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Understanding the consequences of bilingualism for language processing and cognition

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Contemporary research on bilingualism has been framed by two major discoveries. In the realm of language processing, studies of comprehension and production show that bilinguals activate information about both languages when using one language alone. Parallel activation of the two languages has been demonstrated for highly proficient bilinguals as well as second language learners and appears to be present even when distinct properties of the languages themselves might be sufficient to bias attention towards the language in use. In the realm of cognitive processing, studies of executive function have demonstrated a bilingual advantage, with bilinguals outperforming their monolingual counterparts on tasks that require ignoring irrelevant information, task switching, and resolving conflict. Our claim is that these outcomes are related and have the overall effect of changing the way that both cognitive and linguistic processing are carried out for bilinguals. In this paper we examine each of these domains of bilingual performance and consider the kinds of evidence needed to support this view. We argue that the tendency to consider bilingualism as a unitary phenomenon explained in terms of simple component processes has created a set of apparent controversies that masks the richness of the central finding in this work: the adult mind and brain are open to experience in ways that create profound consequences for both language and cognition.

Keywords: Bilingualism; Executive function; Language processing.

One of the most significant paradigm shifts in the cognitive and brain sciences in the past 20 years is the acceptance of the enormous potential for plasticity at both cognitive and neuronal levels. In retrospect, we should not have been so surprised: it was always known that pervasive experience leaves its trace on development and function. Animal studies have shown that rats placed in stimulating environments that include the opportunity for exercise, social interaction, and engagement with interesting toys develop greater synaptic density and perform better on standard maze tasks than rats kept in traditional isolated wire cages (Kolb et al., 2012). These results simulate the well-known effects of socio-economic status (SES) on children's development (Farah et al., 2006). Yet there has been a reluctance to accept that some types of pervasive experience could equally impact human brain structure and function. In our view, bilingualism is one such experience. The acquisition and use of two languages embedded in a mental conceptual structure that is at the centre of human thought and behaviour necessarily results in a different configuration from that found for single-language minds. Bilingualism alters the structure and

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function of the mind. As we will argue, bilingual minds are different not because bilingualism itself creates advantages or disadvantages, but because bilinguals recruit mental resources differently from monolinguals. Those resources may be especially critical when bilinguals comprehend and produce sentences in the less dominant of their two languages, when they select the words to speak in one language only, and when they switch from one language to the other in discourse. They may also be critical during periods of development or decline when the networks that support language and cognition are potentially challenged. Neuroimaging studies support this conclusion, with evidence demonstrating that bilingualism changes the brain to make it more resilient and efficient in particular contexts. These effects of bilingualism that have been documented for language processing and for cognition more generally suggest a significant degree of adult plasticity that we would not otherwise see if research were restricted to speakers of a single language.

The past decade has seen an explosion in the amount of research addressing the language and cognitive processing of bilinguals. If we consider the number of papers published and the number of citations to research on bilingualism in the past 20 years according to Web of Science (Thompson Reuters, 2012), there is little change between 1993 and 2003 and then a steep and continuing rise in both publications and citations from that point to the present (see Figure 1). This research embodies multiple paradigms, diverse tasks, and various outcomes. What is clear, therefore, is convergence on the idea that bilingualism is a consequential life experience. What those consequences are is a matter of some debate.

The key discovery in the research on bilingualism is the overwhelming evidence from behavioural, imageing, and patient studies that both languages are active to some degree when bilinguals are using one of them (see Kroll, Dussias, Bogulski, & Valdes Kroff, 2012, for a recent review). The evidence shows that there is a bidirectional influence between languages for bilinguals, even in strongly monolingual contexts and even when bilinguals are highly proficient in both languages. These effects are found whether or not the two languages use the same writing system (Hoshino & Kroll 2008; Thierry & Wu, 2007) and even when one language is spoken and the other is signed (Morford, Wilkinson, Villwock, Piñar, & Kroll, 2011). This joint activation requires a mechanism to select appropriately between these competing systems so that language processing can proceed fluently in the target language without interference from the other language. That mechanism is most likely found in the executive control system that is largely based on a network of processes in the frontal cortex. Support for this interpretation comes from imaging studies using fMRI demonstrating that the frontal executive control systems involved in switching between languages are the same as those generally used for selective attention to nonverbal executive function tasks (see Luk, Green, Abutalebi, & Grady, 2012, for a meta-analysis) and that these executive control networks are used more efficiently in bilinguals than monolinguals, particularly in older bilinguals (e.g., Gold, Kim, Johnson, Kriscio, & Smith, 2013). Abutalebi et al. (2012) identified the anterior cingulate cortex, a crucial part of the general executive control network, as the centre responsible for monitoring and controlling attention to two languages. The interpretation is also supported by evidence from bilingual patients with damage to a crucial region in the executive control system, the

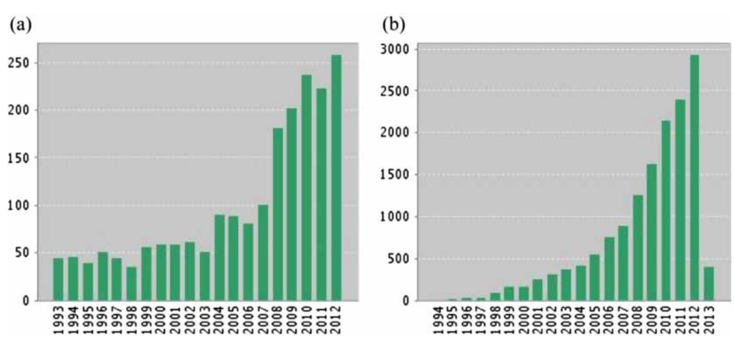

Figure 1. Results of search for topic ''bilingualism'' on Thompson-Reuters Web of Science for (a) number of papers published and (b) number of citations of those papers for years 1993 to 2012. [To view this figure in colour, please visit the online version of this Journal.]

left dorsolateral prefrontal cortex, who demonstrate “pathological switching”, the inability to correctly select the intended language (Abutalebi, Miozzo, & Cappa, 2000; Fabbro, Skrap, & Aglioti, 2000). Thus, the mental landscape for bilinguals integrates cognitive and linguistic systems in a unique way and not surprisingly, therefore, affects how both cognitive and linguistic processing are carried out.

