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Reshaping the Mind: The Benefits of Bilingualism

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Abstract

Studies have shown that bilingual individuals consistently outperform their monolingual counterparts on tasks involving executive control. The present paper reviews some of the evidence for this conclusion and relates the findings to the effect of bilingualism on cognitive organisation and to conceptual issues in the structure of executive control. Evidence for the protective effect of bilingualism against Alzheimer's disease is presented with some speculation about the reason for that protection.

Keywords

bilingualism; executive control; cognitive development; aging

All experiences leave their mark—they change how we respond to a similar situation in the future, create knowledge or expertise in particular areas, a change we usually call "learning," and as it is increasingly becoming apparent, change our brains. It follows, then, that experience has great potential for explaining the way that basic cognitive abilities develop, function, and change throughout the life span. Researchers have reported dramatic effects on brain structure and function following short intensive experiences, such as juggling (Draganski et al., 2004) or video-game playing (Green & Bavelier, 2008), and long-term experiences, such as careers in architecture (Salthouse & Mitchell, 1990) or taxi-driving (Maguire et al., 2000). Bilingualism is different from all of these: like juggling and playing video games it is intense, and like careers in architecture and driving taxis in London, it is sustained over a long period of time. However, unlike all these examples, bilinguals are typically not selected for a preexisting talent or interest, confusing the direction of cause and effect in the previous literature. In the vast majority of cases, individuals become bilingual through life circumstances.

The main empirical finding for the effect of bilingualism on cognition is in the evidence for enhanced executive control in bilingual speakers (review in Bialystok, Craik, Green, & Gollan, 2009). These effects have been found at all stages across the life span beginning in infancy (Kovács & Mehler, 2009) and toddler-hood (Poulin–Dubois, Blaye, Coutya, & Bialystok, 2011), continuing through young (Carlson & Meltzoff, 2008) and middle

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childhood (Bialystok, 2011), into young adulthood (Costa, Hernández, & Sebastián–Gallés, 2008), and older age (Bialystok, Craik, Klein, & Viswanathan, 2004). In all these cases, tasks that include a salient conflict (e.g., Simon task, Bialystok et al., 2004; Stroop task, Bialystok, Craik, & Luk, 2008; or flanker task, Costa et al., 2008) or the need to inhibit a learned or habitual response (e.g., day–night task, Martin–Rhee & Bialystok, 2008) were performed better by bilingual participants than by their monolingual peers.

The key to understanding how bilingualism affects minds and brains is in the surprising, but well-documented, finding that both languages of a bilingual speaker are constantly active to some degree, even in strongly monolingual contexts where there is no reason to expect to use one of the languages. Evidence for this conclusion has come from behavioural studies in which interference from the participant's other language is found on experimental trials designed to maximize such effects (e.g., Beauvillain & Grainger, 1987; Colomé, 2001; Francis, 1999; Grainger, 1993; Hernandez, Bates, & Avila, 1996; Kroll & deGroot, 1997), patient studies in which interference from the irrelevant language is expressed as intrusions or complete language switches (e.g., Fabbro, Skrap, & Aglioti, 2000), and imaging studies in which interference from the nontarget language is salient (Marian, Spivey, & Hirsch, 2003; Martin, Dering, Thomas, & Thierry, 2009; Rodriguez–Fornells, Rotte, Heinze, Nosselt, & Munte, 2002). This joint activation has profound implications for both linguistic and nonlinguistic processing.

If both languages of a bilingual speaker are active, then a problem in attention is introduced for bilinguals that does not exist for monolingual speakers. In addition to the usual selection constraints that apply to rapid linguistic processing regarding, such dimensions as register, collocation, and synonym, the bilingual speaker also has to select the correct language from two competing options. This may be the most difficult of all the selection challenges because it is possible for both languages to satisfy a wide range of criteria for the intended utterance, the only difference being determined by the social context.

