Advanced Review

Bilingualism

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The cognitive and linguistic processes involved in the acquisition and use of two languages are systematically different from those processes engaged in monolingual language use, leading to detectable changes in language and cognitive outcomes for bilinguals. The present article describes these differences and offers speculation on possible mechanisms. Measures of linguistic proficiency and processing are often poorer in bilinguals than in monolinguals: bilingual children have a smaller vocabulary in each language than comparable monolingual children in that language and bilingual adults take longer to retrieve specific words than monolinguals. In contrast, measures of nonverbal executive control, including the ability to selectively attend to relevant information, inhibit distraction, and shift between tasks is generally better in bilinguals than in monolinguals. These two types of outcomes are illustrated and explained through behavioral and neuroimaging evidence. The implications of these effects of bilingualism on cognitive and linguistic processing are considered in terms of both their clinical and theoretical consequences. © 2010 John Wiley & Sons, Ltd. *WIREs Cogn Sci*

The vast majority of research conducted in cognitive science is carried out in English, using research participants who speak English, with no regard for the possibility that English is not their only language. Yet, there is evidence that experience affects cognitive function and brain structure—architects have enhanced visuo-spatial skills,[1] London taxi drivers have enlarged hippocampi,[2] and jugglers have growth in brain areas responsible for complex visual motion.[3] Increasingly, it appears that bilingualism is another such experience with the potential to modify cognitive performance and brain structure. One study showed greater brain density in the left inferior parietal cortex for bilinguals than for monolinguals,[4] with more pronounced differences in early bilinguals and those with greater second-language proficiency. The prevalence of bilinguals in the world is considerably greater than that of architects, London taxi drivers, or jugglers, so evidence for systematic effects on cognition would be dramatic. According to Grosjean,[5] bilingual and multi-language use is not only common but probably characterizes a majority of the population. Romaine[6] notes that there are roughly 6700 languages and 200 nation-states in the world, leaving much room for linguistic multiplicity within communities. Nonetheless, she points out that over 70% of the world's languages are found in only about 20 nation-states, creating concentrations of bilingual societies amid largely monolingual ones. On an individual level, the prevalence of bilingualism is equally impressive: Crystal[7] estimates that two-thirds of the world's children grow up in bilingual environments. And yet, bilingualism is not easy to define at either the societal or individual level. Socially, groups maintain languages for different reasons, not all of them geographic. Edwards[8] describes several relevant dimensions of bilingualism for both individuals and societies and explains the difficulty of making categorical classifications. However, if simply knowing or using two languages affects cognitive systems, then the political and sociological dimensions of bilingualism fade into the background. For the brain sciences, if bilingualism is an experience that affects cognitive performance and brain structure, then our standard models of cognitive development, cognitive processing, and cognitive aging may need to be revised for those individuals whose cognitive systems have been built around the knowledge and use of two languages.

The present review examines the behavioral consequences of bilingualism on cognitive and linguistic performance across the lifespan. In general, bilinguals have been shown to have enhanced functioning of the executive control system but poorer performance in tasks based on rapid lexical retrieval and processing than monolinguals. These

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effects that follow from the experience of bilingualism emerge from an interaction of factors emanating from constructs in cognitive psychology, social experience, and linguistic theory. Individuals function in a social context that constrains language selection and recruits cognitive processes to meet the communicative goals. Thus, bilingual language use stands at the interface of the individual, the social context, and the communicative interaction. Put this way, it is not surprising that access to two languages and the constant possibility that either will be required has enduring effects on cognitive and brain systems.

HISTORY OF RESEARCH IN BILINGUALISM

The idea that bilingualism can significantly alter cognitive functioning is not new; what is new is that this effect might be positive! Pronouncements on the devastating effect of bilingualism on intellectual performance became salient in the late 19th century as immigration from Europe to North America increased. Gould[9] describes a chilling scene in which immigrants to the United States who landed at Ellis Island were given IQ tests in English; unsurprisingly, they performed poorly and were declared mentally unfit and inferior, a condemnation that was generalized to all individuals with whom they shared racial, ethnic, or national origins. This attitude persisted well into the 20th century. Studies comparing IQ scores on the Stanford-Binet test of intelligence invariably reported IQ deficits for bilinguals or children who were exposed to non-English languages in the home.[10–12] The verbal basis of this test, which was always administered in English, never entered the discussion.

The watershed change occurred when Peal and Lambert[13] published a study overturning previous beliefs about the harmful consequences of bilingualism. Their study was the first to pay careful attention to research design and methodology, comparing groups of children in the two language designations who were at least matched on important variables, a detail somehow overlooked in the previous research. The children, who were English–French bilingual francophone children or English monolingual children living in Montreal, were compared on a large number of tests. Peal and Lambert's hypothesis was that monolinguals and bilinguals would score similarly on measures of nonverbal intelligence but that monolinguals would score *higher* than bilinguals on tests of verbal intelligence. It would have appeared irrationally bold to propose that bilinguals would outperform monolinguals since previous research had always recorded bilingual deficits on verbal tests and intelligence measures. Contrary to their predictions, the bilingual children performed better on virtually *all* the tests, including nonverbal intelligence. In particular, the bilingual advantage was found for tests involving mental reorganization. Peal and Lambert's conclusion was that the bilingual advantage was in mental flexibility and that bilinguals profited from a 'language asset', in contrast to the 'language handicap' bemoaned by earlier researchers.

