critical to acknowledge that language learners and language users have experiences that are profoundly distinct.

The goal of the present paper is to illustrate how a focus on variation in language experience may inform our understanding of language learning and language processing. We do not dismiss the significance of identifying universal principles (see Hahn, Jurafsky, & Futrell, 2020, for a recent example of computational approaches to identifying universal mechanisms). Instead, we ask the question what can be learned by adopting a focus on variation. In the brief review in the current paper, we take what we consider to be some of the most exciting new discoveries that have only been made possible by examining variation in language experience. A number of papers have presented a similar perspective and address additional scope (e.g. Baum & Titone, 2014; Pierce et al., 2015). Here we first revisit the issue of native language privilege, examining how the first or native language may be more open to the dynamics of language experience than previously understood. To do so, we use bilingualism as a lens through which the interactions across the two languages provide a unique means to reveal the ways in which the native language adapts to the active use of a second language. Those adaptations not only affect language use but also the cognitive and neural processes that support it (see Bialystok, 2017, for a discussion of the cognitive adaption). We then consider the consequences of variation in experience and context for new language learning and for language processing.

2. The fate of the native language: A view from bilingualism

The data on age of acquisition (AoA) suggest that after early childhood, and certainly by adolescence, there are restrictions on the ease with which adult learners are able to fully acquire the features of a new L2. Although there is agreement that the effects of AoA are robust, there is disagreement about their interpretation (e.g. Bialystok & Kroll, 2017; Birdsong, 2018). Here we concern ourselves not with those interpretations but with an assumption underlying much of the research on this topic, namely that the native or first learned language, L1, remains unchanged and independent of the variation in the language users' life experience.[2] Indeed, much of the history of research that takes a crosslinguistic perspective assumes that it is possible to compare the use of particular structures across native languages by speakers who themselves are native speakers but who

2. An exception to this assumption is the research on L1 language attrition, a situation typically characterized by a relatively complete cessation of L1 use following immersion in a context in which the L1 is not spoken (e.g. see Schmid, 2010).

vary in whether they speak other languages and, if so, the circumstances of their bilingualism. Only recently has bilingualism been addressed in this context (e.g. Scontras, Fuchs, & Polinsky, 2015). Many years ago, Grosjean (1989) issued a warning to the field that the bilingual was not two monolinguals in one. That particular warning was issued around the prevalence and normalcy of code switching and language mixing, but a clear implication is that the native language of the bilingual is not identical to the native language of a monolingual speaker.

We argue here that not only does the native language change in response to learning and using an L2, but that it plays a crucial role in the process of L2 learning beyond transfer of linguistic knowledge. Recent studies suggest that bilinguals come to regulate the activation of the L1 or dominant language to enable the coordination of the two languages and the proficient use of the L2. The changes that occur in acquiring L2 proficiency reflect not only an effect of the L1 on the L2, but also a bidirectional interaction, whereby the L2 comes to shape the L1. In this sense, the L1 is privileged, not as a stable presence, but as an exceptionally skilled domain that gives rise to plasticity in learning in language processing. We consider briefly some of the evidence supporting this view.

2.1 Native language change

Many who acquire an L2 after early childhood begin that process as monolinguals, with only their native L1. In most studies assessing the trajectory of L2 learning in the early stages of acquisition, the expectation is that the dominant L1 will be accessed more rapidly and more accurately than the newly developing L2. The data on language processing for L2 learning support that expectation across many different studies and many different language pairings (e.g. Kroll, Michael, Tokowicz, & Dufour, 2002). The less dominant L2 is not only less accessible for those who are not yet proficient (e.g. Jacobs, Fricke, & Kroll, 2016), but it is also influenced by the L1, and that influence is evident even once speakers become relatively proficient (e.g. Dijkstra, Van Jaarsveld, & Brinke, 1998; Marian & Spivey, 2003). At the lexical level, this research has set out to manipulate properties of the two languages that are shared or in conflict (e.g. semantics, orthography, or phonology) and to determine whether it is possible to process one language on its own, without the influence of the other. For example, translations that are cognates in the bilingual's two languages, sharing aspects of lexical form and the same meaning, are typically processed more rapidly and accurately in the L2 by both learners and proficient bilinguals (e.g. Dijkstra et al., 1998; Kroll et al., 2002). This result is observed regardless of whether the two languages are similar or distinct (e.g. Hoshino & Kroll, 2008; Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011), suggesting that the co-activation of the two languages is a feature of being bilingual, not a property of the languages themselves. Critically, the activation of the two languages does not depend on the requirement to use both languages in the same context. These cross-language interactions can be seen at all levels of language processing (see Kroll, Dussias, Bice, & Perrotti, 2015 for a review).

But what about the other direction? Does the native language maintain its place in the presence of an L2? In an early study (Kroll et al., 2002), we reported a curious finding. When native English speakers were asked to name words in English, their L1, the latency of naming was a function of their proficiency in the L2 (Spanish or French in this study). Learners at low levels of proficiency were slower to name words in English than more proficient speakers of those languages, although the native language was identical for all speakers. We considered the hypothesis that a self-selection mechanism might have accounted for the observed difference, since not all learners become proficient in the L2. In a subsequent study, all participants performed a working memory task, and we asked whether working memory differences modulated the cost to L1 naming. We replicated the cost to L1 naming but failed to find a modulation by working memory. Although working memory is only one of a number of cognitive factors that might play a role, this initial finding suggested that the apparent cost to the L1 may reflect a consequence of L2 learning rather than domain general resources per se.