A likely explanation for how this difficult selection is made in constant online linguistic processing by bilinguals is that the general-purpose executive control system is recruited into linguistic processing, a configuration not found for monolinguals. The executive control system is well known to be involved in situations where selection or conflict resolution is required (e.g., Miyake et al., 2000), but that research has focused on nonverbal tasks. The claim here is that this same system is involved in resolving the conflict created by joint activation of the two languages for bilinguals. If the executive control system is recruited for ordinary language processing, then that system will be fortified through practice, possibly because it integrates with the linguistic systems generally required in these situations to create a more distributed and more robust network.

Evidence for this claim is somewhat indirect but compelling. Luk, Green, Abutalebi, and Grady (in press) conducted a meta-analysis of 10 studies in which bilinguals participated in functional magnetic resonance imaging (fMRI) experiments that involved stimulus naming in their two languages. The paradigm for all the studies was that participants completed both single language and mixed-language conditions, and the relevant variable was the subtraction identifying brain regions or networks involved in switching in the mixed-language condition. In the meta-analysis, these regions indicate the processes involved when bilinguals attend to one and then their other language, a sort of language switching or language control centre. The meta-analysis pointed to six significant regions: left inferior frontal gyrus pars triangularis (BA9), left middle temporal gyrus (BA37), midline presupplementary motor area (BA6), left inferior frontal gyrus pars orbitalis (BA47), bilateral caudate nuclei, and right precentral gyrus (BA6). At least four of these areas are included in the standard set of regions considered to be part of the executive control system (Abutalebi & Green, 2007). Therefore, the ordinary problem of selecting one of the two languages, and in particular, switching between the two languages, showed a role for the nonverbal executive control system. Although these regions were not activated in the single-language conditions, language switching is a normal part of bilingual experience, making the executive control system a crucial feature of language processing for bilinguals.

A demonstration of the involvement of the executive control system in bilingual language processing is necessary for the claim that the constant exercise of this system is responsible for the cognitive outcomes found for bilingualism. The key point is that bilingual language processing must recruit this network to manage attention to the target language within the context of linguistic and environmental selection constraints. The structure of the executive control system, however, is itself controversial. One common interpretation is that it is a domain-general system that consists of three core components: inhibition, updating (working memory), and shifting (Miyake et al., 2000). This view is difficult to confirm empirically because tasks typically involve multiple core components and performance across domains is generally correlated within individuals. However, comparing monolingual and bilingual performance can potentially disentangle some of these factors and contribute to a clearer understanding of the structure of executive control. The research strategy is to demonstrate that monolingual and bilingual participants achieve different levels of success in performing executive control tasks and that these differences cannot be attributed solely to the functioning of the individual core components. Instead, performance differences on executive control tasks by monolingual and bilingual individuals are traced to differences in the recruitment of the entire executive control network, not just core components of that network.

Three examples illustrate both the performance differences between monolingual and bilingual participants on executive control tasks and the potential for these results to elucidate the structure of the executive control system. These examples are based on different paradigms that engage different aspects of executive control and report data at different ages and stages in the life span. The common result in these studies is that there is an overall advantage for bilingual participants in performing these tasks, but it is not possible to attribute that performance difference to a single core component of executive control. Executive control, in other words, is not completely explained by the componential approach.

The first example is from a set of three studies of 6-year-old children performing a task that requires attending to either the global or local level of a set of hierarchical stimuli (Bialystok, 2010). The global–local task has been used as a research tool to investigate the ability to inhibit attention to salient aspects of perceptual displays (Navon, 1977). The stimuli can be created out of letters (e.g., H or S) or shapes (e.g. □, or ○) and the overall global and constituent local features can be the same (congruent trials) or different (incongruent trials). The results typically demonstrate a "global precedence effect," in which global level information is processed faster and more accurately than local information and interferes with identification of the local elements.