The main findings from this body of research on the consequences of bilingualism can all be traced in some measure to this joint activation of two language systems and nonselective access to the target system. From the perspective of language processing, there is evidence suggesting that language comprehension and production depend on the absolute and relative levels of proficiency of both languages, that those levels are moderated by context and experience, and that these processing effects are found bidirectionally with each language affecting the other (e.g., Kroll & Dussias, 2013; Kroll, Dussias, et al., 2012). From the perspective of cognitive systems, there is evidence suggesting that bilinguals at all stages of the lifespan perform better than monolinguals on nonverbal executive control tasks, that bilingual performance compared to that of monolinguals depends on task materials and demands, and that symptoms of dementia in bilinguals are generally delayed relative to comparable monolinguals (review in Bialystok, Craik, Green, & Gollan, 2009). What is not yet well understood is how the network of cognitive resources that regulates language processing also modifies domain-general cognitive and brain mechanisms; that is, how does a specific experience in language processing lead to a change in nonverbal cognitive processing.

Executive function advantages for bilinguals have been found for tasks involving all of the components of executive function as described by Miyake et al. (2000) and have been demonstrated in behavioural evidence as well as neuroimaging using MEG (Bialystok et al., 2005) and fMRI (e.g., Gold et al., 2013; Luk, Anderson, Craik, Grady, & Bialystok, 2010). Our purpose in the present paper is to examine the larger context in which these linguistic and cognitive consequences coexist and interact. To a great extent, research has been conducted on each domain relatively independently, leaving the impression that bilingualism produces effects that are specific and isolated. In our view, this piecemeal approach fails to capture the main point of bilingualism, namely, that it is an experience that profoundly restructures cognitive networks and fundamentally changes how language is processed.

Two methodological issues have impeded progress in advancing our understanding of this problem. Although endemic to all empirical research, these issues are particularly problematic for research examining processing differences between monolingual and bilingual participants across the lifespan because of the complexity of the population and the subtlety of the predicted outcomes. The first is the tendency in research to adopt a componential perspective in which it is expected that ultimate causality can be determined for behaviour, particularly in terms of known constituents. The second is the assumption of categorical hypothesising in which it is expected that mutually exclusive alternatives can be compared such that supporting one invalidates the other. In both cases, research on the cognitive outcomes of bilingualism presents significant challenges to our standard empirical approaches. Failing to deal adequately with the special nature of these questions will inevitably result in experiments that produce no interpretable outcomes. Therefore, we begin with an examination of these methodological issues in terms of the specific problems arising from this type of research.

EXPLAINING THE UNKNOWN IN TERMS OF THE “KNOWN”

A general approach to psychological research is to attempt to explain complex behaviour in terms of known components. This is an effective means of rendering seemingly intractable problems manageable by revealing their basis in simpler processes. For example, the Stroop effect is well-documented in cognitive psychology: The presence of a printed word (i.e., a colour name) influences performance in a simple perceptual naming task (i.e., the font colour), with facilitation when the colour name and colour are congruent, and interference when they are incongruent. Although there are various explanations for this effect, they are all grounded in models of selective attention, a component of executive processing, and within selective attention, explained in terms of simpler processes such as saliency, automaticity, and parallel processing (see for example, MacLeod & MacDonald, 2000). In this way, an understanding of Stroop interference is fully specified by an explanation of these component processes. Although it is a useful approach to understanding human performance on specific tasks, our view is that this is a counterproductive and overly simplistic approach to understanding the broadly based reorganisation that occurs from bilingualism. Even though Stroop performance is different for monolingual and bilingual participants (Bialystok, Craik, & Luk, 2008), the cognitive differences between monolinguals and bilinguals are not properly captured by reference to an analytic interpretation of the Stroop effect. In other words, cognitive differences between monolinguals and bilinguals on the Stroop task cannot be described as "nothing but" processing differences regarding saliency, automaticity, and parallel processing. There is not a one-to-one mapping between bilingualism and each of these component processes.

A more general consequence of this tendency is to equate tasks with the putative process most necessary to perform that task. Thus, the Stroop task becomes a "measure of inhibition", the *n*-back task becomes a "measure of working memory", and a switching task becomes a "measure of shifting". Although these component processes are certainly involved in all these tasks, they are not embodied by them. Task effects, group effects, individual differences, and many other factors intervene between the observation that two groups perform differently on the Stroop task and an explanation of the cause of that difference.

This problem of attribution becomes even more difficult when the target is not a task ("Stroop task is a measure of inhibition") but a population ("bilinguals are better at inhibition"). Early research on the cognitive consequences of bilingualism did attempt to reduce the observations to differences in known components. Thus, an initial hypothesis was that bilinguals were better than monolinguals at inhibiting interference because of their practice in inhibiting attention to the nontarget language (e.g., Bialystok, 2001). However, the limitations of this explanation were apparent very early: In the first study to extend the research in the cognitive advantages of bilingualism to adults, Bialystok, Craik, Klein and Viswanathan (2004) did indeed find bilingual advantages in a Simon task that could be attributed to inhibition, but they also reported that the bilinguals outperformed the monolinguals in a condition in which participants had to press a key in response to one of four coloured patches that were presented in the centre of the screen where there was no conflict and no need for inhibition. Similarly, bilinguals outperformed monolinguals not only on the incongruent trials for which inhibition was a plausible explanation, but also on the congruent trials where no inhibition was required. These results have been replicated in many subsequent studies, showing that bilingualism modifies not only inhibition but also monitoring (Costa, Hernández, Costa-Faidella, & Sebastian-Galles, 2009), switching (Prior & Gollan, 2011), and working memory (Luo, Craik, Moreno, & Bialystok, 2013; Wodniecka, Craik, Luo, & Bialystok, 2010). Moreover, bilingual advantages were found for some types of inhibition but not others; specifically, bilinguals outperformed monolinguals on tasks that required inhibition of interfering cues but not on tasks that required inhibition of executing a salient response (Carlson & Meltzoff, 2008; Colzato et al., 2008; Martin-Rhee & Bialystok, 2008). Thus, a description of the processing components involved in tasks does not correspond to the identification of processing differences found in populations of participants. Yet, our standard research paradigms assume that such an equation is valid. For example, in a recent major review of the literature on bilingualism and executive control, Hilchey and Klein (2011) assemble evidence from studies showing no bilingual advantage on simple inhibition tasks and then use that result to discredit the entire body of work (see also Paap & Greenberg, 2013, for a similar argument). However, as Hilchey and Klein correctly point out, there *are* bilingual advantages when a more holistic approach to tasks is used. Our point is that the relations between complex task performance and complex individual characteristics cannot be reduced to unitary relationships.

