

Language experience changes language and cognitive ability

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Abstract: The sustained use of two languages by bilinguals has been shown to induce broad changes in language and cognitive abilities across the lifespan. The largest changes are seen as advantages in executive control, a set of processes responsible for controlled attention, inhibition, and shifting. Moreover, there is evidence that these executive control advantages mitigate cognitive decline in older age and contribute to cognitive reserve. In this paper, we examine some of the evidence for these findings and explain their relation to bilingual language use. These effects are considered in terms of their implications for our understanding of cognitive and brain plasticity. Some implications for social policy are discussed.

Keywords: Aging · Attention · Bilingualism · Cognitive ability · Cognitive and brain plasticity · Executive control

Spracherfahrung verändert sprachliche und kognitive Fähigkeiten

Zusammenfassung: Der kontinuierliche Gebrauch beider Sprachen bilingualer Menschen hat sich als Anstoß für weitreichende Veränderungen der sprachlichen und kognitiven Fähigkeiten über die Lebenszeit erwiesen. Als bedeutendste Veränderungen werden Vorteile bei der exekutiven Kontrolle gesehen, also eines Systems von Prozessen, das verantwortlich ist für die Kontrolle der Aufmerksamkeit, das Setzen von Zielen und Prioritäten oder das Initiieren und Sequenzieren von Sprachhandlungen. Es gibt starke Hinweise darauf, dass die Vorteile der exekutiven Kontrolle auch eine Abschwächung des Abbaus kognitiver Fähigkeiten im Alter zur Folge haben und zur Ausbildung der Fähigkeit des Gehirns beitragen, Schädigungen zu überwinden kann. In unserem Beitrag setzen wir uns mit Forschungsergebnissen zu diesen Problemen auseinander und erläutern die Zusammenhänge, die sich mit bilingualem Sprachgebrauch zeigen. Die entsprechenden Effekte werden unter dem Gesichtspunkt betrachtet, welche Implikationen sich für das Verstehen kognitiver und neuronaler Plastizität ergeben. Ferner werden gesellschaftspolitische Implikationen angesprochen.

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1 Introduction

In much of the research in psychology, the experimental design is based on comparisons between two groups for their ability to perform a task or solve a problem. Thus, language acquisition can be compared for girls and boys, decision-making ability can be compared for 12-year-olds and 8-year-olds, and episodic memory recall can be compared for participants who receive lists of words with or without accompanying pictures. In all these cases, the individuals in each group are assumed to be equally good and interchangeable representatives of that category. This is a necessary simplification because the purpose of most psychological research is to uncover patterns that describe the “big questions”: How do children learn language? How do we make decisions? What kind of information can we retrieve from memory? But the simplification comes at a cost: We lose the ability to understand the myriad factors that make each of us unique and with it, the ability to understand normal variation in the system.

One important way in which psychology is moving away from these models is by examining how intense experience modifies cognitive performance and brain structure. Systematic effects of experience have been found both in changes to brain structure and function and in behavioral performance. Some of the early research showing effects of experience on the brain demonstrated that the motor cortex controlling the four fingers on the left hand was enlarged in professional string players compared to non-string players (Ebert et al. 1995). These are the fingers that control the musical pitch so sensitivity is crucial. Similarly, London taxi drivers who must pass strict examinations demonstrating their detailed knowledge of the streets of London have enlargement of the region of the hippocampus responsible for spatial navigation (Maguire et al. 2000). More recently, a study by Suo et al. (2012) compared hippocampal volume for older adults who had held supervisory jobs with individuals of the same age who had not. They found that there was greater hippocampal density in those who had been supervisors, a difference they attributed to the cognitive demands of those jobs. Similar effects of experience have been reported using behavioral measures. Salthouse and Mitchell (1990) reported that professional architects outperform non-architects on tests of visuo-spatial ability. In a large research program, Bavelier and colleagues (e.g. Green and Bavelier 2008) report significant modification of perceptual-motor ability in individuals who are intensely involved in video game playing. And finally, a recent study that compared professional football players in two European leagues that differed in their level of competition found that players in the higher league demonstrated better performance on a design fluency test than did players in the lower league (Vestberg et al. 2012), and players in both leagues outperformed non-players. Design fluency requires rapid planning and execution, skills not dissimilar to those used in sport.

These examples all demonstrate the systematic effect of experience on the human mind, but all the examples suffer from problems of direction, selection, and extent. The direction problem is the inability to clearly attribute the outcome to the experience.

There are very few training studies in which the outcomes can be calibrated to the experience or are tested prior to the experience, so the data are substantially correlational. Therefore, there may be hidden factors that are responsible for the outcomes that are concealed by the group comparison. The problem of selection is related: it may be that individuals with excellent visuo-spatial skills choose architecture for a career and those with unusually sensitive finger control become string musicians. Moreover, because these experiences tend to be chosen activities, it is possible that those individuals who are more suited to them persist while those with less suitable skills drop out. Ultimately, individuals who are uniquely qualified for these activities are the ones who pursue them and become part of the experimental group comparisons. Finally, the problem of extent is that the outcomes are generally closely related to the training itself, so the evidence for modification in cognitive ability from experience is limited by the generalizability of those outcomes.