Each of the three studies examining the global–local task included about 25 monolingual and 25 bilingual children who performed comparably on cognitive background measures, such as working memory and nonverbal intelligence. In addition, each study contained various control conditions of the global–local task, in which the stimuli were simple presentations of the individual letters or shapes rather than hierarchically constructed stimuli (i.e., just the letter H rather than a letter H composed of smaller Hs or Ss) or blocks of trials in which all the hierarchical stimuli were congruent. Again, all children performed similarly on these control conditions. Unlike these conditions, the mixed blocks of congruent and incongruent trials of hierarchical stimuli made demands on all core components of the executive control system, creating the possibility of isolating the source of the bilingual advantage in executive control. If the relevant process was inhibition, then bilingual children should respond faster than monolingual children on incongruent trials, with no difference between groups on congruent trials where no inhibition is involved. If the relevant process was shifting, then bilingual children should respond faster than monolingual children on both congruent and incongruent trials in mixed blocks with no group difference for single trial-type blocks. Finally, if the relevant process was working memory, then bilingual children should perform faster than monolingual children on all mixed blocks. The results showed all these patterns: bilingual children produced faster reaction times to both congruent and incongruent trials when presented with mixed blocks of trials. The results were similar in all three studies, exemplified by the reaction time data from Study 1 shown in Figure 1. In spite of performing equivalently to monolingual children in the simple control conditions that used the same stimuli, but without any demands for executive control, bilinguals outperformed monolingual children in the condition in which more effortful and controlled attention was required.

The second example comes from a study conducted with slightly older children. Approximately 30 children in each group of monolingual and bilingual 8-year-olds were again matched on a number of background measures (Bialystok, 2011). Children completed two classification tasks. In the first, pictures appeared one at a time on a computer screen and children indicated whether the picture depicted an animal or a musical instrument by pressing a response key. In the second, wave files representing the sound made by either an animal or a musical instrument were played through the speakers and children classified each sound by saying "animal" or "music" into a microphone to trigger a response. Monolingual and bilingual children performed each of these classification tasks with equivalent accuracy. In the next stage, the two tasks were combined so that a picture and a sound were presented simultaneously and children were required to make both classifications. They could proceed in any order but both responses needed to be completed to move on to the next trial. For this dual task condition, bilingual children were significantly more accurate than monolingual children, particularly in their response to the visual stimuli. These results are shown in Figure 2. As in the study using the global–local task, simple conditions based on the same stimuli were performed comparably by children in both language groups, but when the task was made more demanding, bilingual children outperformed monolinguals. The dual task condition requires executive control to hold the rules in mind, allocate attention to the two tasks, and shift between them as the task proceeds.

The third example comes from research with younger and older adults performing the Stroop task (Bialystok et al., 2008). The task included a number of control conditions (word only, colour only) as well as the crucial colour–word interference condition. The variable of interest in this case was the Stroop effect, calculated as the additional time each participant needed to name the ink colour when the colour name conflicted with the ink colour as compared with when it did not. As shown in Figure 3, the monolinguals required significantly more time to resolve the conflict from the competing colour name than did the bilinguals in both age groups. The Stroop task is generally considered a classic test of executive control, and the Stroop effect is used diagnostically in neuropsychological batteries, such as the Delis–Kaplan Executive Functions System (Delis, Kaplan, & Kramer, 2001).

Three generalisations can be extracted from these examples. The first is that enhanced performance in executive control tasks by bilinguals is found at all stages across the life span. The second is that the control benefits that can be traced to a linguistic experience are expressed in performance on nonverbal tasks, indicating either a domain-general control system or a transfer of skill from verbal to nonverbal domains. Minimally, this pattern suggests there are shared aspects of systems for linguistic and nonlinguistic control. Finally, the effects are found across tasks that engage or emphasise different core components of executive control without one component emerging as decisive. In early views, the notion was that bilingualism enhanced inhibitory control (e.g., Green, 1998), but more recent views have taken a more holistic approach and described the bilingual advantage in terms of better monitoring skills (e.g., Costa, Hernández, Costa–Faidella, & Sebastian–Galles, 2009). The implication is that the core components do not function independently and that the control network is more holistic than suggested by a conceptualisation based on individual core components.