The inability to reduce executive function differences between monolinguals and bilinguals to a single component of executive control is consistent with emerging conceptions of this system. Recently, Miyake and Freedman (2012) acknowledged what they call the "unity and diversity" of executive control, with a common core shared by the component processes and unique features of different parts of the system. To accommodate this broader conception in which there is no single cause of processing differences, researchers have begun to use more general terms than those given by the standard core components to explain differences in performance between monolinguals and bilinguals. Thus, Costa et al.

(2009) argue that the bilingual advantage is in "monitoring" and Bialystok (2011) attributes the advantage to "coordination". It is ironic that as we accumulate data and develop more sophisticated explanatory edifices, the explanation for superior bilingual performance on cognitive tasks increasingly resembles the explanation offered in the first credible paper to report these effects. In their landmark paper, Peal and Lambert (1962) claimed that bilinguals had greater "mental flexibility". The search for precise components that could "explain" processing differences between monolinguals and bilinguals seems to have come full circle.

The search for the correct level of description for cognitive differences between monolinguals and bilinguals is not just a terminological issue. Assuming that tasks and groups can be adequately described in terms of single component processes leads to hypotheses that performance on tasks will reveal differences between groups. For example, Alario, Ziegler, Massol, and De Cara (2012) argued that the ability to select between nonverbal alternatives in a Simon task should be related to the ability to select between words in a naming task for monolinguals as is claimed for bilinguals (Blumenfeld & Marian, 2011). They do not find such a relation and argue that the explanation for bilinguals is therefore incorrect. This is a reductionist error: The point is that a more comprehensive cognitive network is required for bilinguals, making both linguistic and cognitive processing proceed differently than they do for monolinguals. Reducing performance to a few measurable components fails to capture the most crucial outcome of the experience, namely, the reconfiguration of these networks.

The tendency to argue from a simple componential perspective prevents us from understanding the linguistic and cognitive implications of bilingualism. Approaches based on labels applied to tasks and abilities that seek a correspondence between them fail to account for the reorganisation of whole networks that follow from bilingualism. The goal of current research is to identify these correspondences and their interactions. If the new neuroscience approaches have made anything clear, it is that there are not one-to-one correspondences between the brain and behaviour. These correspondences are systematic, but not simple, for all language users. The point is precisely that the bilingual mind comes to be organised differently than that of the monolingual because the representational systems and control networks have developed through a different set of determining circumstances. Minds grow differently in different contexts and they grow in complex ways.

CATEGORICAL HYPOTHESES: POLARISING THE ALTERNATIVES

A dominant model for psychological research is the orthogonal design, an approach that is based on assessing the probability that performance differences between tasks, conditions, or groups are unlikely to have occurred by chance so can be attributed to controlled differences between those entities. The majority of the research on the cognitive consequences of bilingualism has followed this model by comparing participants designated as monolingual or bilingual for their ability to perform various tasks. A significant difference between groups is interpreted as evidence for bilingual effects on processing. However, as argued by Luk and Bialystok (this issue 2013), bilingualism is not a categorical variable. Approaches based on dichotomous distinctions for groups or tasks, therefore, may be inappropriate for investigations of bilingualism.

The essential assumption of orthogonal designs is that the entities being compared are independent and that variation between groups or conditions is confined to the variable of interest, with all other variables being equivalent. Bilinguals, however, vary multidimensionally on linguistic, cognitive, social, experiential, educational, and other factors, all of which must be taken into account when explaining performance. As such, bilingualism needs to be studied in the context of a dynamically changing system of linguistic and cognitive performance, an approach that extends beyond categorical assignment to groups. Relatedly, statistical models often assume that the variables are normally distributed, a precondition that is almost never tested yet leads to null effects when it is violated. Failure to obtain the gold standard of statistical difference between groups is often a problem of the data distribution. Finally, the overlapping distributions of two groups performing the same task, in which participants are drawn from the same population and differ by only one feature, in this case bilingualism, make it extremely difficult to obtain a reliable difference in the mean score if only one measure is being considered. Standard experimental design usually involves about 25 or 30 participants per group, and the similarity of the populations in the two groups, the simplicity of the tasks used in this research, and the tendency for regression towards the mean makes it astounding that significant group differences are ever obtained. The considerable literature that reports group differences between monolingual and bilingual participants is greatly more informative than the attempted replications that fail to find significance.

The failure to accommodate for the complexities of bilingual experience and the limitations of orthogonal design leads to misleading assertions. To illustrate, some researchers have argued that group effects reported for bilingualism cannot be attributed to bilingualism but instead reflect differences in SES, education, immigration, or culture. For example, a small-scale study by Morton and Harper (2007) showed no difference in performance on a Simon task between children classified as monolingual or bilingual but a significant correlation between performance and an estimate of SES. Their conclusion was that bilingualism had no effect on executive functioning (but see discussion of the tendency to oversimplify the attribution of traits to specific tasks) because SES was the crucial variable. Extrapolating from this result, they assumed that previous research reporting group differences was in fact reflecting differences in SES rather than bilingualism. The error in such reasoning is to assume that categorical designs require categorical interpretations: if the effect is caused by X, then it cannot be caused by Y.

The problem in applying this form of logic to studies of experience is that our lives are not arranged according to a factorial design and multiple factors in our experience have multiple outcomes. All of the factors cited in the critiques of the bilingualism literature (e.g., SES, education, etc.) do indeed influence performance on linguistic and cognitive tasks. The issue is not to determine whether one of them is responsible for the outcomes but rather how they work together in complex contexts and how the linguistic and cognitive outcomes themselves interact.