For proficient bilingual speakers, the effects of the L2 on the L1 have been demonstrated in many studies that have taken the approach described above for examining the effects of L1 on L2. Although the L1 is often the dominant language, even for proficient speakers, and is therefore processed more rapidly and accurately than the L2, there is clear evidence that L2 affects the L1. For example, there are cognate effects in both directions, from L1 to L2 and from L2 to L1 (Midgley, Holcomb, & Grainger, 2011; Schwartz, Kroll, & Diaz, 2007; Van Hell & Dijkstra, 2002), although the effects of L2 on L1 are not always in the form of facilitation like those seen for L1 on L2, and in the studies that use electrophysiological methods (e.g. Midgley et al., 2011), the time course of these effects may differ, reflecting the higher proficiency in the L1.

Critically, changes to the native language come online early as adult learners are exposed to a new L2. Bice and Kroll (2015) compared the performance of native English speakers learning L2 Spanish with a group of monolingual English speakers. The learners were immersed in an English dominant university environment with Spanish instruction in a classroom setting. As in some previous studies, the focus was on the effect of cognate status from L2 to L1, with the task being lexical decision in English (i.e. is the string of letters a real word?). The learners were either at the very beginning of their study of Spanish or at an intermediate level. At this early stage of learning Spanish, there was no evidence in the behavioral record of response time and accuracy to suggest that Spanish had any effect at all on English, with performance similar for monolinguals and learners for cognates and controls. However, Event Related Potentials (ERPs) revealed an emerging sensitivity to cognates for the learners. There were no cognate effects in the ERP data for the monolinguals, a trend emerging for cognate learners at the very earliest stages, but a clear sensitivity to cognates in English once learners had some minimal experience with Spanish. None of the learners was proficient in Spanish. The dissociation between the behavioral and ERP data replicates other reports for L2 learning itself (e.g. McLaughlin, Osterhout, & Kim, 2004) and suggests that brain activity may outpace behavior in indicating changes that occur to both languages as the L2 is acquired and as proficiency is achieved. What is notable about the Bice and Kroll findings is that the sensitivity of the native and dominant L1 to the L2 occurred very early in the time course of L2 learning, long before any significant level of proficiency had been acquired.

2.2 From change to regulation

Demonstrating that the L1 is sensitive to the presence of the L2 may be considered a first step towards recognizing that the goal of L2 learning is not to achieve an independent language system for the L2 (see Kroll & Tokowicz, 2005, for a review of early models of representation). The fact that the two languages are largely supported by the same neural architecture (e.g. Abutalebi & Green, 2007; Perani & Abutalebi, 2005), with clear evidence for extensive cross-language interaction, suggests that L2 learning and bilingual language experience create a dynamic situation whereby words, sounds, and structures in each of the two languages co-exist within a shared language system. The problem for such a system, as has been noted by others (e.g. Green, 1998; Green & Abutalebi, 2013), is that the bilingual needs to attain sufficient control over the use of each language to enable the full range of language performance, including single language performance in each language at a high level of accuracy and proficiency, but also mixed language performance as commonly observed in code switching (e.g. Green & Wei, 2016). Research actively focuses on the effort to understand how individuals come to control the use of the two languages when they are continually active and interacting, and how that control might have consequences for domain general cognition (e.g. Bialystok, 2017; Declerck & Philipp, 2015). For the purpose of the present discussion, we argue that the observation of native language change itself may be an important feature of how control comes to be achieved. We have discussed these ideas in other recent reviews (e.g. see Fricke et al., 2019; Zirnstein et al., 2019); the main points are summarized below.

We propose that the changes revealed in the native language of L2 learners and bilinguals are not only a matter of cross-language sensitivity, but also a reflection of how the native language comes to be regulated.[3] Our hypothesis is that language regulation is likely to engage cognitive resources, but is not identical to cognitive control per se. L2 learners and bilinguals come to learn how to adjust the native language, either reactively or proactively (see Section 4 below) to accommodate to the environment in which the two languages are used and to enable proficient language performance. In essence, L2 users adapt language processing to achieve the fluent use of two languages. That adaptation is the reason that the bilingual is not two monolinguals in one; the native language as well as the L2 come to reflect cross-language experience, maintaining features of each language, but also being shaped by their interaction.

What does L1 regulation look like? The most typical manifestation of regulation is the inhibition of the more dominant language to enable the use of the less dominant L2. We see that pattern across multiple contexts and in different paradigms, and we also see it in the phenomenology that bilingual speakers have after being immersed in the L2. The more dominant L1 becomes less available. The apparent inhibition of the L1 has been documented in studies of L2 immersion (e.g. Baus, Costa, & Carreiras, 2013; Linck, Kroll, & Sunderman, 2009) and in the laboratory (e.g. Misra, Guo, Bobb, & Kroll, 2012; Van Assche, Duyck, & Gollan, 2013). Linck et al. examined the consequence of L2 immersion on intermediate learners of Spanish who were native English-speaking university students studying abroad in Spain. They compared the performance of these immersed learners with a closely matched group of learners in the United States who were also native English speakers and intermediate level Spanish learners. On measures of both lexical access and production, there was evidence for suppression of English during immersion in Spanish. While reduced performance in the L1 might be taken as active inhibition, it is also possible that in the L2 environment, the decreased availability of the L1 essentially comes for free, in response to the increase activation of the L2 itself.