Research into the consequences of bilingualism began to proliferate soon after the Peal and Lambert study. The early studies were conservative in that they focused on linguistic outcomes, a reasonable assumption for the type of effect expected to emerge from a linguistic experience, and developmental, in that they focused on children. Thus, a series of studies in the 1970s reported enhanced metalinguistic awareness in bilingual children.[14–17] Clark[18] speculated that 'learning two languages at once ... might heighten one's awareness of specific linguistic devices in both' (p. 36). Tunmer and Myhill[19] went further and postulated metalinguistic awareness as the mechanism by which bilingualism exerts its influence on any aspect of cognition. The age of positive effects of bilingualism had begun.

From that beginning, research in bilingualism has become more balanced in that it has been open to both positive and negative outcomes, more broad in that it has explored effects across a wide variety of domains, and more methodologically diverse in that it has incorporated evidence from behavioral, neuroimaging, and modeling traditions. Not surprisingly, therefore, the results are also more complex.

IMPACT ON LINGUISTIC COMPETENCE AND PROCESSING

The intuitive response to the question of the nature of impact of bilingualism on linguistic processing is that it would be a benefit—people who regularly use two languages should be in some real sense more linguistically sophisticated. This reasoning was behind Peal and Lambert's[13] prediction that bilingual children would at least be more advanced than monolingual children on verbal tasks. The data, however, show otherwise. In both overall assessments of linguistic knowledge and psycholinguistic measures of linguistic processing, bilinguals often indicate deficits relative to comparable monolinguals.

Development of Linguistic Competence in Bilingual Children

Bilingual children acquire language in a path largely similar to that followed by monolingual children[20]: the basic landmarks of language acquisition are intact. Nonetheless, the outcomes of language acquisition are somewhat different for monolingual and bilingual children. The most salient feature of language use by bilingual children is in their mixed use of languages, even in monolingual contexts when only one of the languages is appropriate. Although some early interpretations took this as evidence for confusion, or a single representational system that included both languages,[21] later accounts demonstrated that this behavior is not evidence of confusion but of children's strategic use of limited resources for communication.[22,23]

Much of the language switching that bilingual children engage in is the insertion of words from the nontarget language into a conversation being carried out in the other language. Following the interpretation that language mixing is a strategic solution to a problem, this switching behavior can be seen to signal a persistent deficit in the language resources of young bilingual children. Across numerous studies evaluating children with various backgrounds, bilingual children demonstrate a smaller vocabulary in each language than do comparable monolingual speakers of that language.[24] In evidence accumulated in my lab from over 1700 children, shown in Figure 1, standardized scores on an English receptive vocabulary test, the Peabody Picture Vocabulary Test III[25] are lower for bilingual children who speak English and another language than monolingual English speakers at every age between 3 and 10 years old[26] (Figure 1). There is no reason to believe that bilingual children have a smaller overall vocabulary—in fact, their combined vocabulary may be larger than that of monolinguals—or that they have poorer communicative ability than monolinguals, only that their vocabulary is distributed across two languages. This configuration will inevitably change the shape of communication for bilingual children as they select from two resources to supplement and augment their linguistic repertoire.

The most important linguistic achievement for young children, however, is the acquisition of literacy. Unique features of bilingual children's spoken language may or may not affect their progress in learning to read. Two predictors of the acquisition of literacy in young children are vocabulary size and phonological awareness.[27] As described above, bilingual children enter this process with a smaller vocabulary than their monolingual peers, but evidence for differences in levels of phonological awareness is more mixed.[28–30] In general, differences between monolingual and bilingual children in phonological awareness are small and tend to disappear once instruction has begun in alphabetic literacy.[31] The path of literacy acquisition, especially for bilingual children, however, depends as well on a third factor, namely, the type of writing system in which the language is written. The main distinction is between systems based on phonemic units (alphabetic system, like English) or morphemic units (character system, like Chinese). Each of these systems both requires and fosters the acquisition of somewhat different phonological concepts, with better development of syllable awareness among children learning to read in Chinese and better phonemic awareness among children learning to read in English,[32] but substantial transfer across the two languages for bilingual children