Bilingualism is an intense experience but it is less vulnerable to these interpretative problems than the other experiences discussed. The majority of bilinguals become so because of life necessity, such as immigration, and not by their choice to pursue an experience in which they have already demonstrated talent or interest. Although many people indeed decide to study language, it is not typically a choice for immigrants; geo-political realities by their nature preclude selection at that level of individual difference. Our research is conducted in a culturally diverse city in which English is the community language but more than 50% of the population does not use English at home (Statistics Canada 2007). Thus, people living in these homes and their children are naturally bilingual because the typical pattern is to maintain the heritage language in the home (and local community where there are sufficient numbers) but use English for work, school, and other social and larger community interactions. Because bilinguals are not pre-selected in this context, comparisons between monolingual and bilingual individuals who are matched on other relevant variables can be used to isolate aspects of cognitive and brain function that are different for the bilingual group. This possibility of finding relatively well-matched groups of monolingual and bilingual participants for research alleviates some of the problems of direction and selection although nonetheless the research necessarily remains correlational and not causal.

The problem of the extent of these effects is also attenuated in bilinguals. Bilingualism is clearly a language experience, so evidence for its impact on nonverbal aspects of intelligence would demonstrate a broader range of effect than is typically found in this type of research. To summarize the research, bilingualism has been found to lead to enhanced executive functioning across the lifespan, although often in conjunction with poorer verbal processing than monolinguals, and contribute to “cognitive reserve” that protects against cognitive decline in both healthy aging and dementia.

2 Linguistic effects of bilingualism

Because bilingualism is a linguistic experience, it is not surprising that it has linguistic consequences. What is more surprising is that those consequences appear to be disadvantages. The differences between monolinguals and bilinguals in linguistic processing and

verbal ability are found both in terms of vocabulary size and access to specific lexical entries. In two large-scale studies, each involving more than 1,600 participants, bilinguals had significantly smaller receptive vocabulary scores in English for both children between the ages of 3 and 10 years old (Bialystok et al. 2010) and adults between the ages of 17 and 89 years old (Bialystok and Luk 2012). The bilinguals in both studies were fluent in both languages, with the majority of them speaking the non-English language at home and English at school or work, and the non-English language included a wide variety of different languages. Nonetheless, the depth of their English vocabulary was on average less than it was for their monolingual counterparts, even though English was the language of work, school, and community. It should be noted, however, that studies comparing lexical development in bilingual and monolingual children often fail to incorporate the overlapping conceptual vocabulary of bilingual children. Because there is a significant non-overlapping portion of lexical knowledge between languages in which bilingual children know words for concepts in one of their languages but not the other (e.g. Pearson et al. 1993; Umbel et al. 1992), vocabulary scores in one language do not accurately reflect children's linguistic knowledge.

Differences in lexical access as a function of language background are well documented: bilinguals typically take significantly longer to retrieve individual words than do monolinguals. These results have been shown for simple picture naming tasks (Gollan et al. 2007) as well as lexical decision tasks (Van Hell and Dijkstra 2002). For example, in a study by Gollan et al. (2005), monolingual English-speakers and Spanish-English bilinguals were asked to name a set of pictures over a series of five blocks. The pictures all depicted simple common objects. Over the block repetitions, both groups became faster at naming the pictures, but for all five blocks, the monolinguals performed significantly faster than the bilinguals. These effects are found equally when bilinguals are performing the naming task in their more dominant language, both for adults (Ivanova and Costa 2008) and for children (Poarch and Van Hell 2012a).

Finally, bilinguals generally perform more poorly than monolinguals on verbal fluency tests. These are standardized tests that are used as neuropsychological measures of brain functioning and are routinely administered to evaluate the impact of brain injury, cognitive decline, and dementia. There are two main versions of this task. The first condition, called category fluency, or semantic fluency, requires participants to generate as many words as possible in 60 seconds that are members of a stated category, such as "animals". Performance on this condition is an index of vocabulary size and semantic structure, and consistent with receptive vocabulary scores, bilinguals generally produce fewer words than monolinguals (Portocarrero et al. 2007; Gollan et al. 2002; Rosselli et al. 2000). The second condition is called letter fluency, or phonemic fluency. In this case, participants must generate words that begin with a stated letter, usually F, A, and S. This task also relies on vocabulary knowledge, but it additionally taps executive control processes because our lexical networks are not organized according to initial letters or sounds, so effortful and strategic search processes are required to generate acceptable words. In this case, if monolinguals and bilinguals are matched for vocabulary size, bilinguals actually outperform monolinguals because of their superior executive control (Bialystok et al. 2008). Thus, for performance on this task the vocabulary deficit is outweighed by a more general advantage in executive control.