An example of how multiple factors can be examined within the confines of a factorial design comes from a recent study by Calvo (2011). Multiple tests of language ability, memory, attention, and executive control were administered to 5-year-old children who were monolingual or bilingual (all of whom had been simultaneous bilinguals from birth) and lived in families that were designated as middle class or working class on the basis of mothers' education. The middle-class mothers had university degrees and the working-class mothers had education up to and including a high school diploma. None of the families lived in poverty and in that sense, none of the children were at risk for the developmental delays associated with those stressful environments. The results showed clear effects of both bilingualism and SES that were independent of each other and affected different behavioural outcomes. The primary effects of SES were seen in measures of language ability and attention, and the primary effects of bilingualism were seen in measures of executive functioning. Thus, as Morton and Harper (2007) report, SES does indeed influence children's outcomes, a point made in much greater detail by research studying the effects of poverty on executive functioning (e.g., Mezzacappa, 2004; Noble, McCandliss, & Farah, 2007), but such effects do not imply the absence of an effect for bilingualism. Using a different approach, Engel de Abreu, Cruz-Santos, Tourinho, Martin, and Bialystok (2012) administered a large battery of cognitive tasks to children who were all very low SES and carefully matched on many variables. On the tasks that involved conflict and required executive control, bilingual children outperformed the monolinguals, but, on all other measures, the children in the two groups performed equivalently.

The general problem with the categorical approach is that it fails to account for the inherently noncategorical nature of the relevant constructs. Individuals are not bilingual or not, and tasks are not measures of inhibition or not: These are all continua in which experience expresses itself through multiple facets and task complexity incorporates nuances of the domain and the process, all of which interact in a context. Because of the need to identify categorical variables, gradations in all of these dimensions are washed over, and the interactions between linguistic and cognitive systems are rarely observed. An illustration of this problem can be seen in the recent paper by Paap and Greenberg (2013) in which they call into question all evidence for bilingual advantages in executive function. Using young adults drawn from a highly heterogeneous pool of bilingual and monolingual speakers, they fail to find bilingual advantages on a set of behavioural tasks. Other studies have also demonstrated that behavioural results with young adult bilinguals can sometimes be fragile and that the very same tasks that fail to produce differences for young adults may produce striking results for older bilinguals (e.g., Gold et al., 2013), under different contexts of language use (e.g., Linck, Hoshino, & Kroll, 2008), or only when cognitive tasks make significant processing demands (e.g., Costa et al., 2009). Failures to replicate are important because they require that additional complexity be assumed to provide a comprehensive account of the larger body of evidence. But unless all conditions have been accounted for and all other explanations have been exhausted, it is misleading to call into question the reliability of the phenomena themselves.

An alternative approach to investigating the consequences of bilingualism is to use multivariate approaches that evaluate changes on continua. In a recent example, Bialystok and Barac (2012) examined the relation between the length of time children spent in an immersion education programme and thus experienced a bilingual environment, various measures of their proficiency in both languages, and outcome measures of both nonverbal executive control and metalinguistic ability. The interesting finding is that the relations were different for the different outcomes: Bilingual experience was related to performance on executive control tasks and language ability was related to performance on metalinguistic tasks. Categorical comparisons between groups on specific tasks would not have revealed these emerging differences.

The two methodological issues are important considerations for all psychological research, but they are particularly challenging for studies addressing the effect of a broad and variable experience, bilingualism, on the complex set of cognitive processes that comprise the executive function system. Yet, in spite of these difficulties, a large body of research is now identifying the consequences of bilingualism for language and cognitive processing as revealed by both mind and brain function.

LINKING THE LINGUISTIC AND COGNITIVE SYSTEMS

Research on the linguistic and cognitive consequences of bilingualism is just now reaching maturity. As we can see in Figure 1, a critical mass of research is accumulating and allowing us to consider the full impact of this experience. Although we have not addressed research based on neuroimaging in detail in this brief review, the combination of the brain and behavioural outcomes converge on a rather dramatic picture for the consequences of bilingualism. The primary effect appears to be that the potential to use two language systems reorganises not only the processes associated with language use but also processes involved in a number of crucial nonlinguistic systems (see Abutalebi & Green, 2007, for a review). These nonlinguistic processes, particularly those associated with the executive function system, are irrevocably altered by their recruitment for linguistic functions. Thus, as the bilingual mind is reconfigured to accommodate two language systems that have different relations to each other, to speaker intentions, to communicative contexts, and to pragmatic goals, the impact of that reconfiguration is felt throughout cognitive networks. But the consequences of the hypothesised accommodations will also differ for bilinguals across the lifespan, as illustrated by the recent Gold et al. (2013) study. The greater efficiency of young adult brains may make them less likely to reveal the consequences of bilingual experience than their older counterparts. Not observing a bilingual effect for young adults does not mean that there are no consequences of their language experience, but that their ability to resolve conflict or switch effectively between tasks is operating within a resource-rich context that has not yet been stressed by losses associated with normal ageing. If the apparent null effect for the younger bilinguals were truly a null result, then presumably there would not be any effect for the older bilinguals. Being bilingual as a young adult appears to have a cumulative effect later in life that produces the observed bilingual advantages in the elderly. In the Gold et al. study, the younger and older groups were so closely matched on a host of variables that one would be hard pressed to argue that the reported effects of bilingualism are attributable to group differences rather than to language experience.

There is a growing interest in the role of experience in modifying performance, an interest that directly reflects the acceptance of plasticity as a feature of minds and brains. The research with bilingualism is in this tradition but it is importantly different from most of the other experientially based research. For most studies examining the effect of experience on brain or mind, the outcome of the experience is typically in the same domain as the training and closely related to it. Thus, string players have enhanced representation in the motor cortex responsible for the fingers on the left hand (Elbert, Pantev, Rockstroth, Taub, & Wienbruch, 1995), jugglers have better visuospatial coordination than nonjugglers that is evident after brief training (Draganski et al., 2004), and action videogame players have better reaction time and perceptual accuracy than nongamers (Dye, Green, & Bavelier, 2009). In all these cases, the training or experience directly results in outcomes that are part of the performance. For bilingualism, a linguistic experience has consequences for both linguistic processing, which is not entirely surprising, and for nonverbal cognitive processing, which is both unique to this research and unexpected. Our explanation is that bilingualism forces language processing to be carried out differently than it is for monolinguals, primarily because of joint activation of the two languages, leading to a reorganisation of both linguistic and cognitive systems. Thus, the relation between the linguistic and cognitive outcomes of bilingualism is that they are both part of the reorganisation of complex mental structures in response to a particular linguistic experience. They are, in short, intimately interconnected and mutually interdependent.

The explanation in terms of broad reorganisation of linguistic and cognitive processes that we propose is inconsistent with attempts to isolate the unique source of processing differences found for language or cognitive systems or choices between alternative categorical interpretations that are mutually exclusive. We now turn to research on language processing to consider specifically how the consequences of bilingual language experience might be understood within this framework.