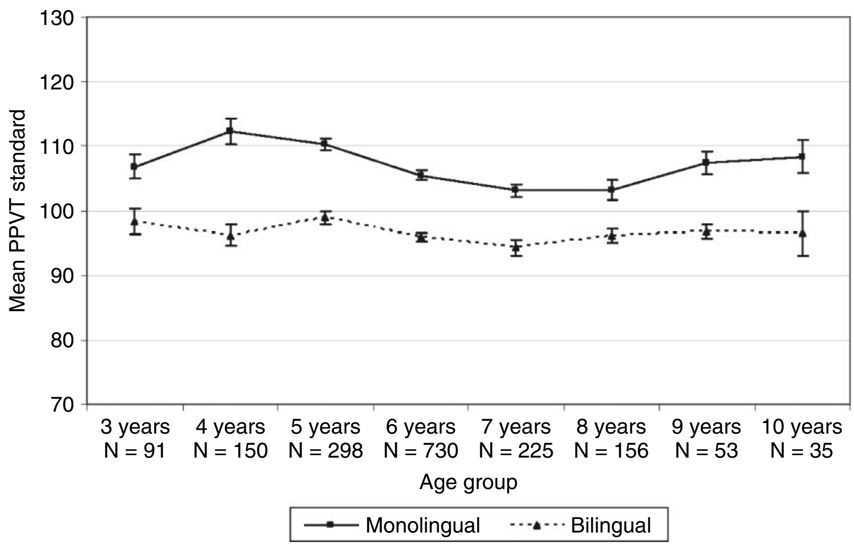

FIGURE 1 | Mean standard score ($M = 100$, SD = 15) on English Peabody Picture Vocabulary Test by age and language group. Language group differences are significant at each age with no interaction between age group and language group. Sample includes 1738 children, with 722 monolinguals and 966 bilinguals who represent a large range of non-English languages as the other language. (From Bialystok et al. Ref 26).

once they have established the skill in one of their languages.[33,34]

In contrast to the pattern found for the development of phonological awareness, learning to read, defined by the ability to decode new words, must be learned individually for each writing system. In a study comparing groups of children in first grade who were learning to read, there was substantial correlation across languages in the ability of bilingual children to read in English and Spanish ($r = 0.72$) and English and Hebrew ($r = 0.57$), where both languages are based on sound-symbol correspondences, but no relation between successful decoding in English and in Chinese ($r = -0.09$), languages written in different systems.[35] This absence of a relation between reading ability in English and in Chinese was replicated in another study comparing English monolingual and Chinese–English bilingual children.[33]

The persistent deficit in vocabulary size in each language does not appear to impede progress in learning to read. Even with significant differences in vocabulary size, Chinese–English bilinguals performed as well as English monolinguals on a test of decoding written English; when vocabulary scores were partialled out of the analysis, the decoding scores of the Chinese–English bilingual children were significantly better than those of the English monolingual children.[35] Thus, the initial differences in assessments of language proficiency of bilingual children do not lead to impairments in the crucial linguistic abilities developing in the early school years.

Bilingual Language Ability in Adulthood

In adulthood, differences in language competence between monolinguals and bilinguals shift from representational aspects of how much language is known, as in the vocabulary differences in childhood, to processing differences in how efficiently language is accessed. These differences in accessing, retrieving, and remembering verbal material, usually tested at the level of individual words, are found equally in the bilingual's two languages (review in Ref 36). For example, bilinguals experience more tip-of-the tongue states than monolinguals,[37] take longer to name pictures,[38] make more naming errors than monolinguals,[39] and produce fewer responses in verbal fluency tests.[40,41]

These patterns reflect more effortful language processing for bilinguals than for comparable monolinguals and not simply differences in linguistic resources or vocabulary, as was the case for children. Bilinguals, for example, demonstrate poorer word identification through noise,[42] indicating less automatic access or retrieval to words. Similarly, the deficits in a picture naming task relative to monolinguals are observed even when bilinguals are performing the task in their first and dominant language.[43] More dramatically, a study by Linck et al.[44] reported that American college students spending time in Spain on a study abroad immersion program showed deficits in their performance on a verbal fluency test in English while they were in Spain; performance returned to typical levels shortly after their return home. Thus, aspects of language processing associated with rapid automatic retrieval of words are broadly affected by bilingualism, with effects seen in both languages including the dominant first language.

Basis of Linguistic Differences Between Monolinguals and Bilinguals

In research with both children and adults, bilinguals frequently perform more poorly than monolinguals on linguistic tasks. There are two types of deficits involved in these comparisons. The first is a difference in the linguistic representations developed during language acquisition and sustained through adulthood. Specifically, the representations created by bilinguals for each language are less rich or less accessible than are those for monolingual speakers of that language. In children, this is clearly manifest as a smaller vocabulary in each language, but in adults the evidence is less direct. The second is a difference in the ease or fluency with which linguistic items can be retrieved. Although poorer performance on such tasks as picture naming may partly reflect poorer vocabulary knowledge, that explanation alone is insufficient. Instead, it seems that the actual process of accessing specific linguistic items is more effortful for bilinguals, resulting in longer response times (RTs) and more errors.

It is straightforward to attribute a difference in vocabulary size to a difference in the representation that learners construct for each of their languages. Simply put, a second language for adults, or two shared languages for young children have less complete representations than the corresponding systems for native speakers or monolingual children. But why would accessing linguistic items be more effortful? An explanation may come from a feature of bilingual language processing.