The explanation proposed for the enhanced executive control found in these studies is that bilinguals use this system to manage attention to jointly activated competing languages (for review see Bialystok et al., 2009). One way of testing that claim is to see if the executive control advantages would still be found if bilinguals did not experience conflict for selection from their two languages. Although this possibility seems to contradict the assertion that both languages are always active to some degree, there is nonetheless one situation where the conflict between them is greatly reduced. Bimodal bilinguals, individuals who speak English and American Sign Language, do not need to choose between the languages the way that speech bilinguals do. Although speech bilinguals cannot say two words at the same time, bimodal bilinguals can, and do engage in code blending, simultaneously producing both the spoken and signed word or phrase (Emmorey, Borinstein, Thompson, & Gollan, 2008a). Therefore, if the source of the advantage in executive control comes from managing two competing languages, then bimodal bilinguals would not be expected to demonstrate this effect. In a study of participants who were monolingual, bilingual, or bimodal bilingual performing a flanker task, all participants performed similarly on a control condition, but bilingual participants performed faster than monolinguals on the condition requiring executive control in which congruent and incongruent trials were presented in a mixed block, and the bimodal participants performed like the monolinguals (Emmorey, Luk, Pyers, & Bialystok, 2008b). Therefore, there was no executive control advantage for the bimodal participants, as shown in Figure 4.

More direct evidence for this explanation comes from neuroimaging studies of executive control tasks. In one study, monolingual and bilingual participants performed a Simon task with magneto-encephalography (Bialystok et al., 2005). In a whole-brain analysis called partial least squares, which calculates the correlation between reaction time and brain networks, monolinguals and bilinguals showed different patterns of brain activity in the conflict condition consisting of mixed presentation of congruent and incongruent trials. Of particular interest, the network used by bilinguals included Broca's area, a language region not generally involved in performing a nonverbal conflict task like Simon. In another study, monolingual and bilingual participants performed a flanker task in fMRI (Luk, Anderson, Craik, Grady, & Bialystok, 2010). Again, the partial least squares analysis indicated that different brain regions were involved for the two groups, with the greatest differences found for incongruent trials. Therefore, not only do bilinguals typically perform these executive control tasks more effectively than monolinguals but they also recruit different brain networks in those performances.

To summarise the argument to this point, the constant use of two languages by bilinguals leads to changes in the configuration of the executive control network and results in more efficient performance on executive control tasks, even those that are completely nonverbal. Although the executive control system is involved in a wide range of cognitive activities—in general, anything that requires effortful attention or selection—it is not known how widespread an enhanced executive control system would be detected throughout cognitive processing. It is well known that the executive control system declines with normal aging (Daniels, Toth, & Jacoby, 2006), and that bilinguals continue to outperform monolinguals in executive control tasks into older age for individuals experiencing healthy aging (Bialystok et al., 2004). What is not known is whether bilinguals maintain any benefit if aging is not normal but is accompanied by dementia.

There has been growing interest in the concept of cognitive reserve, the idea that stimulating mental activities protect against cognitive decline and continue to provide benefit as dementia develops (Scarmeas, Levy, Tang, Manly, & Stern, 2001; Stern, 2009). These activities include formal education, physical activity, stimulating leisure involvement, and social engagement. Since bilingualism places constant pressure on the executive control system to manage attention to the target language, it is possible that this constant mental activity contributes to cognitive reserve. Following the logic of that literature, bilinguals should be able to cope with the early symptoms of Alzheimer's disease more effectively than monolinguals, and continue to function without signalling that the disease has taken hold.

We tested that idea in two studies that compared the clinic records of monolingual and bilingual patients who had been diagnosed with dementia to determine how old they were when their families first noticed there was a problem. The first study (Bialystok, Craik, & Freedman, 2007) included 91 monolingual and 93 bilingual patients with dementia, two thirds of whom had been diagnosed with Alzheimer's disease. Information about the number of years patients had waited to visit the clinic after the family detected a problem, the type of occupation the individual had held through life, number of years of formal education, and Mini-Mental State Exam scores (Folstein, Folstein, & McHugh, 1975) to establish level of cognitive impairment were extracted from the records. Patients in the two language groups were equivalent on all measures except formal education, in which monolinguals had significantly more years of education (12.4) than bilinguals (10.8), a difference that should contribute to cognitive reserve for the monolinguals. However, the monolinguals were on average 71.4 years old and the bilinguals, 75.5 years old when symptoms of dementia were detected, a difference of 4.1 years. In the second study (Craik, Bialystok, & Freedman, 2010), there were 109 monolingual and 102 bilingual patients, all of whom had been diagnosed with Alzheimer's disease. The background results replicated those found in the first study, with monolinguals having significantly more formal education (12.6 years) than bilinguals (10.6 years) and all other measures being equivalent. Again, the monolinguals were 72.6 years old and the bilinguals were 77.7 years old when their families first noticed cognitive problems, this time a difference of 5.1 years. These studies, together with other research showing similar results (Chertkow et al., 2010), demonstrate a significant delay in the onset of symptoms of dementia, particularly Alzheimer's disease, for people who have been lifelong bilinguals.