What is the connection between these linguistic processing costs associated with bilingualism and the idea that there are advantages in executive control? It is now well documented that both languages are activated to some extent when bilinguals are using one of them, creating a situation of perpetual conflict between language representations during any linguistic performance. There is evidence for this claim from behavioral (Francis 1999; Kroll and De Groot 1997; Grainger 1993), imaging (Martin et al. 2009; Marian et al. 2003; Rodriguez-Fornells et al. 2002), and patient (Abutalebi et al. 2000; Fabbro et al. 2000) studies. The fact that this competition does not impede performance—bilinguals are not prone to massive intrusions from the unwanted language in their speech production or comprehension—signals that the competition is resolved before it becomes a problem. Our speculation on the mechanism for resolving this conflict is that the domain-general executive control system, a network of brain regions and processes whose job it is to monitor and resolve conflict, shift attention, and manipulate working memory, is recruited into language processing (for a review see Bialystok et al. 2009). This constant involvement of the general executive control network in language processing has two consequences: first, the network itself is reconfigured relative to that used by monolinguals (e.g. Luk et al. 2010), and second, the efficiency and power of the network is increased through massive practice (e.g. Gold et al. 2013).

3 Cognitive effects of bilingualism

Behavioral evidence for superior performance of bilinguals compared to monolinguals in nonverbal executive control tasks has been shown across the lifespan (Bialystok et al. 2005). The tasks used in this research are typically simple perceptual conflict tasks, such as the flanker task. Participants see a simple perceptual display, such as a row of five arrows, and are asked to press a key indicating the direction in which the center arrow is facing. The four irrelevant arrows can be facing in the same direction as the central target, creating congruent trials, or in the opposite direction, creating incongruent trials and requiring attentional effort to ignore those stimuli. Reaction times are always slower on incongruent trials. Studies of both children (Martin-Rhee and Bialystok 2008) and adults (Costa et al. 2008) have shown that reaction times for both congruent and incongruent trials are also slower for monolinguals than for bilinguals. There are no performance differences between groups when simple trials, such as congruent or neutral trials are presented in a single block, but the combination of both congruent and neutral trials, and the need to monitor and shift between them leads to faster performance by bilinguals on the entire block of trials. This pattern of faster performance by bilinguals indicates that bilinguals have better ability than monolinguals on all aspects of executive control, not only the difficult incongruent trials. Thus, in this simple problem of resolving nonverbal perceptual conflict, a number of effortful processes that are part of the executive function system are implicated, and in all respects, bilingual participants perform more efficiently than monolinguals.

An important part of the argument for attributing these outcomes to bilingualism is to show that greater degrees of bilingualism are associated with larger outcomes. One approach to this issue is to study children who are in the process of becoming bilin-

gual and examining emerging differences in their executive control ability. Bialystok and Barac (2012), for example, approached this question by investigating children between 7- and 9-years old who were attending immersion programs for their schooling. All the children spoke English at home but their education was being conducted in either French or Hebrew. Children were given a range of tests of language ability, metalinguistic ability, and executive control and were also assessed for how bilingual they were (ratio of vocabulary score in both languages), how long they had been in the immersion program, and their level of formal language ability. In both programs, performance on linguistic and metalinguistic tasks was predicted by children's level of language proficiency and nonverbal intelligence, but performance on executive control tasks was predicted by how long they had been in the immersion program and how bilingual they were. As children became increasingly bilingual and had more experience in a bilingual education environment, their performance on nonverbal executive control tasks improved.

In another recent study, Poarch and Van Hell (2012b) compared the performance of second-language learners who were in the process of becoming bilingual to children who were bilingual or trilingual as well as a group of monolinguals. Thus, groups of 6- to 8-year old children who were English-German dual-immersion students, German-English bilinguals, German-Language X-English trilinguals, or monolinguals were given two measures of executive control, the Simon Task and the flanker task. All of the children in the three multilingual groups outperformed monolingual children on the Simon Task, although the difference only became statistically significant for the bilinguals and trilinguals, and the bilinguals and trilinguals outperformed the second-language learners in the flanker task. Thus, for some aspects of executive control, there may be a threshold of bilingual experience before the cognitive advantages become apparent.

The interpretation of these effects is that the use of the executive control system for language processing in response to the problem created by jointly activated languages strengthens that system more broadly so that performance on nonverbal problems that involve conflict is also enhanced. Evidence for that claim requires demonstrating the involvement of nonverbal executive control in distinctly verbal activities. Such evidence comes from a meta-analysis by Luk et al. (2012) in which they analyzed results from 10 different studies in which bilingual participants performed a language switching task in fMRI. The tasks were different but all included the requirement to switch between languages while producing verbal responses to stimuli. By using meta-analysis, the authors were able to extract the brain network common to language switching across the 10 studies. Importantly, this network overlapped substantially with the network known to underlie domain general executive control (Abutalebi and Green 2007), confirming the use of this general purpose system in managing attention to jointly activated languages.