It is now uncontroversial that both languages of a bilingual are jointly activated during all linguistic processing, even in strongly monolingual contexts in which the nontarget language would be inappropriate.[45–50] Moreover, neuroimaging studies have provided evidence that the neuronal networks underlying the use of both languages are the same (review in Ref 51, see also Refs 52–54). Therefore, language use in bilinguals presents a problem that is not an issue for monolinguals: there is functional activation of both languages that use the same brain networks even though fluent performance requires selecting from only one set of linguistic structures. Thus, a powerful conflict in both functional and neural systems must be resolved to confine performance to the target language. A widely accepted explanation for this problem was first posed by Green[55] in his description of the 'inhibitory control model'. He argued that bilinguals use general attentional resources that are part of the executive control system to inhibit attending to the competing language and allow performance to proceed from the relevant target language. This attention and inhibition is the additional step that adds processing cost, time, and the potential for errors, all of which have been observed in bilingual language production.

A different view focuses more on the representation than on the processing component. According to Gollan and colleagues, bilinguals naturally use each language less frequently than monolinguals, so the crucial networks that underlie language performance by connecting words with concepts, for example, are simply less practiced and therefore less entrenched for bilinguals in each language than they are for monolinguals in their only language.[38,56] This explanation, called the 'weaker links hypothesis', provides a logical account of the evidence showing poorer or less automatic retrieval of words by bilinguals. It can also account for developmental differences in children's vocabulary in that children have less experience in each language and so take longer to build the representational system that provides the foundation for their linguistic knowledge. In this case, a processing account that is based on the effortful attention to one of two jointly activated languages is unnecessary.

An important difference between the weaker links hypothesis and the inhibitory control model is in their implications for nonverbal cognitive processing. The weaker links hypothesis is specific to language and is based on the assumption of dedicated processing networks for language. Thus, the frequency effects that underlie language performance have no bearing on nonlinguistic cognitive processing. In contrast, the inhibitory control model directly involves domain-general cognitive mechanisms in the real-time production of language. This feature opens the possibility that bilingualism could systematically affect cognitive systems simply through language use experiences. If the general executive control system is used to solve competition between jointly activated linguistic systems, then there should be evidence for bilingual differences in these domain-general functions. Moreover, if the changes in the executive control system are consistent with the prediction that follows from practice effects, namely, enhanced ability in bilinguals, then the pattern would be consistent with an interpretation in which the competition between jointly activated languages or shared processing networks was responsible for both the costs observed in language processing and any benefits that might be observed in nonverbal executive control.

IMPACT ON NONVERBAL EXECUTIVE CONTROL

In the early research reporting metalinguistic advantages for bilingual children, the greatest effects were found in tasks that were based on conflict between attending to the linguistic form, the source of the correct response, and ignoring the salient but irrelevant meaning. Since the main purpose of language is to communicate, it is unnatural and effortful to ignore meaning, as demonstrated by the classic Stroop task. In that task, color words are printed in various ink colors and participants are required to ignore the word and simply name the color of the ink, a surprisingly difficult feat. The extra time required to respond compared with either reading the same color words in blank ink or naming neutral patches of color is the Stroop effect, and is a reliable index of executive control. Similarly, in a task in which children were trained to judge whether the grammatical form of a sentence was correct and to ignore the meaning, bilingual children were more able than monolinguals to report that sentences like 'Apples grow on noses' are said the right way, even if they are silly.[57] The difficulty is in controlling attention to the relevant feature of the stimulus when there is a strongly distracting cue, in both cases from meaning. This configuration in which the correct response conflicts with a more salient or usual alternative is the signature for events that lead to a bilingual processing advantage.

Subsequent explanations have broadened the scope to include executive processes beyond inhibition, such as task switching.[58–60] Nonetheless, the main outcome of this situation is that the aspects of the executive function, especially the processes involved in selective attention and inhibition, are massively practiced in the course of ordinary bilingual language use. The consequence might be a more robust system, more focused on relevant cues and immune from distraction across a range of functions. This would amount to a bilingual advantage in executive control.

Executive Control in Bilingual Children

The executive control system is the last cognitive system to develop, and the responsible cortical areas in the frontal cortex are the last part of the brain to be myelinated.[61] Nonetheless, early evidence for children's emerging executive control can be traced to the first year of life when infants learn to disengage from a routine in order to execute a more appropriate action.[62] In the first 2 years, children learn to avoid the classic A-not-B error that was famously documented by Piaget, in which infants will persist in searching for a toy in the same place that they have previously seen it hidden in spite of watching the experimenter hide it in a new place. The visual knowledge of the toy's current position is insufficient to change the search routine that had been successful in the past. Children are finally successful in directing their search to the correct location at about 18-months old, an achievement that Piaget interpreted as evidence for the concept of object permanence. In more current theoretical terms, however, their success is evidence that they have established some control of the executive function; they are able to over-ride a habitual response and execute a nonsalient but correct alternative. In a dramatic demonstration, Kovács and Mehler[63] reported a study in which 7-month-old infants who were raised in monolingual homes in which only Italian was spoken or in bilingual homes in which Italian and another language were used performed differently in an executive control task that had some commonality with the A-not-B task. The bilingual babies learned to redirect their gaze to the opposite side of a screen to receive a visual reward, but the monolingual babies persisted in looking to the previously rewarded side even when the reward no longer appeared there. Thus, even this primitive origin of executive control may be influenced by a bilingual environment long before children become verbal.