Many subsequent studies have simulated the effect of language immersion in the laboratory by giving speakers an opportunity to speak only the L2 for a period of time and then switching them to the L1. The duration of L2 use prior to the switch has been varied from a single prior utterance in language switching paradigms (e.g. Meuter & Allport, 1999) to multiple utterances in blocked naming paradigms (e.g. Misra et al., 2012; Van Assche et al., 2013). If the suppression of the L1 that has been found under conditions of language immersion reflects a passive

3. We use the term *language regulation* to differentiate the control of language processes from domain general control.

adaptation to the environment, then one might not expect short term switches of the language context to have similar consequences. The findings from these studies show that there is persistent and differential inhibition of the L1 following production in the L2. The effects are seen in the immediate spillover from a single naming trial to the next, also when the opportunity to speak the two languages is extended, and when the languages are mixed so that there is uncertainty about which language will be spoken. Recent work suggests that the mechanisms of inhibitory control may include a number of different processes that may manifest distinctly in different contexts (e.g. Declerck, 2020; Stasenko, Hays, Wierenga, & Gollan, 2020). A critical question in the ongoing research is understanding how they may relate to domain general cognitive control (see Section 4 below). Notably, these effects appear to be robust and have been reported in behavioral measures of reaction time and accuracy (Van Assche et al., 2013), in the earliest moments of planning speech in the ERP record (e.g. Misra et al., 2012), and in brain activation revealed by imaging studies (e.g. Guo, Liu, Misra, & Kroll, 2011).

It is beyond the scope of the present paper to consider the implications of language regulation at levels of language processing beyond those we have illustrated at the lexical level, but critically, we see these dynamic changes in the L1 across the language system (e.g. see Dussias & Sagarra, 2007 for evidence on changes to native language grammar and Chang, 2013, for evidence of changes to native language speech). Likewise, the discussion of how language processes more generally recruit cognitive resources is a major area of research (e.g. Green & Abutalebi, 2013; Hsu & Novick, 2016). It remains to be seen how L1 regulation in bilinguals engages cognitive control processes. In addition, it would be fascinating to learn when these ordinary dynamic changes in the L1 become attrition following extended disuse (e.g. Schmid, 2010). We hypothesize that the regulatory dynamics that we have identified reflect the ordinary circumstances of bilingualism rather than attrition. It is not clear which of these dynamics might develop into genuine attrition. For the present discussion, the observation of changes to the native language during ordinary language use suggests that there is likely to be extensive variation across speakers and contexts.

2.3 The consequences of regulating the native language

If the L1 is regulated to enable use of the less dominant or less proficient language, then what are the consequences other than the inhibitory effects we have reported? In the short term, there appears to be temporally extended suppression of the L1 that perhaps lasts longer than we might have predicted. For example, Misra et al. (2012) found that when bilinguals spoke the L1 following L2, not only was there greater negativity in the ERP record for the L1, but this negativity remained present in the experiment following the opportunity to speak the L1 repeatedly. Although there is documented recovery in the studies on L2 immersion, at least months following a return to the L1 environment (e.g. Linck et al., 2009), there is little known about the scope of these regulatory effects. We hypothesize that, at least to some extent, the presence of L1 modulation in response to the demands of bilingual experience may contribute to longer term adaptations than have been reported (e.g. Bialystok, 2017).

In a recent study on word learning, Bogulski, Bice, & Kroll (2019) taught monolingual and bilingual participants a set of 60 words in Dutch, a language that was equally unfamiliar to all. Previous studies have shown that bilinguals are better word learners than monolinguals (e.g. Kaushanskaya & Marian, 2009), although the source of the benefit for bilingual learners remains unclear. Bilinguals have more experience learning languages than monolinguals, but there are also consequences of bilingualism, such as in the realm of executive function (e.g. Bialystok, 2017), that might potentially affect these learning processes indirectly (for discussion, see Hirosh & Degani, 2018). The starting point for the Bogulski et al. study was the observation that most past experiments on bilingual word learning had taught the new vocabulary via the L1. Three groups of bilinguals were tested and their performance was compared with that of a group of monolingual speakers of English. One of the bilingual groups were native speakers of English who were relatively proficient in L2 Spanish. The two other bilingual groups were L2 speakers of English, one with L1 Spanish and the other with L1 Chinese. All participants were taught the Dutch vocabulary via English, the L1 for the monolinguals and English-Spanish bilinguals, but the L2 for other two bilingual groups. The results showed that only the bilinguals learning via their L1 outperformed the monolinguals. Scores on a measure of executive function were not predictive of the learning outcomes. Bogulski et al. argued that the performance of the English-Spanish bilinguals could be explained as a function of their experience in learning to regulate English, their L1. Although English was also the L1 (and only language) of the monolingual speakers, they had little or no strategic experience in using the L1 for this purpose. For the bilinguals for whom English was the L2, there was also little experience in regulating English for the purpose of new learning. Although these are novel findings and require additional research and replication, they suggest that the changes to the native language that result from bilingual language experience may have profound consequences. They also demonstrate that without adequate characterization of variation in bilingual experience, we cannot accurately predict learning outcomes.

In the next sections we consider how variation in language experience may affect learning from a developmental perspective, and how language processing in diverse contexts may reflect the consequences of that variation.