THE SCOPE AND CONSEQUENCES OF CROSS-LANGUAGE ACTIVATION IN LANGUAGE PROCESSING

The discovery that information about both languages is available whenever bilinguals listen to speech, read, and plan spoken utterances in even one language alone, has led to an intensive examination of the scope of cross-language interactions. In each context of language processing, there is evidence that the two languages become active in parallel and compete with one another, producing benefits when there is cross-language convergence and costs when the two languages diverge. Our goal in the present paper is not to review the primary evidence for language nonselectivity because it has been discussed elsewhere in detail (see, for recent reviews, Kroll, Bogulski, & McClain, 2012; Kroll, Dussias, Bogulski, & Valdes-Kroff, 2012). Rather, we focus here on the scope of these cross-language interactions and the consequences that the open architecture of the linguistic system appears to create for language processing, cognition, and the neural networks that support them. As in the earlier section of the paper, our concern is with noncategorical aspects of processing. Just as bilingualism is not categorical, so too different aspects of language processing also draw on different types of resources that fall on a continuum.

The notion that the bilingual cannot switch off one language at will is counterintuitive if we assume that each language is represented and processed autonomously. Superficial observation might suggest that the bilingual is able to function as two monolinguals because proficient bilinguals rarely make the error of using the wrong language (e.g., Gollan, Sandoval, & Salmon, 2011). Yet the same bilinguals may actively code switch with other similar speakers, switching from one language to the other even in midsentence, and they may have accented speech in the second language (L2), suggesting a trace of the native language and of their learning history. The data on the parallel activation of the two languages when bilinguals are intentionally using only one of the two languages provides compelling evidence that although they may not be aware of the activation of the language not in use, there is at least a moment in processing when that information is available (e.g., Thierry & Wu, 2007).

What is even more surprising about the emerging picture of an open language system in which there are persistent cross-language influences is that these interactions are present for learners and for highly skilled bilinguals, they occur even when the two languages are markedly different in form, and they are observed at every level of language processing, from the lexicon and phonology to the grammar. It was once thought that these cross-language effects were more likely to be seen in learners who have limited knowledge of the L2 and for whom the more dominant first language (L1) plays a critical role in acquiring the L2 (e.g., MacWhinney, 2005). And although it is true that learners at early stages of L2 acquisition are particularly vulnerable to the influence of the

L1 (e.g., Sunderman & Kroll, 2006), an important discovery in this recent period of research is that these cross-language interactions are robust in even the most proficient bilinguals. Indeed, many of the initial studies demonstrating the activity of the language not in use involved word recognition experiments with Dutch-English bilinguals who speak English as an L2 at a high level of proficiency (e.g., Van Heuven, Dijkstra, & Grainger, 1998). The earlier view was that the goal of L2 learning was to approximate the automaticity available in the L1 for the L2 (e.g., Segalowitz & Hulstijn, 2005). The new research requires a revision of that position that acknowledges that, although L2 may indeed become more skilled with increasing proficiency, there is nonetheless continuing activation of both languages regardless of the level of automaticity associated with the L2.

For present purposes, the critical point is that cross-language activation and interaction are observed across a broad range of conditions. Notably, it does not depend on low levels of proficiency, although proficiency affects the form that these interactions take and more skilled bilinguals are more likely to reveal effects from the L2 to the L1 in addition to the effects seen from the L1 to the L2. At the level of lexical processing, there is also very little evidence that bilinguals are able to easily modulate their performance to be more sensitive to the target language in the presence of cues that logically indicate the presence of that language, such as the script of a word or the language or a sentence context. The effects of sentence context are particularly compelling because sentences provide a rich source of information that goes largely unused in guiding attention to the intended language (e.g., Van Assche, Duyck, Hartsuiker, & Diependaele, 2009). The general result in these studies is that word recognition reveals cross-language interactions in sentence contexts that are virtually identical to those reported for word recognition out of context. The only documented exception is when sentences are highly constrained semantically (e.g., Schwartz & Kroll, 2006; Van Hell & De Groot, 2008), but even then, studies using temporally sensitive measures, such as eye tracking, suggest that the locus of the semantic constraint effect is late in processing, after cross-language activation has occurred (e.g., Libben & Titone, 2009).

READING, LISTENING, AND SPEAKING: DIFFERENT LANGUAGE PROCESSING TASKS

Although parallel activation of the bilingual's two languages has been reported for spoken word recognition (e.g., Marian & Spivey, 2003), visual word recognition (Van Heuven et al., 1998), and spoken word production (e.g., Kroll, Bobb, & Wodniecka, 2006), there are differences in the way that the coactivation of the two languages is manifest across these lexical domains. As noted earlier, the research on visual word recognition provides little evidence that overt cues to the language in use modulate the activity of the language not in use to enable language selective access. Even when the context or form of the word provides a clear indication of which language should be selected, there are persistent effects of the language not in use that have been documented in behaviour (e.g., Schwartz, Kroll, & Diaz, 2007), in the earliest stages of processing revealed in the ERP record (e.g., Midgley, Holcomb, & Grainger, 2011), and in the patterns of brain activity seen in fMRI studies (e.g., Van Heuven & Dijkstra, 2010). For visual word recognition, bilinguals simply seem not to exploit available information to bias lexical processing to the target language.

The research on spoken word recognition generally converges with the pattern of persistent cross-language activation seen in visual word recognition. For example, Lagrou, Hartsuiker, and Duyck (2011) reported a series of auditory lexical decision experiments which included interlingual homophones. The typical result in the bilingual word recognition literature is that interlingual homophones produce interference, presumably because the parallel activation of the alternative meanings of the homophone across languages results in conflict that must be resolved. Lagrou et al. asked whether this pattern would be affected by whether the spoken word was produced by a native or nonnative speaker. In theory, accented speech might provide a cue to the language of the spoken word. They found that Dutch-English bilinguals were sensitive to the difference between hearing words spoken by a native Dutch or native English speaker, but that sensitivity to the accentedness of speech did not modulate the effect of the interlingual homophone. There was similar interference for interlingual homophones regardless of the speaker's accent. On the face of it, this result appears similar to the findings on bilingual word recognition in the visual domain, where obvious cues do not effectively bias lexical access to one language alone. However, other studies of spoken word recognition have shown that under the right conditions, bilinguals are indeed able to exploit the cues available in speech to achieve selective access (Ju & Luce, 2004; Weber & Cutler, 2004). It will remain for future research to identify the conditions under which spoken word recognition is language selective or not, but the evidence provides at least a preliminary suggestion that spoken word recognition may be more open to the influence of cues to language membership than visual word recognition. In considering the mechanisms that underlie lexical selection and that may subsequently affect cognition more generally, these differences may turn out to be as critical as the observed similarities. Cross-language competition and its resolution may take different forms under different circumstances. Like the cognitive processes we described earlier, it may not be a unitary phenomenon.