Children's development of executive control increases dramatically over the next 4 or 5 years (e.g., Ref 64), and evidence for the effect of bilingualism on this development becomes more clear. The precise timetable for this development and the explanations for how it progresses differ but the evidence is consistent that children become more able to behave intentionally, especially when there is conflicting or misleading information. If bilingualism enhances children's control over attention in conflict situations, then bilingual children should master these executive control tasks more efficiently or more precociously than comparable monolingual children.

Research with children between approximately 4- and 6-year-old has supported this prediction. Bilingual children outperform monolinguals on perceptual conflict tasks[65–67] and on theory of mind tasks,[68,69] all of which involve the need to avoid distraction by misleading cues. Typically, however, bilinguals are not better than monolinguals on tasks that require the inhibition or withholding of a response when there is no need to choose between competing response options. For example, there is no difference between young monolingual and bilingual children in their ability to postpone opening an enticing gift that they are instructed not to touch[67] or to refrain from executing the response primed by the direction of an arrow and over-ride it with an alternative response.[70] Thus, the bilingual advantage is specific to the need to selectively attend to competing options. This choice is parallel to the need to selectively attend to competing language systems, and the benefit of this attentional control is seen in children's developing control across cognitive domains, including nonverbal ones.

Adult Cognition and Cognitive Aging

Just as the executive function is the last cognitive system to fully develop in childhood, it is the first casualty of healthy cognitive aging.[71] Lifelong bilinguals, however, appear to be protected from the decline in executive control in that, although inevitable, the decline is delayed and perhaps modulated by this experience.

Parallel to the research with children, bilingual young adults are more able than comparable monolinguals to resist the interference in such tasks as the Simon task,[72] flanker task,[58] and Stroop task.[73] Older bilingual adults benefit at least as much as their younger counterparts on these tasks[73] and sometimes more.[72,74] It is not clear from these studies what conditions enhance these effects in older age to increase the gap between monolingual and bilingual performance.

To illustrate these patterns, consider performance on the Simon task from a study by Bialystok et al.[72] In this task, a colored square is presented on the computer screen and participants are instructed to press the right key if a green square appears and the left key if a red square is shown. In the control condition, the red and green squares are presented in the center of the display, so RT is a simple index of speed. In a study of middle-aged and older adults between the ages 30 and 80 years old, monolinguals and bilinguals at each age group performed equivalently, as shown in Figure 2a. In the Simon conditions, the square is presented on one of the two sides of the display. When the presentation position and the correct response key correspond (a green square presented on the right), then the trial is congruent; when they conflict, the

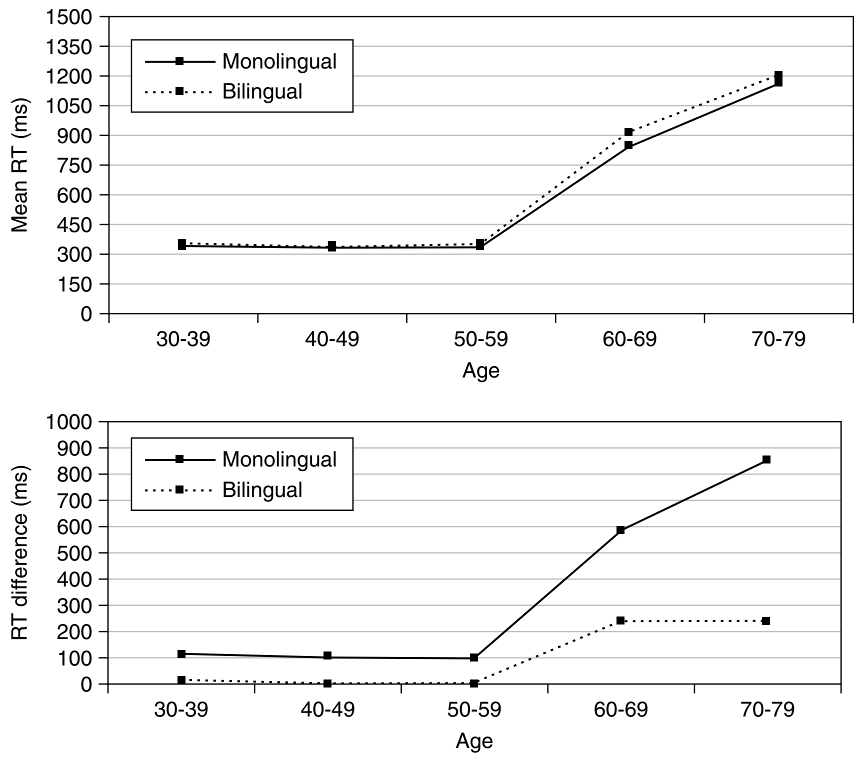

FIGURE 2 | Mean reaction time (RT) by decade for monolinguals and bilinguals. (a) Mean RT for control condition. (b) Mean RT cost as the difference between congruent and incongruent trials (Simon effect). (From Bialystok et al. Ref 72).