3. Multiple sources of variation in L2 learning: Evidence from children and adults

While all babies are able to learn any language to which they are exposed, this openness to language input only lasts until the end of the first year of life. By the end of the first year, babies have tuned to the specific language(s) to which they have been exposed (Kuhl, 1993; Werker & Tees, 1984). In a seminal study, Kuhl, Williams, Lacerda, Stevens, & Lindblom (1992) presented six-month-old infants from the United States and from Sweden with auditory stimuli including prototypes and variants of the English vowel /i/ and of the Swedish vowel /y/. Using the head turn procedure, the infants' dishabituation to the stimuli were used to determine when they detected a change in sound. Results showed that the infants from Sweden were more accurate to classify the familiar /y/ prototype and variants than the unfamiliar /i/. On the other hand, the American babies were more accurate in classifying the familiar /i/ prototype and variants than those of the unfamiliar /y/ vowel. These results suggested that infants are actively learning from their environment early in life and that they begin to lose sensitivity to unfamiliar sounds. A large number of studies have demonstrated that infants undergo L1 tuning (for a review, see Kuhl et al., 2006).

This early work focused on differences in monolingually-exposed infants with different L1s. It is only recently that we have begun to understand how experience with multiple languages affects the trajectory of phonetic learning.[4] Pettito et al. (2012) compared brain activation of "monolingual" English-exposed infants and "bilingual" infants, who were exposed to English and another language other than Hindi, while listening to native English and non-native (Hindi) phonological contrasts using functional near-infrared spectroscopy (fNIRS). The infants ranged from 4 to 12 months old, with the older infants having undergone L1 tuning and the younger ones still showing sensitivity to non-native contrasts. For monolingually-exposed babies, brain activity in the left Inferior Frontal Cortex (IFC) increased when listening to native contrasts, but activation for non-native contrasts did not vary by age. For bilingually-exposed infants, however, activation in the left IFC increased with age for both native and non-native contrasts. These results suggest that infants with monolingual language exposure become increasingly tuned to their L1 as they age, whereas bilingually-exposed infants are able to retain some of the perceptual openness with which they were born

4. It is likely that in some of the early studies on phonetic learning infants had some exposure to a second language, as many studies were conducted in places were bilingualism was commonplace. However, since the effect of the L2 was not of primary interest in those studies, little was known about how exposure to other languages affected speech perception.

when they are processing foreign language sounds. It is important to emphasize that behaviorally, phonetic learning studies show that all babies lose their sensitivity to non-native contrasts by the end of the first year of life. The fact that these neural measures capture differences in how monolingually- and bilingually-exposed children process native and non-native contrasts at the point at which they no longer differ in behavior suggests that language experience alters the neural mechanisms used to accomplish the same language learning outcomes. This study is one of many suggesting that early experience with multiple languages influences the way in which language comes to be processed in childhood (Ferjan Ramírez, Ramírez, Clarke, Taulu, & Kuhl, 2017; Sebastián-Gallés, Albareda-Castellot, Weikum, & Werker, 2012; Weikum et al., 2007).

There is evidence that bilingual language exposure in infancy changes processing not only in regions traditionally involved in language but also in domain-general areas. Ferjan Ramírez et al. (2017) investigated brain activation patterns in eleven-month-old English monolingually-exposed and Spanish-English bilingually-exposed babies when listening to English and Spanish sounds. The results showed that monolingually-exposed babies were sensitive to English and bilingually-exposed babies were sensitive to both English and Spanish. Notably, bilingually-exposed babies were found to activate the prefrontal and orbitofrontal cortices, areas involved in executive functions, while listening to English and Spanish sounds. These results suggest that early bilingual language experience alters language processing mechanisms, broadening them to include areas involved in domain-general cognition for monolinguals. Taken together, these studies suggest that babies' language environments shape how they process language. These findings raise the question of the extent to which adaptations to early language experience endure past early childhood, and whether they continue to influence subsequent language learning later in life.

One remarkable demonstration of the enduring consequences of early bilingual experience is the brain activation patterns of adults who were internationally adopted as children. Pierce et al. (2014) compared the brain activity of three groups of adults while listening to Mandarin tones: Mandarin-French bilinguals who are actively using both languages, international adoptees (who as infants had been exposed to Mandarin and learned French when they were adopted into Canadian families), and a group of French monolinguals. On average, the adoptees lived in China until about age three and discontinued Mandarin exposure permanently since their adoption, becoming functionally monolingual in French. The results showed that the Mandarin-French bilinguals and the international adoptees both activated predominantly the left Superior Temporal Gyrus (STG) and to a lesser extent the anterior STG in the right hemisphere. The adoptees showed a strikingly similar activation pattern to the active bilinguals, activating the left STG and to a lesser extent the right anterior STG. In contrast, a control group of French monolinguals only activated the right STG, processing the Mandarin pseudowords as non-linguistic stimuli. The results of this study suggest that despite the discontinued use of the native language (Mandarin), the adoptees' experience with two languages early in life had enduring consequences on how they processed French as adults. Critically, the adoptees had L2 experience past the first year of life, suggesting that exposure to a second language can shape the language system well past the initial year of life.