Why do bilinguals show delay of symptoms of dementia? Valenzuela and Sachdev (2006a, b) distinguished between, “neurological brain reserve” and “behavioural brain reserve” to reflect two possibilities for how reserve might work. Neurological brain reserve is biological and possibly genetic in origin and functions through the effect of peak brain volume to ameliorate the effects of brain pathology on cognitive performance and signs of dementia. In contrast, behavioural brain reserve (also referred to as cognitive reserve) works through the effect of sustained complex mental activity protecting against dementia. If the reserve mechanism for bilingualism is brain reserve, then bilinguals should have more intact brains than monolinguals, and the reason bilinguals were older than monolinguals when symptoms occurred in the previous studies is that their brains were more robust and could stave off the disease. For patients at the same level of cognitive impairment, the prediction is that their brains will show the same level of disease pathology. If the reserve mechanism is cognitive reserve, then the disease will continue to advance, but bilinguals will be able to cope better with the disease because of the compensation that has been derived from stimulating mental activities. In that case, comparing monolingual and bilingual patients at the same level of impairment will show more advanced disease in the bilinguals.

We tested these predictions in a study comparing monolingual and bilingual patients diagnosed with Alzheimer's disease (Schweizer, Ware, Fischer, Craik, & Bialystok, in press). Forty patients with Alzheimer's disease who were matched on age, cognitive status, and other background measures received computed tomography scans. All patients were the same age and the same cognitive status. Half of the patients had been lifelong bilinguals and half were monolingual. On measures of overall brain atrophy, the two groups were equivalent. However, on three measures of atrophy in the medial temporal lobe that are positively associated with the severity of Alzheimer's pathology (Frisoni, Rossi, & Beltramello, 2002), bilingual patients showed significantly more atrophy than did the monolinguals. The interpretation is that the disease was more advanced in bilingual patients than monolinguals, but they managed to maintain cognitive function at a higher level than that predicted by their disease severity. This is the mechanism involved in cognitive reserve compensation for declining function through increased cognitive resources. Since patients in the two language groups were matched on many lifestyle factors, the obvious difference between the groups was bilingualism.

The research on bilingualism has investigated cognitive performance across the life span, beginning with infants less than 1 year old (Kovacs & Mehler, 2009) and continuing into old age, sometimes including patients suffering with dementia (Bialystok et al., 2007). At every stage, individuals who spend their lives engaged in more than one language reveal differences from their monolingual counterparts in both brain organisation and cognitive performance. It is logical to expect that linguistic processing and ability would be different for those who have a unique linguistic experience. For example, for both children (Bialystok, Luk, Peets, & Yang, 2010) and adults (Bialystok & Luk, in press), bilinguals have a more restricted receptive vocabulary in the language of the community than do monolingual speakers of that language. What is surprising is that the linguistic experience of bilingualism has consequences for nonverbal cognitive performance and that those consequences are to the advantage of bilinguals. Moreover, the advantages documented for executive control across the life span seem to contribute to cognitive reserve, allowing bilinguals to better cope with Alzheimer's disease and postpone the appearance of its devastating symptoms.

At present, the mechanism that is responsible for the bilingual advantage in executive control and the means by which cognitive reserve protects against the decline of cognitive function are not understood. To this point, the research is largely descriptive. The dynamic likely works through a compensatory mechanism, but those details are also speculative at this time. What is clear is the evidence: in controlled studies of cognitive performance across the life span, bilinguals consistently outperform their monolingual counterparts.