trial is incongruent. The Simon effect is the reliable increase in RT necessary to resolve the conflict on the incongruent trials. This cost, plotted as the difference in RT between the two types of trials, was reliably smaller for bilinguals than for monolinguals at all ages, as shown in Figure 2b. These data illustrate the influence of bilingualism on improving control over competing cues, in this case, the position of the stimulus and the position of the correct response key, and the persistence and enhancement of this effect across the lifespan.

Interactions of Language Proficiency and Executive Control

The profile of effects that follow from bilingualism shows two opposing consequences—costs for aspects of linguistic processing and benefits for aspects of nonverbal executive control. These effects were derived from controlled experiments in which the target processes were isolated and compared across groups. Life, however, tends to be more complex than laboratory research, and most of the cognitive activities in which we engage recruit the full repertoire of our cognitive abilities. Linguistic tasks often require executive control, and executive tasks are often verbal. How are these opposing consequences integrated in these situations?

Two examples show that the combination of linguistic processing demands and executive control involvement changes the relation between overall performance for monolinguals and bilinguals. In the first example, a release from proactive inhibition (PI) task was given to children and adults. In this task, participants are required to remember lists of words in which the first three lists contain words from the same semantic category, for example, animals, and the fourth list represents a new category. The usual finding is that memory recall decreases across the lists based on the same category and is restored when the final list using a different category is presented. This PI effect, which has been found with both children (e.g., Refs 75 and 76) and adults (e.g., Ref 77), indicates the inability to selectively attend to the new words and monitor their source, both functions of executive control. In studies comparing both children and adults on a PI task, bilinguals were more able than monolinguals to resist intrusions from an incorrect list.[78]

Second, as discussed above, bilinguals typically produce fewer words than monolinguals on verbal fluency tasks. These are standardized neuropsychological instruments that are used to gauge performance in language processing and to detect pathology related to specific brain areas. There are two components to these tasks. In category fluency, participants name as many words as possible in a fixed time that are members of a specified category; in letter fluency, participants name as many words as possible that begin with a specified letter, but excluding proper names, numbers, and morphological variants of words already produced. According to one standard testing manual, the category fluency test assesses language proficiency and performance and the letter fluency test assesses language proficiency plus executive control.[79] Since bilinguals typically demonstrate language processing deficiencies and smaller vocabularies than monolinguals, it is not surprising that they produce fewer words than monolinguals on these tests. But what if language proficiency were controlled in that bilinguals were selected to be matched with monolinguals on vocabulary size? In a study comparing monolinguals, bilinguals matched on cognitive variables but not on language proficiency (low-proficiency bilinguals), and bilinguals matched on both cognitive variables and language proficiency with monolinguals (high-proficiency bilinguals), the high-proficiency bilinguals performed as well as monolinguals on the category fluency test but better than monolinguals on the letter fluency test.[80] Performance on a set of nonverbal background measures was identical for participants in all three groups. However, once vocabulary levels had been controlled, the bilingual advantage in executive control allowed the high-proficiency bilinguals to outperform the monolinguals on a verbal task that had difficult demands for monitoring, inhibiting, and switching.

MECHANISM FOR BILINGUAL INFLUENCES ON LANGUAGE AND COGNITIVE PROCESSING

The proposed mechanism for the bilingual effects on performance that has been implicit in the discussion to this point is that the joint activation of the bilingual's two languages creates a conflict that is resolved by recruiting the domain-general executive system. Support for this explanation requires evidence that the frontal executive system is more actively involved in language production for bilinguals than it is for monolinguals, particularly where selection from a set of competitors is required. Monolinguals also make choices among competing lexical options, such as synonyms and neighborhood competitors, slowing their time to produce words[81] but bilinguals additionally need to choose the option from the target language. Evidence that frontal lobe regions are involved in selection for bilinguals to a greater extent than monolinguals has been produced in a number of studies. There is great variability in the brain regions identified across these studies, some of it attributable to differences in the tasks used or the proficiency of the bilinguals, yet several commonalities have emerged. The primary areas found to be involved uniquely in bilingual language processing, most notably when bilinguals are switching between languages or selecting a response language, are the caudate nucleus,[82,83] the prefrontal cortex,[50,84] the anterior cingulate cortex,[85] and the supramarginal gyrus.[50,85] All these structures are central to the executive function system.[86,87] Thus, the executive systems known to be recruited for performing in nonverbal executive control tasks, particularly those involving conflict, are also involved in language selection.