The constant recruitment of the domain-general executive control network for resolving competition between languages has the further effect of reconfiguring that network and improving its efficiency. A study by Luk et al. (2010) that compared monolingual and bilingual participants performing a flanker task showed that the two groups engaged slightly different networks, particularly for the difficult incongruent trials. More importantly, two recent studies have demonstrated that these reconfigured networks are more efficient. First, a study by Abutalebi et al. (2012) identified the anterior cingulate cortex as the executive control region that is modified by bilingualism in that it is less activated

by bilinguals than monolinguals in solving conflict tasks and that less activation is associated with better behavioral performance. Extending these results, Gold et al. (2013) demonstrated that there was less activation by bilingual than monolingual older adults in a switching task that required executive control and crucially showed a significant negative correlation between the amount of activation in several regions involved in the executive control network and performance on the task. In other words, in both studies, bilinguals achieved better performance with less effortful activation of the brain networks recruited for that task. The conclusion from both studies is that the executive control network for bilinguals is more efficient than it is for monolinguals.

4 Bilingualism and cognitive reserve

The research discussed to this point has focused on the impact of bilingualism that emanates from the joint activation of two languages and so requires the recruitment of the executive control system, leaving its trace both in costs for linguistic processing and benefits for nonverbal conflict processing. Importantly, the benefits of bilingualism have been found through the lifespan including in older age, modulating the natural decline of cognitive function with healthy aging. This general notion of protection against cognitive decline is called “cognitive reserve” (Stern 2002) and refers in the most general terms to the types of stimulating cognitive activities (crossword puzzles, formal education, social engagement) that are associated with the maintenance of cognitive function through aging. From the research on bilingualism in which it has been shown that older bilingual adults outperform monolinguals on tests of executive control, it may be hypothesized that bilingualism also contributes to cognitive reserve. However, the complaints of aging are not generally described in terms of difficulty with executive control; instead, they are overwhelmingly documented as complaints of memory, yet there is little research that has connected bilingualism to memory function. Is there any evidence that bilingualism might in fact mediate cognitive decline with aging in a significant way?

As an initial investigation of this possibility, we conducted two studies from the records of patients who had visited a memory clinic and had been diagnosed with either dementia (two-thirds of whom were diagnosed with Alzheimer’s disease; Bialystok et al. 2007) or specifically with Alzheimer’s disease (Craik et al. 2010). Together the two studies included approximately 400 patients, about half of whom had been lifelong bilinguals. In both studies, bilingual patients experienced the onset of dementia symptoms about 4 to 5 years later than the monolingual patients who were largely comparable on other measures. This is a substantial and highly significant delay.

There are two possibilities for the mechanism by which cognitive reserve protects cognitive functioning, especially in the context of dementing disease. The first is a direct effect in which cognitive reserve enables the brain to resist the development of neuropathological changes underlying dementia, such as the deposit of beta-amyloid in the medial-temporal areas which creates atrophy in those regions (e.g. Landau et al. 2012; Valenzuela et al. 2012). The second is a compensatory effect in which neuropathological changes continue to progress but more intact aspects of brain function supplement impaired functions and permit the person to cope with the pathology (e.g. Bennett et al.

2003; Kidron et al. 1997). In support of the compensation hypothesis, we demonstrated that bilingual patients with Alzheimer's disease who were matched with monolingual patients on age and cognitive level at time of testing showed *more* atrophy in the medial-temporal regions than did the monolinguals (Schweizer et al. 2012). Thus, for the same cognitive level, bilinguals had more neurodegeneration and therefore more advanced disease. Our interpretation is that preserved functioning for the bilinguals was achieved through compensation, a boost that presumably came from their enhanced networks and function of the executive control system. This interpretation is consistent with evidence showing that bilinguals outperform monolinguals on memory tasks that require executive control but not on those that do not (e.g. Wodniecka et al. 2010).

This research showing protection against dementia by compensating for a compromised memory system with a more intact cognitive network is powerful evidence for the reorganization of crucial brain networks through experience. If the compensation account is correct, then the impact of enhancing specific cognitive networks reverberates throughout multiple cognitive networks, modifying performance broadly. Thus, intense experience that employs specific processes as part of routine functioning has the capacity to make fundamental changes in the structure and function of the mind.

5 Experience-induced plasticity from bilingualism

Not long ago, it was assumed that the adult brain was a fixed structure, unable to generate new neurons, and locked into the levels and types of processing it had achieved when it was young and flexible. Research with both humans and other animals has categorically proven these assumptions to be false: brains are continually adapting to experience, changing in both their structural and functional organization, and constantly incorporating traces of their experience. This principle is easily proven with animals: rats raised in stimulating environments develop greater synaptic density (brain structure) and perform better on learning tasks such as mazes (brain function) than do rats that are raised in simple environments (e.g. Kolb et al. 2012), even when the experience is introduced in adulthood (Winocur 1998). The interpretation of such experiments is straightforward because the rats that are randomly assigned to each of these two environments have no relevant measurable differences between them at birth so all subsequent differences can be safely attributed to their experience. Therefore, the conclusion from this active body of research is that enriched experience for rats leads to enhancements in brain structure and function.