The effect of bilingualism on cognitive performance is a striking example of how ordinary experience accumulates to modify cognitive networks and cognitive abilities. The bilinguals included in these studies did not typically learn a second language because of a preexisting talent or interest but because life required it. Their lives included two languages, and their cognitive systems therefore evolved differently than did those of monolingual counterparts. The research with bilinguals, therefore, provides clear evidence for the plasticity of cognitive systems in response to experience. One possible explanation in the case of bilinguals is that the executive control circuits needed to manage attention to the two languages become integrated with the linguistic circuits used for language processing, creating a more diffuse, more bilateral, and more efficient network that supports high levels of performance. This mechanism was noted by Hebb (1949) more than half a century ago: "Cells that fire together, wire together." He was probably right.

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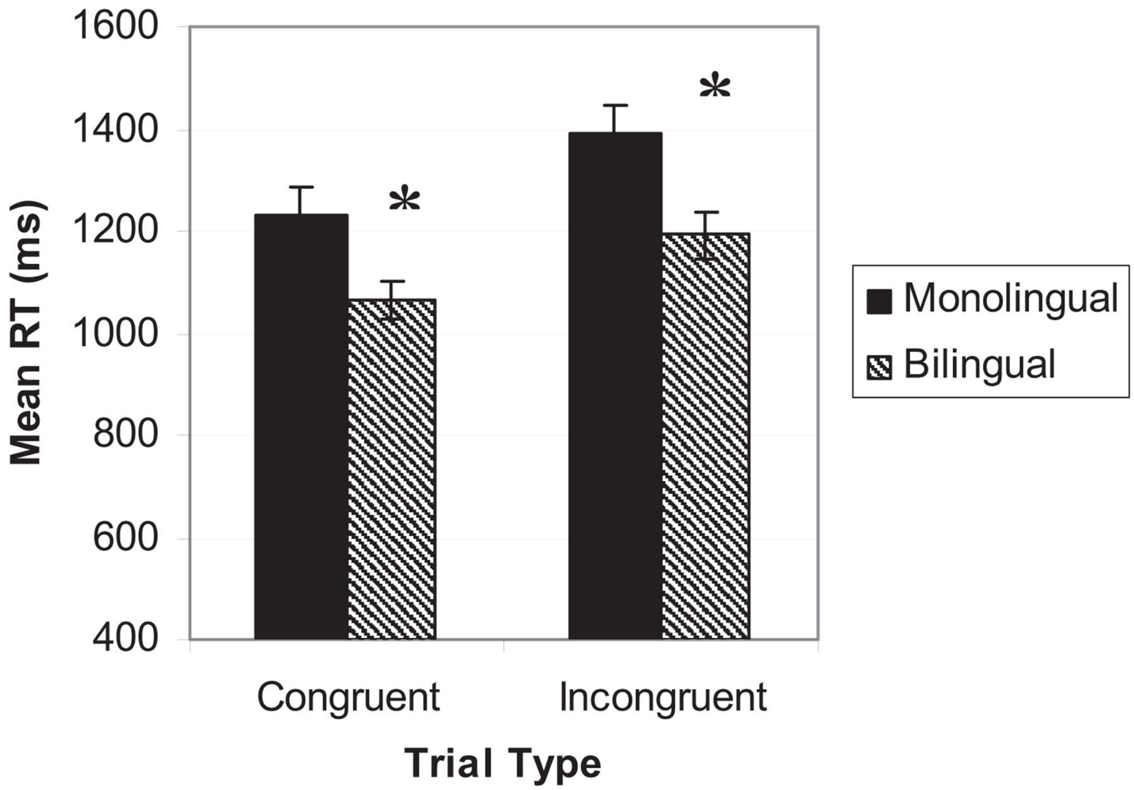

Figure 1.
Mean reaction time and standard error on congruent and incongruent trials in the global-local task, adapted from Bialystok (2010), Study 1.