Perhaps the most counterintuitive evidence for the parallel activation of the bilingual's two languages comes from research on lexical production, where the intention to speak a word in one language is not sufficient to constrain activation to lexical candidates in that language (e.g., Costa, 2005; Kroll et al., 2006). In production, unlike word recognition, the language to be spoken must necessarily be selected to enable articulation. Logically, then, the language of production should be able to be planned in advance so that only alternatives in that language are active. The conceptual constraints in place to enable meaningful speech should, in theory, also be able to encode the intended language. Yet most of the research on lexical production shows that there is at least momentary activation of the language not in use. This result is perhaps not surprising when bilinguals plan to speak the L2, because the L2 is typically slower and less skilled than the L1 (e.g., Hanulovà, Davidson, & Indefrey, 2011), but it is unexpected for planning speech in the dominant L1. Moreover, the effects of cross-language competition in bilingual speech planning can be seen in the earliest stages of brain activity in electrophysiological studies for both the L1 (e.g., Misra, Guo, Bobb, & Kroll, 2012) and the L2 (e.g., Hoshino & Thierry, 2011).

The issue in research on bilingual production has been less about whether lexical candidates are activated in both languages and more about whether they compete for selection (see Kroll & Gollan, in press, for a recent review). As in the studies on cognitive outcomes of bilingualism, the initial claim (e.g., Green, 1998) was that the unintended activation of lexical candidates in both of the bilingual's two languages creates competition for selection that requires inhibition of the language not in use. Other models (e.g., Costa, Miozzo, & Caramazza, 1999) argued that language-specific selection is possible because lexical alternatives activated in the wrong language are simply not considered to be candidates for selection. An alternative frequency-based account (e.g., Gollan, Slattery, et al., 2011) proposes that what changes in production for bilinguals relative to monolinguals is the availability of words in each language rather than competition across the two languages. On this view, words in each of the bilingual's two languages are functionally less frequent than words in a monolingual's single language because a bilingual has fewer opportunities to use each word than a monolingual.

It is beyond the scope of the present paper to review and contrast the evidence that has been taken to support each of these models of bilingual production. We note that both the competition for selection model of production and the language-specific model allow predictions to be generated about how a lexical selection mechanism might influence domain-general cognitive processes, whereas the frequency model carries no obvious implications for these processes. The competition for selection model assumes a late locus of selection, once lexical candidates have been activated in both languages; in contrast, the language-specific model assumes an early locus of selection, exploiting the intention to speak one language only to create a kind of mental firewall that separates the two languages. If we assume that repeated experience in language selection creates expertise in executive function, then the competition for selection model might be hypothesised to generate specific expertise in resolving competition across conflicting alternatives, once those alternatives are already available. In contrast, the language-specific model might be hypothesised to affect early attentional mechanisms that guide the intention to establish a separation between alternative conditions. The frequency-based account does not provide a basis on which to generate predictions about the cognitive consequences of lexical selection.

For adult bilinguals, the initial evidence on the consequences of language experience for cognition provided more support for the idea that bilingualism affects later conflict resolution rather than early attentional biases (e.g., Hernandez, Costa, & Humphreys, 2012) in that the effects were mostly seen in the ability to resolve conflict between alternatives. That evidence alone, however, may neither provide a sufficient basis on which to adjudicate among alternative models of lexical selection nor an adequate account of how bilingual experience in lexical selection comes to alter the network that supports executive function. A number of very recent studies have demonstrated bilingual advantages on perceptual tasks that reflect early rather than late resolution of conflict (e.g., Singh & Mishra, 2012). It is of interest to note that the evidence for crib bilinguals suggests that there may indeed be an early attentional enhancement that results from multiple language exposure early in life (e.g., Kovács & Mehler, 2009; Sebastian-Gallés, Albareda-Castellot, Weikum, & Werker, 2012). Infants appear to be exquisitely sensitive to the presence of cues to each of the languages to which they are exposed. The research we have reviewed on cues to language membership in bilingual word recognition shows that adults are not as consistently sensitive as babies to the cues that are associated with each of their two languages, even when those cues are quite easy to identify. The circumstances under which adults are able to behave more like children may turn out to be important in understanding how control in language processing maps onto domain general control processes.

In considering how cross-language activation and its consequences may come to affect domain-general cognitive processes, it is also important to note that what is activated in word production differs from what is activated in word recognition. Production is a conceptually driven task, engaged by the intention to name a picture, translate a word, produce a word in response to a definition, or simply label a thought. The conceptual process that initiates speech planning requires that semantic alternatives are activated first and only later will the lexical and phonological properties of the possible words be available (e.g., Levelt, 1989). Word recognition is fundamentally a bottom-up process (e.g., Dijkstra & Van Heuven, 2002), with activation of the orthography and phonology driving later semantic access. Although it may be appealing to think that there might be a single mechanism of selection that maps onto executive control, both the requirements for selection and the nature of the activated lexical alternatives differ for word recognition and word production and may also differ for spoken versus visual word recognition. In visual and spoken word recognition, lexical neighbours are the competitors, either by virtue of similar orthography or similar phonology. In spoken production, semantic relatives are the competitors. In each case and depending on the particular task goals in a given context, there will be cascaded activation to other lexical and sublexical codes. For example, in production, the phonology of the planned utterance will eventually be activated but the planning process will itself be initiated at the conceptual level, with semantic candidates activated first. As Kroll et al. (2006) argue, the locus of selection in production may vary depending on a set of variables that include the task, the proficiency of the speaker, and the relative dominance of the two languages. The implication is that there is not necessarily a single locus of selection for production and, across production and comprehension, the locus and mechanism of selection may vary. Why should the consequences of selecting a word in one language then be the same under all of these conditions?

HOW CAN LANGUAGE PROCESSING HAVE CONSEQUENCES FOR COGNITION?