To what extent do the mechanisms created by early language experience continue to shape language learning later in life? There is compelling evidence from childhood overhearers that early language experience not only shapes neural function but also learning outcomes. Childhood overhearers are adults who as children were substantially exposed to a language other than their native language, but never learned to speak it. Au, Knightly, Jun, & Oh (2002) asked whether having overheard a second language in childhood might confer benefits to learning the second language as an adult. This study compared productions of Spanish voiceless stops and of intervocalic voiced stops by English monolinguals who had overheard Spanish as children, English monolinguals who had not overheard Spanish, and Spanish-English bilinguals. Because Spanish has a shorter Voice Onset Time (VOT), if the overhearers experienced any benefits from their early overhearing exposure, they should produce Spanish VOTs shorter than those of English monolinguals and comparable to those of Spanish-English bilinguals. Moreover, since Spanish voiced stops are lenited in intervocalic contexts, if the overhearers benefited from early exposure, they would also produce a higher percentage of lenited voiced stops in word medial position relative to word initial position. The results showed that the childhood overhearers did indeed produce VOTs shorter than those of English monolinguals, and identical to those of proficient Spanish-English bilinguals. They also lenited voiced stops in intervocalic position at a similar rate to proficient Spanish-English bilinguals. One interpretation for the finding that childhood overhearers were better learners of Spanish is that they had phonetically tuned to Spanish early in childhood, and had retained some of that sensitivity as adults. Yet another possibility is that there are effects of early L2 experience that go beyond the specific language of exposure.

A number of studies with bilingually-exposed infants suggest that they exhibit not only effects specific to the languages to which they have been exposed but also different attentional strategies (Pons et al., 2015; Sebastián-Gallés et al., 2012; Weikum et al., 2007). The different strategies used by bilingual infants seem to be driven by the need to rely on not only auditory but also visual cues for distinguishing between the two languages. Pons et al. (2015) found that bilingual babies show a different developmental trajectory than monolinguals in terms of whether they attend to the eyes or to the mouth. The idea is that bilingual babies exploit visual language cues from the mouth for a longer period of time than do monolingual infants. Bilingually-exposed babies' expertise attending to visual cues has also been demonstrated in studies looking at infants' audio-visual integration abilities. One study, Weikum et al. (2007), presented bilingually-exposed and monolingually-exposed four and six-month-olds with silent movies of a French-English bilingual speaking either in French or in English. Dishabituation was used to measure the infants' detection of a language change. Results showed that the bilingually-exposed infants, but not the monolingually-exposed infants, could distinguish a language change by using visual cues alone, suggesting bilingual exposure enhances the use of visual cues in speech perception. Crucially, a subsequent study used the same French and English stimuli with three groups of infants: Spanish-Catalan bilinguals, Spanish and Catalan monolinguals (Sebastián-Gallés et al., 2012). Since none of the infants in the study were exposed to French or English, the study was a test of whether bilingual infants might be better able to use visual cues regardless of their experience with the particular languages viewed. The results of the study revealed that the infants with Spanish-Catalan bilingual exposure, but neither of the monolingual groups, were able to reliably detect a language change in the absence of auditory information. These results highlight that the changes in language learning that occur as a result of bilingual language experience are not merely language-specific, but also include broader changes in attentional strategies.

Taken together, these studies suggest that variation in early language experience in childhood has a lasting effect for how language is processed and learned. One way to think about these findings is that adults who were exposed to an L2 early in life retained beneficial neural adaptations created by their early language experience. These findings raise the question of the degree to which adults are sensitive to L2 experience in the same way as children. Older behavioral research examining age of acquisition in adult L2 learners suggested that the ability to learn a second language in adulthood is very constrained, especially in the domains of phonology (Flege, 2007; Iverson et al., 2003) and grammar (DeKeyser, 2000; Johnson & Newport, 1989). These difficulties were interpreted as maturational constraints for language learning (Lenneberg, 1967). Another major focus on second language learning research has examined the way in which L1 and L2 feature overlap affects the ability to acquire the L2 (Iverson et al., 2003; Sabourin, Stowe, & de Haan, 2006). While the L1 and age of acquisition are two important factors that shape L2 learning, in this article we aim to identify additional factors that contribute to variation in adult L2 learning outcomes in the domains of phonetics and phonology.

Recent research reveals that there is a great deal of variability in L2 learning outcomes even among speakers in the same age group sharing the same L1. At least some of these individual differences map onto structural brain differences. Wong et al. (2008) investigated how anatomical differences in Heschl's gyrus, an area typically involved in non-linguistic auditory processing, relate to tone learning in English monolinguals. In the study, English monolinguals were scanned pre-test. They were then asked to learn an artificial lexicon combining English phonology and three tones (rising, falling, level), and were tested on their knowledge of the meanings of words. This study found that higher grey matter density in the left Heschl's gyrus predicted more successful learning of pitch. This study highlights the individual differences in the brains of adult learners which play a role in language learning. It is not enough to consider the native language and age of acquisition to form a comprehensive account of language learning. Neurocognitive and experiential individual differences may be just as important.

One of the cognitive skills that appears to be important for language learning is cognitive control. Bartolotti, Marian, Schroeder, and Shook (2011) examined Morse code learning outcomes in bilingual speakers of different languages. They first introduced a Morse code sequence, followed by a second sequence that conflicted with the first. They were able to introduce conflict by increasing the duration of pauses, thereby changing the interpretation of the cues to word boundaries. Results showed that individual differences in cognitive control only predicted learning outcomes for high conflict sequences. These results suggest that bilinguals may benefit from cognitive control when learning an L2 in a high conflict scenario, when the conditions make it difficult to interpret the information presented. The findings underscore that the cognitive profile of the speaker is important to consider as well as how it may interact with the particular context of learning.