Investigating the role of experience in humans is infinitely more complex. In addition to the greater complexity of individual differences and individual experiences, the tendency for humans is to gravitate to activities in which they already have talent or interest. The central logical point in the animal studies is that the individual rats are randomly assigned to groups, a technique obviously impossible with humans. In this sense, bilingualism is a better test case for experience-induced plasticity than some of the other experiences that have been studied: (a) the majority of bilinguals in our studies did not choose to become bilingual, ruling out talent or predisposition, (b) the effects of bilingualism on executive control emerge gradually with increased experience (e.g. Bialystok and Barac 2012; Poarch and Van Hell 2012b), and (c) the most dramatic effects of bilingualism are

not found in the domain of language, but in different domains that share processing with bilingual language use, namely nonverbal executive control (e.g. Bialystok et al. 2005). Together, these results support the conclusion that bilingualism modifies cognitive networks and enhances executive control functioning. Therefore, bilingual individuals do not have minds and brains that are identical to their monolingual counterparts. Accordingly, they will not perform the same on tests of language ability or executive control, they may express symptoms of cognitive disability or impairment differently from monolinguals, and they will likely produce different results from monolinguals on standardized neuropsychological assessments. Thus, bilingualism is not individual-difference “noise” in the data—it is an experience that has sustained, profound, and systematic effects on cognitive systems.

6 Implications for society

Evidence for different cognitive and linguistic competencies in bilinguals and monolinguals has large-scale social implications that follow from the tendency for interpretations of performance and policy decisions to be based on monolingual norms. Consider first the problem of assessment. It is standard procedure in education, clinical practice, and health care to evaluate individuals on the basis of test results and then make highly consequential decisions from those results (see for example Kohnert 2007). For example, children in school may be told they have learning problems, speech-language pathologists may describe a child as having a language impairment, or an older adult may be diagnosed with a condition such as fronto-temporal dementia based on word-finding problems. The problem is that almost all of the tests used for diagnosis in these domains and considered in the interpretation of the condition presented by an individual or patient are standardized instruments, and almost all of the standardization is based on monolinguals. However, as we have seen, there are significant differences in both verbal and nonverbal performance by monolinguals and bilinguals. To simplify, bilinguals typically have poorer verbal ability in each language but superior executive control than monolinguals. What happens when bilinguals complete tests that have been designed for monolinguals? Shohamy (2011) explains how this problem is compounded when social and political factors are included and further obfuscate actual performance levels. It is unlikely that we will turn away from our obsession with standardized testing; it is therefore incumbent upon us to guarantee that these tests are as fair and valid as possible. Ideally, tests should be re-constructed to provide accurate assessment of bilingual individuals, but failing this, teachers and clinicians need to be educated in the proper interpretation of test results for bilinguals. The decision that an individual has a learning disability, language impairment, or dementia has profound consequences, and the evidence for those conclusions needs to be revisited for bilinguals.

The second social implication concerns how findings from bilingualism research are reflected in educational policy. Consider for example Canada and Germany. In Canada, early research in dual-language immersion programs made it possible to assess the impact of bilingualism in educational contexts, research that remains relevant in lending scientific credibility to the success of such educational programs. One may presume that this

educational approach was driven by the need to positively endorse Canada's national identity as a bilingual nation, but that was not and is not the case as official bilingualism in Canada has always been controversial and contentious. Nonetheless, this educational initiative sends a clear signal to Canada's immigrant population that bilingualism is viewed as an asset. Germany, in contrast, has only recently begun to implement dual-language immersion programs and, indirectly, realized the potential inherent in its immigrant population and their additional languages. Gebauer et al. (2013), for example, report positive cross-language transfer of reading skills in children's L2 English to their L1 German. The children had been enrolled in English partial immersion programs in Germany, programs that offer children more second language input than regular second language classes in German primary schools (for an overview of various immersion programs, see Baker 2011). As such, these findings indicate that fostering and supporting a second language from an early age can have effects above and beyond those illustrated in the above sections, effects that may be accrued irrespective of which L2 a child is acquiring. Finally, recent research has also begun to focus on the extent and length of bilingual exposure needed for changes associated with bilingualism to emerge in children (see Barac and Bialystok 2012; Bialystok and Barac 2012; Bialystok et al. 2012).