The executive function system is a collection of various cognitive processes distributed over many brain regions, although concentrated in the frontal lobes. At this level, therefore, the claim for executive function involvement in bilingual language processing is not very precise. Some attempts have been made, however, to provide more specific proposals for how the components of these networks contribute to specific aspects of language processing. One ambitious attempt to specify these relations was proposed by Abutalebi and Green.[88] They acknowledge that no single region is responsible for these complex choices in language production and that managing and resolving conflict might involve different neural mechanisms, yet propose a model that relates the mechanisms used to control language selection and the mechanisms used to control other aspects of behavior through a common network. The key mechanism in this network is inhibition. An elegant demonstration that there is inhibition of the unwanted language system when a bilingual is using the target system is offered by Philipp and Koch.[89] Using a naming task in which the target language is systematically manipulated, they are able to rule out competing interpretations in support of the conclusion that there is inhibition of the entire linguistic system that is not required on a particular trial.

A different way of thinking about inhibition is in terms of lateral inhibition between competing options in a connectionist network. Using these assumptions, Dijkstra and colleagues[90] have developed a model called the Bilingual Interactive Activation (BIA) model that simulates word production under conditions of inhibition from neighborhood competition. In this model, there are no assumptions about language systems or domain-general executive processes, yet the model produces a reasonably accurate demonstration of bilingual word production.

A more complete proposal for the role of inhibition has been offered by Rodriguez-Fornells et al.[91] Their suggestion is that there are two interrelated inhibitory mechanisms that are involved in bilingual language production, each responsible for a different aspect of the inherent conflict resolution. The first is a general top-down mechanism residing in the prefrontal cortex that controls attention to the required language scheme, possibly by inhibiting the nontarget system (cf. Philipp and Koch[89]), and the second is a local bottom-up mechanism that regulates nontarget activation during competition (cf. Dijkstra[92]). The distinction in this model addresses an important question that has rarely been considered: is the selection at the level of the whole language system that is needed for this situation or is it at the level of individual competition between items throughout the production of a target language? The solution offered by Philipp and Koch[89] was that inhibition is applied to the whole language, but their study did not examine linguistic representations beyond the lexicon. The model proposed by Rodriguez-Fornells et al.[91] accommodates both processes.

The Rodriguez-Fornells et al.[91] explanation may help to understand a new puzzle that has arisen in this research. The beneficial outcomes of bilingualism on nonverbal executive control have been assumed to evolve from extensive practice in using two languages, an activity that necessarily recruits domain-general executive functions. Thus, the networks responsible for conflict resolution, inhibition, and flexibility are strengthened over time and fortified for all uses. Recently, however, Kovács and Mehler[63] have reported advantages in executive control in bilingual 7-month-old infants—clearly a group who have had no experience in producing language in the context of competing interference from the other language! Although the reliability of this result must still be confirmed, the intriguing possibility is that the two systems proposed by Rodriguez-Fornells et al. appear at different times. In this case, the top-down system is responsible only for selecting between similar representational systems to focus attention on the current problem. This type of control is an early development that can be used in response to any system for which overlapping or similar representations have been developed. Changes in the bottom-up systems, and possibly systems more specific to linguistic processing, would then develop later. Further research is needed to explore these possibilities.

CLINICAL IMPLICATIONS OF BILINGUALISM

If an experience affects the normal progression of cognitive ability through the lifespan, then there is the real possibility that the experience is also implicated in cognitive processing under conditions that are outside the typical trajectory of performance. There is a reasonable literature on how brain injury may be expressed in the linguistic behavior of individuals who are bilingual[93] but the question here is more subtle: Do functional impairments in development or aging express themselves differently in bilingual people than they do in the monolingual population in which most of neuropsychological tests were standardized?

The two areas of development most directly affected by bilingualism are language proficiency in terms of fluent use of the native language, and executive control in terms of selective attention and inhibition. Each of these systems is associated with a prevalent learning disability in childhood. Children who fail to develop typical levels of linguistic competence in the context of normal intelligence are considered to suffer from specific language impairment (SLI), a selective deficit in linguistic processing. Children who fail to develop typical control over attention and inhibition are considered to suffer from attention deficit/hyperactivity disorder (ADHD). Since bilingualism tends to compromise linguistic competence but enhance attentional control, it may mediate each of these conditions in a different way.

There is almost no literature on these questions, so the answers are speculative. However, in an extensive review of the research examining the nature of language deficits in monolingual children with SLI and bilingual children and second-language learners with this condition, Paradis[94] demonstrates important qualitative differences in all cases. In other words, the expression of SLI in children with more than one language is different from its presentation in monolingual children. At this point, it is impossible to compare the severity or the prevalence of the disability across these populations, but the detailed analyses of the linguistic differences reported by Paradis point to the need to develop diagnostic and perhaps remedial procedures that are appropriate for bilingual children.

Information is even more sparse for the possibility that bilingualism might influence the detection or course of ADHD. The prediction is that the attentional control advantage conferred by bilingualism will mitigate the severity of attentional disorders in bilingual children. This hypothesis is currently being investigated.