Differences in the environment in which L2 learning occurs are also important factors that shape language learning in adults. A recent study by Bice and Kroll (2019) compared English monolinguals from two locations (Central Pennsylvania and Southern California) on their ability to learn Finnish vowel harmony. The Southern California group had significantly more ambient foreign language exposure than the Central Pennsylvania group due to differences in the demographics of each location. Despite the differences in linguistic diversity, it is very unlikely that either group was exposed to Finnish in their respective environments. Although in behavior, the two groups did equally well on the generalization of Finnish vowel harmony, Event Related Potentials (ERPs) revealed differences in the way the two groups processed Finnish. The monolinguals from Southern California were found to be sensitive to violations in Finnish Vowel Harmony whereas the Central Pennsylvania group revealed no online sensitivity to the rule. These results suggest two important things. First, ambient language exposure may benefit language learning even if the learner has not been exposed to the same language being learned, similar to the way in which bilingually-exposed infants are better able to distinguish two unfamiliar languages from visual cues. In other words, mere language diversity may provide a richer environment for adults to learn an L2. It is tempting to speculate that ambient language diversity may help adult learners to retain the openness to the sounds of new languages found in bilingual infants.

These findings call for a revision of theoretical assumptions made about second language learning. In this article, we have focused on reviewing literature from phonetics and phonology, as these are domains in which there is ample evidence that it is speech that reflects the earliest stages of language development, as well as the enduring features of early language experience across the lifespan. Traditional models of the development of speech perception assumed that the native language is crucial for the way in which the L2 would be acquired (Kuhl, 1993; Kuhl et al., 2008). The studies reviewed here paint a much more complex picture of the L2 learner. Exposure to multiple languages, even passive and even discontinued, results in a set of neural and cognitive changes that go beyond tuning to the native language. By studying these different language experiences, we learn more about the brain plasticity in both children and adults. Although the work on language learning begins to show that language experience and cognitive skills are important individual differences, it is the literature on language processing which more clearly illustrates the relation between language experience and cognitive adaptation. In the next section, we turn to the issue of how individuals adapt their cognitive resources to the demands of their language environment.

4. Multiple paths, one outcome: Individual differences in language processing and cognitive control engagement

Individuals differ in how they employ cognitive and language abilities. A critical issue in the study of language processing is the extent to which it draws from domain-general resources (Nozari, 2018). While some studies suggest that language processing is primarily determined by factors unique to the language system (e.g. Acheson & Hagoort, 2014; Blank, Kanwisher, & Fedorenko, 2014; Daneman & Carpenter, 1983; Engelhardt, Nigg, & Ferreira, 2017; Vuong & Martin, 2014), others suggest that it engages control processes that are independent of language (e.g. Boudewyn, Long, & Swaab, 2012; Engle & Kane, 2004; Hsu, Kuchinsky, & Novick, 2021). Part of the issue may be that biological and cognitive systems possess the ability to develop different structural configurations that achieve analogous functions (Edelman & Gally, 2001; Green, Crinion, & Price, 2006). On evolutionary grounds, this type of variation facilitates the adaptability of systems to novel environments (Mason, Domínguez, Winter, & Grignolio, 2015). Thus, the engagement of specific processes for language will depend on information content and on task and environmental demands (Hsu, Jaeggi, & Novick, 2017; van den Heuvel & Sporns, 2013). Bilingualism is an ideal case to explore this topic because the control networks that regulate behavior more generally show adaptation to the demands of a second language (Abutalebi & Green, 2007; Green & Kroll, 2019; Li, Legault, & Litcofsky, 2014) and may also come to adapt to the contexts in which the two languages are used (Green & Abutalebi, 2013; Green & Wei, 2016). In this section we examine a few recent bilingual studies examining individual differences to illustrate how individuals are capable of systematically exploiting multiple strategies when engaging cognitive resources during language processing.

The idea that different structural arrangements can generate similar outputs is evident in language itself: multiple linguistic forms can often be used to convey equivalent meanings (Mason et al., 2015). For instance, we can refer to a *quick shower* or a *fast car* to express the idea of motion with great speed (Goldberg, 2019), and choose between *I gave her the ball* or *I gave the ball to her* to convey who did what to whom (Allen, Pereira, Botvinick, & Goldberg, 2012). Likewise, bilinguals may come to exploit language processing in ways that differ from monolinguals while still achieving similar outcomes. To further our understanding of this issue, we examine demanding aspects of language processing that may rely on cognitive control engagement. For example, during comprehension, meanings are rapidly assigned to words and phrases as an utterance unfolds (Altmann & Kamide, 1999; MacDonald, Pearlmutter, & Seidenberg, 1994), however at times individuals generate incorrect predictions due to momentary syntactic ambiguity (e.g. a headline from a online news article on CNET: "Google's computer might betters translation tool") or due to biases induced by the global semantic context (e.g. "The woman was born with a rare gift" as opposed to "The woman was born with a rare disease"). In such cases, comprehenders must quickly revise and recover from their initial predictions. What factors allow individuals to recover from such prediction errors?