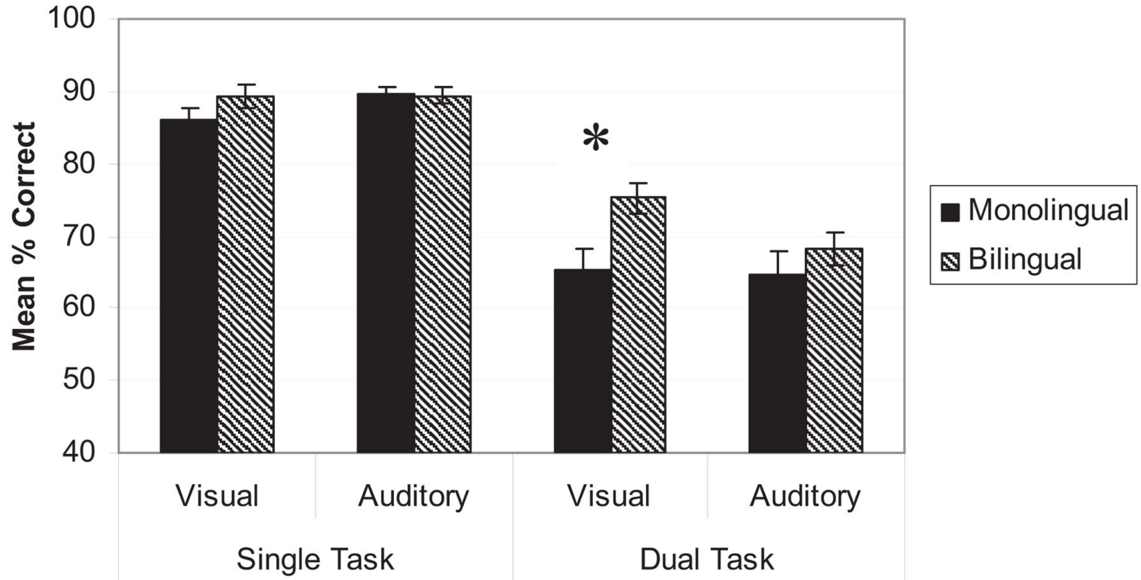

Figure 2.
Mean percent accuracy and standard error for classifying visual or auditory stimuli in either the single task or dual task conditions, adapted from Bialystok (2011).

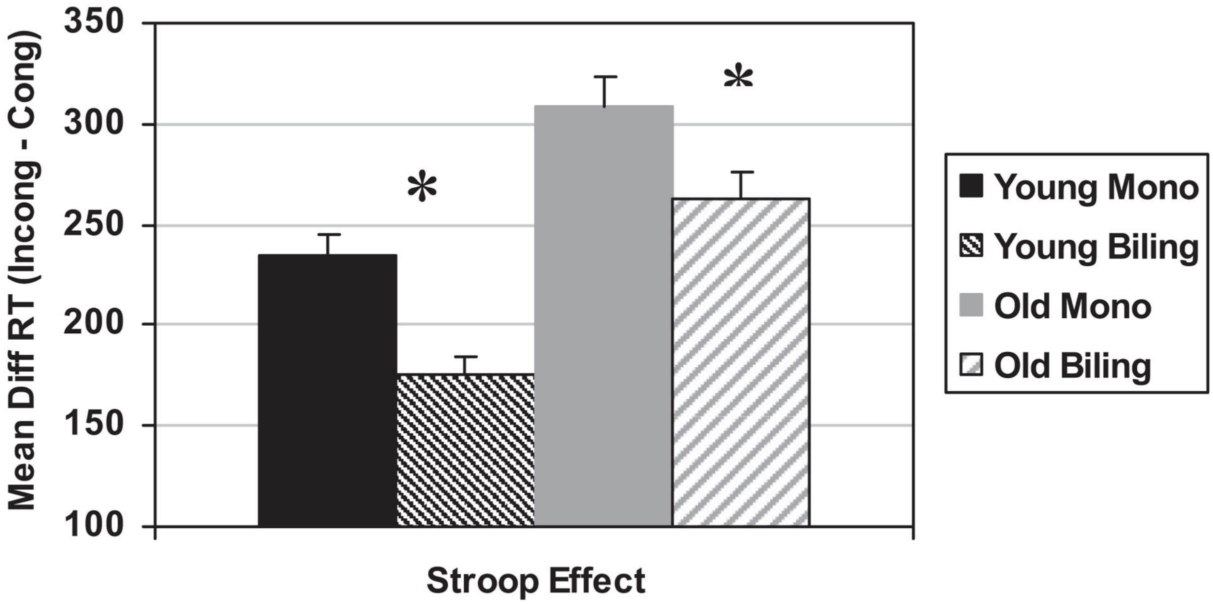

Figure 3.