Our discussion of cognitive differences in bilinguals and language processing differences attributed to bilingualism leaves unanswered the question of how these two domains are related. We review here three recent studies that have investigated the consequences of resolving competition in visual word recognition, spoken word recognition, and word production. These studies illustrate the type of evidence that might allow us to link bilingual language processes and their cognitive consequences more directly. Martín, Macizo, and Bajo (2010) asked Spanish-English bilinguals to perform semantic relatedness judgements to pairs of visually presented English words. On the critical trials of the experiment, the word pair contained an interlingual homograph (e.g., *pie*-toe, where *pie* is the Spanish word for foot) and on the following trial, the word pair included the English translation of the Spanish interpretation of the homograph (e.g., *foot*-hand). Bilinguals were slower to judge word pairs that contained a homograph, but critically they were also slower to judge a subsequent pair that contained the translation of the homograph rather than an unrelated control. The spillover to the second trial was taken as an index of inhibitory control in that the English translation had been inhibited along with attention to the Spanish homograph on the previous trial. Martín et al. found that when the two trials were separated by 750 ms, the inhibition on the second trial was eliminated, suggesting that there is momentary inhibition of the L1 interpretation that is resolved within that time period.

Using a very different paradigm to test spoken word recognition, Blumenfeld and Marian (2011) asked bilingual and monolingual participants to perform a visual world task in their L1 in which their eye movements were monitored while they identified a target picture associated with a spoken word among a display of four pictured objects in a grid. One of the pictures in the display was designed to be a phonological competitor with the named target. Both bilinguals and monolinguals produced the typical pattern in this sort of competitor task, with increased fixations to the phonological competitor relative to an unrelated control. The innovation in this study was to have a second nonlinguistic trial in which the same display was presented without any pictured objects but with asterisks in the four picture locations; three of the asterisks were black and the target item was grey and participants were asked to indicate the location of the grey target. Blumenfeld and Marian reported longer reaction times interpreted as reflecting inhibition for identifying the location of the target asterisk when it appeared in the position that had previously contained the phonological competitor, but only for monolinguals and not for bilinguals. The fact that the two groups revealed similar patterns of phonological competition on the first trial suggests that bilinguals were able to resolve the inhibition of the incorrect competitor more quickly than monolinguals. Although this study did not vary the timing between the first and second trial, the general spirit of the results is similar those reported by Martín et al. (2010), demonstrating competition in cross-language word recognition that appears to be resolved by inhibition.

In the third study, Misra et al. (2012) used a blocked switching task in an ERP paradigm to investigate language selection in bilingual lexical production. Chinese-English bilinguals named pictures in blocks of trials that were either in Chinese, their L1, or in English, their L2. The same pictures were named in both languages. The critical manipulation was the order in which the languages were designated across the blocks. The researchers predicted that naming the same pictures in the two languages would produce a pattern in the ERP data that reflected repetition priming; specifically, there would be reduced negativity for repeated trials where the same picture was named in the other language. The data supported that prediction for the L2 (English) but the pattern for the L1 (Chinese) was reversed. In this case, there was increased negativity when the L1 followed the L2, a pattern that is consistent with inhibition of the L1 after naming the pictures in L2. That negativity extended throughout the immediate time course of speech planning and over many intervening trials, even once pictures had been named in the L1 over an entire block of trials. The use of repeated pictures made it impossible to identify the precise scope of the observed inhibition, but the enduring inhibition over the course of the experiment suggests that it was long lasting, unlike the inhibitory patterns observed in the word recognition studies described earlier.

These studies illustrate three points about cross-language lexical processing. First, they provide evidence that bilinguals inhibit the language not in use in both word recognition and word production. Second, they show that the time course of these inhibitory processes appears to differ for comprehension and production. In word recognition, they are relatively short lived, as suggested by the Martín et al. (2010) study, but in word production, they may be long lasting, persisting over many trials. Although there may be shared mechanisms of inhibition, there are certainly distinct mechanisms as well. Future studies will have to determine the precise scope and time course of each of these effects. In the Misra et al. (2012) production study, extended inhibition was not anticipated, so the study was not designed to ask the question of how long it might last. Third, and perhaps most crucially, each of these studies shows that it is the L1 or native language that is inhibited. The Blumenfeld and Marian (2011) study was performed in the L1 alone, yet differences were revealed between bilingual and monolingual performance. In the Martín et al. study, the primary task was performed in the L2 but it was the L1 alternative that was suppressed to create the observed homograph effect. In the Misra et al. study, the act of planning speech in the L2, for even relatively proficient bilinguals, appears to require the inhibition of the L1 that then has subsequent consequences for speech planning in the L1. The apparent ease with which these inhibitory effects can be induced experimentally suggests that they are available in natural language use. Indeed, studies of language when individuals are immersed in the L2 reveal similar inhibition of the L1 (e.g., Linck, Kroll, & Sunderman, 2009). The implication is that the native language changes in response to acquiring and using a second language. The accommodation that bilingualism requires of the L1 has important implications for language processing itself and for traditional claims about the privileged status of the native language. But as these illustrative studies demonstrate, these changes within the L1 reveal one source of the link between language processing and their cognitive consequences.

DO ALL LEVELS OF BILINGUAL LANGUAGE PROCESSING HAVE CONSEQUENCES FOR COGNITION?

A striking feature of the research we have reviewed is that it is all about words, as if language were simply a bunch of words to be juggled and categorised. If the effects that have been observed for words were all we knew, they would be interesting, but also easy to dismiss on the grounds that the cognitive control evident in bilingual language processing may be supported by the higher level context available in full sentences and in actual discourse. The research described earlier on the effects of sentence context on lexical access provides dramatic evidence that, at least for lexical access, a sentence context does not appear to provide bilinguals with the scaffolding needed to overcome the activity of the language not in use. But again, that evidence is about lexical processing.

Research on sentence processing in bilinguals and second language learners has focused primarily on the question of whether late bilinguals are capable of fully acquiring the grammar of the L2 at a level that approximates native speakers since early studies suggested gaps for even highly proficient L2 users (e.g., Johnson & Newport, 1989; but see Hakuta, Bialystok, & Wiley, 2003, and Birdsong, 2005, for discussion of the interpretation of critical period effects in L2 acquisition). Although this issue is still under debate (e.g., Clahsen & Felser, 2006), the recent evidence suggests greater plasticity within adult learners than might have been predicted (e.g., Steinhauer, White, & Drury, 2009), much of which has been revealed by using neuroscience methods that track these processes more sensitively than behaviour alone (e.g., Foucart & Frenck-Mestre, 2012). Within research on L2 acquisition, there are also studies that examine transfer in the way that L1 knowledge may be applied to the L2 (e.g., MacWhinney, 2005). Much of that work considers how the presence or absence of grammatical features in the native language affects the acquisition and processing of sentences in the L2 (e.g., Tokowicz & MacWhinney, 2005).