Recent studies suggest that individuals engage a combination of language-related and domain-general resources to achieve language processing. For example, Navarro-Torres, Garcia, Chidambaram, & Kroll (2019) conducted an eye-tracking experiment with English monolinguals and bilinguals who spoke L2 English to examine syntactic ambiguity in comprehension (e.g. by listening to goal-directed sentences such as "Put the frog on the napkin onto the box" while dragging the corresponding objects on a computer screen). The authors used a cross-task adaptation paradigm that interleaved Stroop sequences with the sentence comprehension task, allowing them to measure how Stroop-related conflict affected recovery from syntactic ambiguity on a trial-by-trial basis. In general, eye-movement results replicated previous work with monolinguals (Hsu & Novick, 2016) and yielded comparable group performance: comprehension of ambiguous sentences improved (i.e. increased looks to the correct target "box" and decreased looks to the incorrect target "napkin") when preceded by Stroop-incongruent sequences, suggesting that, for both groups, the control mechanisms engaged in the Stroop task are also engaged during sentence comprehension. However, decreased looks to the incorrect target emerged earlier for bilinguals, suggesting that they disengaged incorrect interpretations more proactively.

Perhaps more telling were the individual difference analyses on working memory ability, which revealed different patterns of association with eye-movements for each group. In the case of monolinguals, better working memory ability predicted decreased looks to the incorrect target (e.g. the napkin). This effect was true for both ambiguous and control (unambiguous) sentences, suggesting that working memory was capturing effects primarily related to cumulative linguistic experience (i.e. increased language practice improves processing more generally, thus improving working memory), and not necessarily control processes per se. However, for bilinguals, the opposite effect was true: better working memory was associated with increased looks to the incorrect target. Unlike monolinguals, this pattern of association was specific to ambiguous sentences, suggesting that high working memory bilinguals were better able to actively generate and maintain the incorrect-goal interpretation. These bilinguals would therefore be more susceptible to interference when revising that interpretation, but would also be better suited to engage cognitive control in the recovery process. More generally, the effects of working memory in monolinguals and bilinguals illustrate how the same measure can tap into both language-related and domain-general processes, though the extent to which one domain is emphasized over the other will depend on language experience.

What about instances where both language-related and domain-general resources are manifested within the same group of people? For bilinguals, the language system is fundamentally nonselective, and the neural tissues supporting L1 and L2 processing are largely the same (Perani & Abutalebi, 2005). Yet, bilinguals typically function in one language most of the time, even in the case of highly proficient bilinguals who habitually engage in codeswitching, the seamless alternation between two languages within an utterance (Beatty-Martínez, Navarro-Torres, & Dussias, 2020a). Bilinguals must therefore rely on a combination of language regulatory and domain-general processes to manage and segregate the co-activation of the two languages. Evidence for this regulatory process comes from studies showing that speech in the L1 is disrupted after speaking in the weaker L2 (Guo et al., 2011; Misra et al., 2012; Rossi, Newman, Kroll, & Diaz, 2018; van Assche et al., 2013). One possibility is that extensive experience regulating the dominant L1 allows bilinguals to attain high proficiency in both their languages.

Zirnstein, Van Hell, and Kroll (2018) tested this hypothesis by examining the engagement of prediction mechanisms during sentence comprehension in a group of English monolinguals and proficient Mandarin-English bilinguals with L2 English. The authors measured ERP responses while participants read sentences in English containing a target word that was either highly expected (e.g. "After their meal, they forgot to leave a <u>tip</u> for the waitress") or unexpected (e.g. "After their meal, they forgot to leave a <u>ten</u> for the waitress"). Group results showed that, whereas monolinguals generated an N400 for expected words (reflecting lexical-semantic facilitation) and a late positivity for unexpected words (reflecting a recovery process from prediction errors), bilinguals only produced the N400.

At first glance, one would be tempted to conclude that the Mandarin-English bilinguals in this study, by virtue of reading sentences in the L2, were incapable of generating predictions for unexpected words. However, Zirnstein and colleagues conducted a series of individual differences analyses examining domain-general control (indexed by the AX Continuous Performance Task (AX-CPT), a measure of proactive and reactive control) and language regulation ability (indexed by a semantic verbal fluency task) to identify the cognitive processes that enabled participants to engage prediction mechanisms. These results revealed a much richer picture: both groups recruited control to recover from prediction costs, with better control predicting a reduction in the late positivity. However, for bilinguals, the positivity was also modulated by L1 semantic fluency, but in the opposite direction: increased semantic fluency in Mandarin related to a larger positivity, suggesting that those with high L1 regulation ability were able to generate predictions errors like the monolinguals. Notably, the effects of control and L1 fluency were not independent from one another, as revealed by an interaction between the two measures. There are several important observations to make here. First, the results suggest that L1 regulation involves the recruitment of language-specific and domain-general resources, both of which may be partially dependent, but separate from one another. Second, the fact that verbal fluency mediated prediction abilities during reading suggests that production and comprehension must rely on overlapping processes (Humphreys & Gennari, 2014). Finally, if we had only examined monolinguals, or only asked whether bilinguals are able to generate predictions in the L2, we might have come to different conclusions regarding the nature of ERP effects or differences between L1 and L2 speakers.

A key commonality between the two studies reviewed above is that both bilingual groups grew up in an L1 environment, but were immersed in an L2 (English) environment at the time of testing (Edinburgh, Scotland in Navarro-Torres et al. 2019; Pennsylvania, US in Zirnstein et al. 2018). As mentioned previously, the evidence suggests that L2 immersion reduces the accessibility of the L1 in advanced learners (Baus et al., 2013; Linck et al., 2009), suggesting that L1 regulation is key for learners to develop high L2 proficiency. It is possible that L2 immersion also affects proficient bilinguals by increasing the demands on L1 regulation, thus triggering a greater need for domain-general control processes. In this sense, L2 immersion may explain why the Navarro-Torres et al. (2019) study found differences in how bilinguals recruited cognitive control and working memory resources when disengaging incorrect interpretations, and may also explain the interaction between L1 fluency and control reported by Zirnstein et al. (2018). If that is correct, in what ways would these control processes adapt? To explore this question, we turn to Beatty-Martínez et al. (2020b).