The third social implication is more optimistic, although emanates from a deeply unpromising fact: in spite of years of research, there are still very few pharmaceutical treatments for dementia, and those that exist have small to moderate effects at best. Not surprisingly, therefore, increased attention has been devoted to persuading people to adopt the lifestyle factors that contribute to cognitive reserve and protect cognitive function as dementia progresses. These factors include formal education, physical exercise, and social engagement. Our research suggests that bilingualism is another such factor that prolongs cognitive health. The additional advantage in this case is that little or no extra effort is required: the simple act of maintaining a heritage language in the home confers long-term benefits on cognitive function. Even a short postponement of cognitive impairment has enormous consequences for health care systems and families because individuals are able to live independently for a longer time, make fewer demands on expensive and scarce health resources, and enjoy quality of life for several more years.

It would be dramatic if these results that accrued from research with individuals could be extrapolated to societies. Nations differ in the degree to which they support and encourage bilingualism, so is it the case that nations that are more demographically or socio-politically bilingual have lower incidence of dementia? Unfortunately, such comparisons are not possible; as much as individuals differ from each other, societies differ even more. The problem is that many factors converge on the comparative evaluation of societies, and the outcome depends on a wide range of environmental factors that are not included in a simple count of the languages heard on the streets. Among these are questions concerning the educational system, health care system, general economic situation, and sociological support for minority and non-official languages. It is also important to remember that cognitive reserve does not *prevent* dementia, so fluctuations in the incidence or prevalence of the disease across nations will be difficult to document.

There is an inherent tension between our concern with individuals whom we acknowledge to have distinct profiles, some of it reflecting their unique experiences, and the social conventions around testing and assessment, including research in psychology, in which

we assume the uniformity and equivalence of all the people we encounter. Although an approach to assessment and clinical practice that treats each person as utterly individual and unique is impractical, a testing culture that fails to acknowledge systematic differences from experience is invalid. Accommodation from both sides of this divide is necessary to produce social structures that are appropriate and responsive to as many individuals as possible.

In summary, this research shows that the long-term and sustained language control that is associated with bilingualism has an influence on brain structure and function throughout the lifespan. The most dramatic outcome is in enhanced executive control for bilinguals when performing tasks in which attentional control, conflict resolution, and set shifting are necessary. While evidence for better spatial skills for taxi drivers or perceptual-motor ability for video game players may be due to these individuals choosing these occupations and activities based on prior skill in these domains, bilinguals in most cases do not choose or self-select to be bilingual but become so by circumstance. Thus this research not only points to specific outcomes of experience on cognition but also addresses the important general issue of experience-induced plasticity and its consequences for the human mind.

References

- Abutalebi, J., & Green, D. W. (2007). Bilingual language production: The neurocognition of language representation and control. *Journal of Neurolinguistics*, 20, 242–275.
- Abutalebi, J., Miozzo, A., & Cappa, S. F. (2000). Do subcortical structures control language selection in bilinguals? Evidence from pathological language mixing. *Neurocase*, 6, 101–106.
- Abutalebi, J., Della Rosa, P. A., Green, D. W., Hernandez, M., Scifo, P., Keim, R., Cappa, S. F., & Costa, A. (2012). Bilingualism tunes the anterior cingulate cortex for conflict monitoring. *Cerebral Cortex*, 22, 2076–2086.
- Baker, C. (2011). *Foundations of bilingual education and bilingualism* (5th ed.). Clevedon: Multilingual Matters.
- Barac, R., & Bialystok, E. (2012). Bilingual effects on cognitive and linguistic development: Role of language, cultural background, and education. *Child Development*, 83, 413–422.
- Bennett, D. A., Wilson, R. S., Schneider, J. A., Evans, D. A., Mendes de Leon, C. F., Arnold, S. E., Barnes, L. L., & Bienias, J. L. (2003). Education modifies the relation of AD pathology to level of cognitive function in older persons. *Neurology*, 60, 1909–1915.
- Bialystok, E., & Barac, R. (2012). Emerging bilingualism: Dissociating advantages for metalinguistic awareness and executive control. *Cognition*, 122, 67–73.
- Bialystok, E., & Luk, G. (2012). Receptive vocabulary differences in monolingual and bilingual adults. *Bilingualism: Language and Cognition*, 15, 397–401.
- Bialystok, E., Craik, F. I. M., & Freedman, M. (2007). Bilingualism as a protection against the onset of symptoms of dementia. *Neuropsychologia*, 45, 459–464.
- Bialystok, E., Craik, F. I. M., & Luk, G. (2008). Cognitive control and lexical access in younger and older bilinguals. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 34, 859–873.
- Bialystok, E., Martin, M. M., & Viswanathan, M. (2005). Bilingualism across the lifespan: The rise and fall of inhibitory control. *International Journal of Bilingualism*, 9, 103–119.
- Bialystok, E., Peets, K. F., & Moreno, S. (2012). Producing bilinguals through immersion education: Development of metalinguistic awareness. *Applied Psycholinguistics*. doi:10.1017/S0142716412000288.