But does learning and using an L2 also affect the grammatical processing of the native language? Most of the research on sentence processing has compared L2 comprehension in learners and bilinguals to native speakers of the target language. The evidence reviewed here on bilingual lexical processing suggested a high level of interaction across the two languages. These questions have begun to be asked about the grammar as well. Bilinguals typically use two languages whose grammars are similar in some ways and different in other ways. If the grammars of the two languages are represented separately, then L1 sentence processing would be expected to remain relatively constant as adults acquire and then become proficient in the L2. One line of research has addressed the influence of the L2 on L1 parsing preferences in Spanish-English bilinguals immersed in the L2 (e.g., Dussias, 2003; Dussias & Sagarra, 2007). The observation here, consistent with what we have seen in our review of cross-language lexical interactions, is that the grammar of each language is influenced by the bilingual's experience with the other language. Dussias and Sagarra (2007) asked Spanish-English bilinguals to process sentences in Spanish that were ambiguous with respect to relative clause attachment. Spanish and English differ in their preferences for high or low attachment. For example, consider the sentence: *Peter fell in love with the daughter of the psychologist who studied in California*. Who studied in California? Native English speakers prefer to attach low, answering that it was the psychologist who studied in California, but native Spanish speakers prefer to attach high, saying that it was the daughter. Dussias and Sagarra tracked the eye movements of a group of highly proficient Spanish-English bilinguals living in the US while they read sentences in Spanish, their native language. They found that bilinguals who had been immersed in English for a long time processed Spanish using the English parsing preferences. These were not bilinguals who had suffered language attrition, so the effect of the L2 English on the L1 Spanish was not from lack of use of Spanish but rather from the effect of the exposure to English. Other studies using a variety of methods have shown similar interactions across the bilingual's two languages at the level of the syntax (e.g., Bernolet, Hartsuiker, & Pickering, 2007; Dussias & Cramer Scaltz, 2008; and see Kroll & Dussias, 2013, for a recent review). Taken together, the evidence suggests that this is not just a story about words. Cross-language interactions and competition occur at the level of the grammar as well as the lexicon. What we don't know, of course, is whether the consequences of repeatedly resolving conflict or ambiguity across two grammars draw on the same cognitive and neural mechanisms that are affected by lexical competition.

HOW BILINGUALISM AFFECTS COGNITION

In this review, we have mentioned the neuroscience evidence only in passing. There is now accumulating evidence for both cognitive and language measures demonstrating that bilingualism has structural consequences for the brain and functional consequences for neural processes. As we noted earlier, some areas of the brain, such as the anterior cingulate cortex (e.g., Abutalebi et al., 2012) may play a particularly important role in monitoring the conflicts that characterise bilingual language processing and its cognitive consequences. A recent paper by Zou et al. (2012) shows that the brain network for the L1 is also changed by experience with the L2. What is not yet known is how the range of language processes that we have reviewed impacts the documented cognitive and neural consequences and how the diversity of bilingual language experience modulates the effects that have been reported (see Luk & Bialystok, this issue 2013). Recent reports of bilingual advantages are diverse, from enhancements to the subcortical encoding of auditory processing of speech (Krizman, Marian, Shook, Skoe, & Kraus, 2012), to enhancing white matter integrity as bilinguals age (Luk, Bialystok, Craik, & Grady, 2011). We simply do not know whether learning to juggle two grammars has the same consequences for generating these advantages as repeatedly selecting words to speak in one language only, or whether code switching at grammatically acceptable points in midstream in the flow of a sentence alters the brain and cognition in ways that differ from other sorts of multitasking.

From the perspective of this framework, it is not surprising that some studies fail to reveal the benefits of bilingualism or fail to demonstrate effects on certain tasks. Rather, the circumstances under which we fail to observe these consequences provide critical evidence to refine hypotheses about the conditions that give rise to them. A study by Emmorey, Luk, Pyers, and Bialystok (2008) illustrates the usefulness and also the limitations of negative findings. Emmorey et al. exploited the circumstances associated with bimodal bilingualism to ask whether language selection contributes to the bilingual advantage that has been reported on the flanker task. They compared the flanker performance of hearing bilinguals who use one spoken language and another signed language, with that of hearing bilinguals who speak both languages, and monolinguals who speak one language only. Only the bilinguals who speak both languages showed the bilingual advantage. The flanker performance for the bimodal bilinguals was no better than that of the monolingual controls. They reasoned that, because bimodal bilinguals do not have to choose between their two languages to produce speech (they can speak and cogesture at the same time, e.g., Emmorey, Borinstein, Thompson, & Gollan, 2008), they do not have to repeatedly select the language to speak. By this logic, the benefits for unimodal bilinguals can be attributed to the repeated requirement to select the language to speak. Do we then assume that expertise in language selection is the primary mechanism that affects executive control? The unimodal bilinguals in the Emmorey, Luk, et al. study were also faster overall, a point that has been discussed in the recent literature (e.g., Hilchey & Klein, 2011). In addition, the bimodal bilinguals were children of deaf adults (CODAs) and are actually heritage speakers of sign, educated and dominant in their spoken language. Their failure to produce a bilingual advantage in the flanker task might indeed be due to the special circumstances of bimodal bilingualism, but it may also be due to other aspects of their language experience. Notably, the bilinguals in the recent Zou et al. (2012) study that revealed a reorganisation of the brain network for L1 as a result of L2 use also tested bimodal bilinguals who used one spoken and one signed language. Bimodal bilingualism may have some similar and some different consequences relative to unimodal bilingualism.

The goal of this paper was to examine the story that we and others have told in the past about bilingualism and its cognitive and linguistic consequences. The evidence that we have reviewed and the rapidly emerging findings on the consequences of bilingualism make clear that the bilingual is indeed a mental juggler at all levels of language processing and that there are a host of consequences that result, many of which can be characterised as benefits. But which aspects of that juggling produce which constellation of consequences are just beginning to emerge. The resulting research will not only enhance our understanding of how language experience affects the mind and the brain, but will also require nothing short of a revision to traditional accounts of language development.

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