Beatty-Martínez and colleagues examined lexical access (using a picture naming task) and cognitive control (using the AX-CPT) in three groups of highly proficient Spanish-English bilinguals who reside in different locations (Granada, Spain; San Juan, Puerto Rico; Pennsylvania, US), each with unique language environments. In the Spain group, individuals live in a context where Spanish is the predominant language across most social contexts and English is spoken as the L2. These individuals have little to no code-switching experience, and the languages are usually kept separate. Participants of the Puerto Rico group live in an environment where there are greater opportunities to use and hear both languages. Unlike the first group, these individuals habitually engage in code-switching, and are part of a community where using both languages opportunistically is an established form of communication. The Pennsylvania group included bilinguals who grew up in Spanish-speaking environments where code-switching was also prevalent, but were immersed in an L2 (English) environment at the time of testing, unlike the other two groups. Rather than focusing on group comparisons, the authors conducted a series of individual difference analyses to examine how different cognitive control strategies (i.e. proactive vs. reactive control), as measured by the AX-CPT, related to picture naming performance in each group.

Although naming accuracy was high across the three groups, individual difference analyses revealed different patterns of association between picture naming performance and the AX-CPT. For bilinguals in Spain, those with increased reactive control tendencies tended to perform better on the picture naming. Since conversational exchanges in this context typically involve Spanish, its usage may become highly predictable. Thus, these bilinguals may reactively adjust to the less-predictable instances where English is encountered, allowing them to detect and resolve cross-language interference as needed. In the case of bilinguals in Puerto Rico, no reliable patterns of association emerged between cognitive control and naming performance. One possible interpretation for the null results is that these individuals live in an environment that allows the exploration of the two languages opportunistically (see Beatty-Martínez et al., 2020a for an illustration), thus minimizing the need to rely on cognitive control to engage language regulation. Does this also apply to the Pennsylvania bilinguals, who also came from code-switching communities like those in Puerto Rico? In this group, the association was opposite to the one found in Spain: bilinguals who had greater proactive control tendencies showed better naming performance. Since the critical difference between the Puerto Rico and Pennsylvania groups was the L2 immersion experience, the authors concluded that it was the latter variable, and not code-switching experience per se, that created greater relevance for proactive control. Arguably, the Pennsylvania group has to carefully monitor when to use Spanish, since these bilinguals are no longer in an environment that globally supports Spanish. This result closely patterns with the one reported in Gullifer et al. (2018), who found that high-entropy bilinguals (who have high diversity in using multiple languages across social contexts) were more likely to show greater proactive control tendencies, and were also more likely to engage brain regions associated with monitoring and goal-maintenance processes. Therefore, contexts that yield a high degree of uncertainty and increase interactional costs (be it L2 immersion or high entropy environments) may require a shift to using proactive control.

5. Conclusion

Through the lens of bilingualism, we argue that variation in language experience, which was traditionally seen as a deviation from normative behavior, is in fact a central and illuminating source of psycholinguistic evidence. In the past, bilinguals were viewed as a complication to standard research approaches, adding unwanted noise. We now know that the native language is not a rock of stability as once thought, that across learning and development there are effects of language experience and sensitivity to the context in which languages are used, and that bilingualism itself is not a categorical variable (Luk & Bialystok, 2013). This view requires that we not only revisit assumptions about the native language and monolingualism, but that we revise our views about second language learning and bilingualism. The focus on variation makes clear that considering only language proficiency or language dominance fails to capture the scope of the factors that determine language performance. At the same time, the new research places language in a social context in which the networks that are defined by human interaction and culture also shape the ways that languages are learned and processed. We propose here that this is a far cry from adding noise. Instead, it is embedding language in the rich context in which it is experienced and bringing that experience to the models and metaphors that guide our research. As we go forward, we need to embrace the complexity revealed by variation in language experience. Unlike noise, it is a regular expression of the impressive ways that language, cognition, and social existence converge.

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Résumé

L'un des buts des premières recherches sur le traitement du langage était de caractériser ce qui est universel dans le langage. La plupart des recherches antérieures se sont concentrées sur les locuteurs natifs parce que la langue maternelle était considérée comme la source de vérités privilégiées concernant l'acquisition, la compréhension et la production. Des populations ou des circonstances qui déviaient de ces normes idéalisées étaient d'un certain intérêt, mais sans être vues comme essentielles pour notre entendement du langage. Dans les deux dernières décennies, il s'est produit un changement marquant dans notre conception de comment la variation dans l'exposition au langage peut renseigner les questions primordiales et persistantes qui se posent sur le langage. Il est maintenant prouvé qu'une plasticité importante demeure dans l'apprentissage du langage au-delà de la petite enfance, et il a été démontré que la variation dans l'exposition au langage influence à la fois l'apprentissage et le traitement du langage. Dans cet article, nous mettons l'accent sur ce qui constitue à notre avis les découvertes récentes les plus prometteuses qui suggèrent que la variation dans l'exposition au langage permet de mettre en lumière les mécanismes linguistiques, cognitifs et neuraux qui président au traitement du langage.

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