- Bialystok, E., Craik, F. I. M., Green, D. W., & Gollan, T. H. (2009). Bilingual minds. *Psychological Science in the Public Interest*, 10, 89–129.
- Bialystok, E., Luk, G., Peets, K. F., & Yang, S. (2010). Receptive vocabulary differences in monolingual and bilingual children. *Bilingualism: Language and Cognition*, 13, 525–531.
- Costa, A., Hernández, M., & Sebastián-Gallés, N. (2008). Bilingualism aids conflict resolution: Evidence from the ANT task. *Cognition*, 106, 59–86.
- Craik, F. I. M., Bialystok, E., & Freedman, M. (2010). Delaying the onset of Alzheimer's disease: Bilingualism as a form of cognitive reserve. *Neurology*, 75, 1726–1729.
- Ebert, T., Pantev, C., Rockstroth, B., Taub, E., & Wienbruch, C. (1995). Increased cortical representation of the fingers of the left hand in string players. *Science*, 270, 305–307.
- Fabbro, F., Skrap, M., & Aglioti, S. (2000). Pathological switching between languages following frontal lesion in a bilingual patient. *Journal of Neurology, Neurosurgery, and Psychiatry*, 68, 650–652.
- Francis, W. S. (1999). Analogical transfer of problem solutions within and between languages in Spanish-English bilinguals. *Journal of Memory and Language*, 40, 301–329.
- Gebauer, S. K., Zaunbauer, A. C. M., & Möller, J. (2013). Cross-language transfer in English immersion programs in Germany: Reading comprehension and reading fluency. *Contemporary Education Psychology*, 38, 64–74.
- Gold, B. T., Kim, C., Johnson, N. F., Kryscio, R. J., & Smith, C. D. (2013). Lifelong bilingualism maintains neural efficiency for cognitive control in aging. *Journal of Neuroscience*, 33, 387–396.
- Gollan, T. H., Montoya, R. I., & Werner, G. A. (2002). Semantic and letter fluency in Spanish-English bilinguals. *Neuropsychology*, 16, 562–576.
- Gollan, T. H., Fennema-Nostestine, C., Montoya, R. I., & Jernigan, T. L. (2007). The bilingual effect on Boston naming test performance. *Journal of the International Neuropsychological Society*, 13, 197–208.
- Gollan, T. H., Montoya, R. I., Fennema-Notestine, C., & Morris, S. K. (2005). Bilingualism affects picture naming but not picture classification. *Memory & Cognition*, 33, 1220–1234.
- Grainger, J. (1993). Visual word lexicon in bilinguals. In R. Schreuder & B. Weltens (Eds.), *The bilingual lexicon* (pp. 11–25). Amsterdam: John Benjamins.
- Green, C. S., & Bavelier, D. (2008). Exercising your brain: A review of human brain plasticity and training induced learning. *Psychology and Aging*, 23, 692–701.
- Ivanova, I., & Costa, A. (2008). Does the bilingualism hamper lexical access in speech production? *Acta Psychologica*, 127, 277–288.
- Kidron, D., Black, S. E., Stanchev, P., Buck, B., Szalai, J. P., & Parker, J. (1997). Quantitative MR volumetry in Alzheimer's disease. *Neurology*, 49, 1504–1512.
- Kohnert, K. (2007). *Language disorders in bilingual children and adults*. San Diego: Plural Publishing.
- Kolb, B., Mychasiuk, R., Muhammad, A., Li, Y., Frost, D. O., & Gibb, R. (2012). Experience and the developing prefrontal cortex. *Proceedings of the National Academy of Sciences*, 109, 17186–17193.
- Kroll, J. F., & De Groot, A. M. B. (1997). Lexical and conceptual memory in the bilingual: Mapping form to meaning in two languages. In A. M. B. de Groot & J. F. Kroll (Eds.), *Tutorials in bilingualism* (pp. 169–199). Mahwah: Erlbaum.
- Landau, S. M., Mintun, M. A., Joshi, A. D., Koeppe, R. A., Petersen, R. C., Aisen, P. S., Weiner, M. W., & Jagust, W. J. (2012). Amyloid deposition, hypometabolism, and longitudinal cognitive decline. *Annals of Neurology*, 72, 578–586.
- Luk, G., Green, D. W., Abutalebi, J., & Grady, C. (2012). Cognitive control for language switching in bilinguals: A quantitative meta-analysis of functional neuroimaging studies. *Language and Cognitive Processes*, 27, 1479–1488.