Interpretations of standard clinical tests may well need to be modified to accurately reflect the ability of bilingual individuals. As described above, the verbal fluency test is generally performed differently by bilinguals than by monolinguals so standardized scores may be inaccurate for bilingual populations. Similarly, a neuropsychological test called the trail-making task is commonly used to detect disorders in executive control, presumably related to damage in the frontal cortex. The task has two conditions: In Trails A, a sheet of paper shows a series of randomly positioned circles each containing a number. The task is to connect the numbers in consecutive order without lifting the pen. In Trails B, the circles contain a number or a letter, and the task is to proceed in sequence but alternating between numbers and letters, i.e., 1—A —2—B, and so on. The task, especially Trails B, requires planning, working memory, and inhibition, so reflects overall executive functioning. In a series of studies with typically developing 8-year-olds, however, bilingual children performed the trail-making task more efficiently than monolingual children, indicating better executive control.[65] Therefore, this standard test may not be a reliable tool for diagnosing specific cognitive or brain problems in bilingual children.

Finally, the most overwhelming deviation from normal cognitive aging is the impairment experienced in dementia, especially Alzheimer's disease. The disease devastates a large number of cognitive functions, including memory and executive control. A growing body of research, however, has demonstrated the protective benefits from stimulating cognitive and physical activities throughout life in delaying onset of the symptoms of the disease in spite of the presence of brain pathology. These protective activities, called cognitive reserve, enable afflicted individuals to continue functioning at a higher level than would be typical for their level of disease.[95–97] Does bilingualism contribute to cognitive reserve? Comparing the onset of symptoms in groups of monolingual and bilingual patients diagnosed with dementia, the majority being Alzheimer's disease, bilinguals showed symptoms 4 years later than monolinguals, with all other measures being equivalent.[98] This is an enormous difference and suggests that bilingualism, like other stimulating mental activities, allows the brain to continue to function in spite of growing pathology. Possibilities such as these move us a great distance from the intellectual condemnation routinely attributed to bilingualism in the 20th century. With more detailed research, the profile of costs and benefits of bilingualism will ultimately reveal as well new insights about the human mind.

CONCLUSION

It not surprising that the experiences we have influence the content of our minds; it is more surprising that experiences can also influence their structure and quality. Yet increasingly, evidence for brain plasticity is opening the possibility of changes in brain structure and function throughout the lifespan. It has always been self-evident that bilingualism conferred certain social and communicative advantages because of the increased possibility for interacting with groups of people, for an enriched understanding of different nations, cultures, and rituals, and perhaps for enhanced opportunities in the workplace. Yet for a long time it was believed that these benefits came with a significant cost, especially for children. The received wisdom was that children raised with two languages grew up 'confused' and 'retarded'. Those ideas have been thoroughly discredited with the more recent research on bilingualism and its impact on language and cognition. The most salient finding is the consistent advantage found for bilinguals in the cognitive processes based on the frontal lobes, namely, the executive function system responsible for controlling attention, inhibiting distraction, and shifting set. Systematic differences in these functions between monolinguals and bilinguals who are matched on all relevant dimensions have been reported for infants as young as 7 months old and adults as old as 90 years, even after being diagnosed with dementia.

There is always an uncertainty in research of this type regarding the underlying cause. Could it be that people who were more intelligent, or had more skilled executive control became bilingual, leaving their less talented peers as monolingual? This seems extremely unlikely. In the research showing better spatial skills for architects[1] or visual attention for jugglers,[3] it is plausible to consider that these activities were selected by individuals who were already skilled in these ways, making the group difference not surprising. This is not the case with bilinguals. The majority of bilinguals in our studies were not selected by choice but created by circumstance. The children were born into homes where the parents spoke a different language than the one being used at school, and they all learned both languages. The adults arrived in a new country at some point in their lives, perhaps as children, and incorporated the new language into their first, making space for both. These are indeed challenges, but they are not challenges at which people fail. Although some have claimed that the results described here for bilinguals are confounded with social class and ethnicity,[99] there is simply no basis for those claims.[100] Monolingual children learning one language all learn that language even though they learn it to different levels of proficiency—only some children will grow up to become poets. It is the level of basic language competence that is mastered by all children that is the criterion for bilingualism. There is no self-selection and there is no *a priori* level of cognitive skill. These bilinguals learn two languages because they must. The incredible outcome is that the experience of learning and using two languages has enduring benefits for a crucial cognitive system.

Descriptions of the changes in language and cognitive abilities that are traced to bilingualism are becoming more precise, but an explanation for exactly how and why those changes take place is still to be determined. In the first study that promised a positive outcome for bilinguals, Peal and Lambert[13] noted: 'Intellectually [the bilingual child's] experience with two language systems seems to have left him with a mental flexibility, a superiority in concept formation, a more diversified set of mental abilities' (p. 20). They were remarkably correct. Cognitive flexibility is part of executive control, and 40 years after Peal and Lambert's observation, it is to the executive control system that the neuroimaging evidence has pointed. Bilingualism affects the most fundamental aspects of cognitive and linguistic processing. It might be time to revisit our standard models of the mind and brain that were built out of research with monolingual speakers of English and consider how to make them more inclusive.

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