Mean reaction time cost and standard error for incongruent items (Stroop effect) in Stroop task by younger and older monolingual and bilingual participants, adapted from Bialystok et al. (2008).

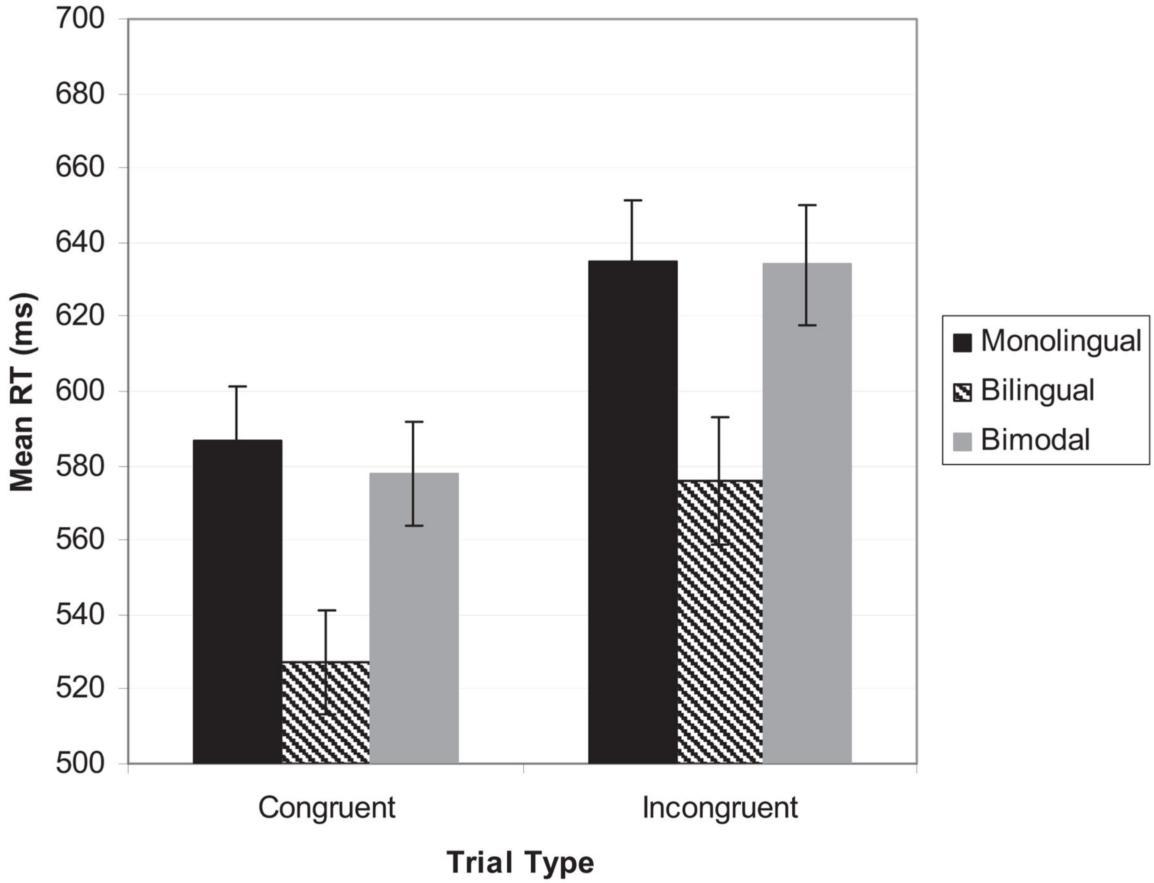

Figure 4.
Mean RT (and standard error) on congruent and incongruent trials in flanker task by monolinguals, bilinguals, and bimodal speech-sign bilinguals, adapted from Emmorey et al. (2008b).