- Luk, G., Anderson, J. A. E., Craik, F. I. M., Grady, C., & Bialystok, E. (2010). Distinct neural correlates for two types of inhibition in bilinguals: Response inhibition versus interference suppression. *Brain and Cognition*, 74, 347–357.
- Maguire, E. A., Gadian, D. G., Johnsrude, I. S., Good, C. D., Ashburner, J., Frackowiak, R. S., & Frith, C. D. (2000). Navigation-related structural change in the hippocampi of taxi drivers. *Proceedings of the National Academy of Sciences, USA*, 97, 4398–4403.
- Marian, V., Spivey, M., & Hirsch, J. (2003). Shared and separate systems in bilingual language processing: Converging evidence from eyetracking and brain imaging. *Brain and Language*, 86, 70–82.
- Martin, C. D., Dering, B., Thomas, E. M., & Thierry, G. (2009). Brain potentials reveal semantic priming in both the ‘active’ and the ‘non-attended’ language of early bilinguals. *NeuroImage*, 47, 326–333.
- Martin-Rhee, M. M., & Bialystok, E. (2008). The development of two types of inhibitory control in monolingual and bilingual children. *Bilingualism: Language and Cognition*, 11, 81–93.
- Pearson, B. Z., Fernández, S. C., & Oller, D. K. (1993). Lexical development in bilingual infants and toddlers: Comparison to monolingual norms. *Language Learning*, 43, 93–120.
- Poarch, G. J., & Van Hell, J. G. (2012a). Cross-language activation in children’s speech production: Evidence from second language learners, bilinguals, and trilinguals. *Journal of Experimental Child Psychology*, 111, 419–438.
- Poarch, G. J., & Van Hell, J. G. (2012b). Executive functions and inhibitory control in multilingual children: Evidence from second language learners, bilinguals, and trilinguals. *Journal of Experimental Child Psychology*, 113, 535–551.
- Portocarrero, J. S., Burright, R. G., & Donovick, P. J. (2007). Vocabulary and verbal fluency of bilingual and monolingual college students. *Archives of Clinical Neuropsychology*, 22, 415–422.
- Rodriguez-Fornells, A., Rotte, M., Heinze, H.-J., Nosselt, T. M., & Munte, T. F. (2002). Brain potential and functional MRI evidence for how to handle two languages with one brain. *Nature*, 415, 1026–1029.
- Rosselli, M., Ardila, A., Araujo, K., Weekes, V. A., Caracciolo, V., Padilla, M., & Ostrosky-Solis, F. (2000). Verbal fluency and repetition skills in healthy older Spanish-English bilinguals. *Applied Neuropsychology*, 7, 17–24.
- Salthouse, T. A., & Mitchell, D. R. D. (1990). Effects of age and naturally occurring experience on spatial visualization performance. *Developmental Psychology*, 26, 845–854.
- Schweizer, T., Ware, J., Fischer, C. E., Craik, F. I. M., & Bialystok, E. (2012). Bilingualism as a contributor to cognitive reserve: Evidence from brain atrophy in Alzheimer’s disease. *Cortex*, 48, 991–996.
- Shohamy, E. (2011). Assessing multilingual competencies: Adopting construct valid assessment policies. *The Modern Language Journal*, 95, 418–429.
- Statistics Canada. (2007). 2006 Census of Canada highlight tables: Population by language spoken most often at home and age groups, 2006 counts, for Canada, provinces and territories—20% sample data. (Catalogue number 97-555-XWE2006002). <http://www12.statcan.ca/census-recensement/2006/dp-pd/hlt/97-555/T402-eng.cfm?Lang=E&T=402&GH=4&SC=1&S=99&O=A>. Accessed 4 Aug 2011.
- Stern, Y. (2002). What is cognitive reserve? Theory and research application of the reserve concept. *Journal of the International Neuropsychological Society*, 8, 448–460.
- Suo, C., Leon, I., Brodaty, H., Trollor, J., Wen, W., Sachdev, P., & Valenzuela, M. J. (2012). Supervisory experience at work is linked to low rate of hippocampal atrophy in late life. *NeuroImage*, 63, 1542–1551.
- Umbel, V. M., Pearson, B. Z., Fernández, M. C., & Oller, D. K. (1992). Measuring bilingual children’s receptive vocabularies. *Child Development*, 63, 1012–1220.

- Valenzuela, M. J., Matthews, F. E., Brayne, C., Ince, P., Halliday, G., Kril, J. J., Marshall, A. D., Richardson, K., Forster, G., & Sachdev, P. S. (2012). Multiple biological pathways link cognitive lifestyle to protection from dementia. *Biological Psychiatry*, 71, 783–791.
- Van Hell, J. G., & Dijkstra, T. (2002). Foreign language knowledge can influence native language performance in exclusively native contexts. *Psychonomic Bulletin & Review*, 9, 780–789.
- Vestberg, T., Gustafson, R., Maurex, L., Ingvar, M., & Petrovic, P. (2012). Executive functions predict the success of top soccer players. *PLoS ONE*, 7, e34731.
- Winocur, G. (1998). Environmental influences on cognitive decline in aged rats. *Neurobiology of Aging*, 19, 589–597.
- Wodniecka, Z., Craik, F. I. M., Luo, L., & Bialystok, E. (2010). Does bilingualism help memory? Competing effects of verbal ability and executive control. *International Journal of Bilingual Education and Bilingualism*, 13, 575–595.