The Babylonian benefit

Neurological research shows that being bilingual enhances mental performance and may protect from Alzheimer's disease

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Enter any research laboratory and you will most likely find an almost Babylonian confusion: French researchers discussing their experiments in French, but quickly switching to English when joined by their Chinese colleague. A German researcher may answer the phone in German while talking to a Spanish colleague in English. English is the de facto *lingua franca* of science: of research papers, grant proposals, and at conferences. In many laboratories, even outside Anglo-Saxon countries, English is the working language. In addition, for many scientists who move abroad, English will not be their only language problem. They and their family may be confronted with yet another foreign language in their daily life.

Researchers whose first language is not English may envy native speakers for their linguistic advantage: responding spontaneously to a question, expressing complex ideas or communicating subtle nuances is so much easier in one's mother tongue, even if one has reached high proficiency in a foreign language. However, there is some solace for those who are confronted with the challenge of having to master two languages. There is now growing evidence that learning more than one language enhances mental performance beyond the language domain. Bilingualism, in fact, has an impact on general cognitive functioning at all ages, and recent research shows that it could even delay the onset of symptoms in Alzheimer's disease.

"The overwhelming belief for a long time was that bilingualism was a source of confusion and difficulty", said neuroscientist Ellen Bialystok, Distinguished Research Professor at York University in Toronto, Canada. Exposing children to more than one

language was originally regarded as a mental burden, which would handicap children in their language development and hamper their general performance. First serious evidence against this view came from a bilingual country: A study in the early 1960s by Elizabeth Peal and Wallace E. Lambert from McGill University, Montreal, Canada, showed that bilingualism was not a problem, but perhaps a boon.

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It was still an unsolved question when Bialystok entered the field by coincidence in the 1980s. She was studying language and cognitive development in children when she made some interesting observations with children who were learning two languages. "I wasn't looking for it, but consistently the bilingual children outperformed monolingual children on certain types of tasks", Bialystok recounted. In a metalinguistic test, for example, Bialystok would ask children whether sentences were grammatically correct. All children performed equally well when faced with sentences like "apples grow on trees" or "apples trees on grow". But when Bialystok confronted them with nonsense statements, she spotted a difference. "I would tell them: 'don't worry if it's silly. Just tell me if it is said the right way' and give them a sentence like 'apples grow on noses'",

Bialystok explained. "The meaning is so crazy that it distracts their attention. But they know they are not supposed to pay attention to the meaning. Only bilingual kids could do that".

Since, a growing number of studies have further demonstrated that bilinguals are better at cognitive tasks that fall in the category of "executive function". "Executive function" could roughly be translated as "mental flexibility" and comprises skills that enable goal-directed behavior. One test to assess executive functions is the so-called "Stroop task": Words are printed in colored ink and participants have to name the color of the font as rapidly as possible. It becomes challenging if there is a mismatch between font color and word meaning; if participants, for example, read the word "GREEN" in blue ink. Most people can read words more quickly than name colors, but bilinguals are better than monolinguals at suppressing this knee-jerk reaction and naming the correct font color [1]. Bilinguals have also been shown to outperform monolinguals on the "Flanker task" or the "Simon task", where the reaction time depends on the ability to suppress irrelevant information. In addition, bilinguals are particularly adept at switching between tasks without becoming befuddled. In a number of studies, for example, participants were required to match figures either according to their color or according to their shape. Whenever the participant is directed at switching from one task to the other, the reaction time increases—a phenomenon termed "switch cost". For bilinguals, this switch cost is lower than for monolinguals, indicating that they can switch between tasks more easily [2].

Yet, it remains difficult to pin down the exact nature of the bilingual benefit. Is it task switching? Is it inhibition, or working memory? "There is a big debate in the literature over whether or not it makes sense to take executive control and divide it on into the sub-component processes", said Bialystok. "My view now is that it doesn't make sense. Underlying all of these components there is something generic about executive control and that is the ability to use attention appropriately".

There is in fact more to bilingual advantage than a decrease in reaction time in behavioral experiments. Juggling two languages reorganizes the structure and function of the brain, as has been shown in brain-imaging studies. For example, a network including

fronto-temporal and subcortical regions was active in bilinguals, but not in monolinguals, during tasks that require interference suppression [3]. Bilinguals use the anterior cingulate cortex (ACC) more efficiently in conflict monitoring [4]. Gray and white matter increase in several brain regions required for language processing and executive control. But most importantly, such changes seem to contribute to the so-called cognitive reserve that would protect from age-related cognitive decline and Alzheimer's disease. The exact mechanism is not fully understood, but Bialystok has a hypothesis. "As dementia begins to compromise cognitive performance, bilinguals seem to use their intact structures more than monolinguals to compensate for failures in the areas that have been struck by dementia", she explained.

The secret behind the bilingual advantage lies in the way languages are represented in the brain. "Recent neuroimaging studies show that, for the most part, it's the same brain tissue that supports both languages", said Judith Kroll, a cognitive scientist and Distinguished Professor at Pennsylvania State University in the USA. "This suggests that each time one language is activated, both are going to come online at the same time". Yet, errors in language selection rarely occur, which suggests the existence of a control mechanism to prevent interference. "There is now a fair amount of studies that show that language selection in a bilingual is carried out by the ordinary domain-general executive control system", said Bialystok. "The executive control system is recruited into everyday language processing so you are using it all the time. It becomes

stronger and more efficient. It becomes a better cognitive system”.

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A study by Augusto Buchweitz and colleagues at Carnegie Mellon University, Pittsburgh, USA, demonstrated the extent to which language representations in the brain overlap [5]. Based on functional magnetic resonance imaging (fMRI) data of presenting proficient Portuguese–English late bilinguals with words in one of their languages and machine-learning techniques, they were able to decode fMRI images of certain words: Intriguingly, this worked when the words were presented in either language. The finding suggests that the same neuronal networks are engaged for processing words, even if the second language, as in this case, was acquired later in life.

“When most people think of learning a new language as an adult, they think that it’s a matter of adding a new system”, said Kroll. But in fact, it is also changing the existing language system as the constant interaction between the two languages leads to a convergence. “As the two languages are essentially sitting in the same place in the brain, the second language comes to have consequences for the native language, at the level of the grammar, phonology, lexicon”, said Kroll.

Juggling two languages is a complex task. First of all, it requires interpreting environmental cues to select the appropriate language. Speaking to a French colleague requires French, even if other people in the vicinity speak English. In addition, the non-target language needs to be effectively inhibited to avoid language intrusions. The language context may also have to change quickly when, for example, an English person enters the conversation. Jubin Abutalebi, cognitive neurologist and Assistant Professor of Neuropsychology at the University Vita Salute San Raffaele, Milan, Italy, investigates how these aspects

of bilingualism are implemented in the brain. Based on the analysis of several brain-imaging studies, he and his colleagues have developed a model describing how the executive control networks are involved [6]. According to the most recent version, suppressing the non-target language and maintaining the target language are performed by the left prefrontal and inferior cortex (suppression) and the parietal cortices (target maintenance). The ACC has been implicated in choosing the right language depending on the context and to verify whether language and requirements still match. “We use the ACC to monitor if we have made any mistakes”, Abutalebi describes its role. “The ACC cannot correct mistakes, but it can signal to other brain regions that a mistake has occurred”. Finally, subcortical areas—most notably the caudatus of the basal ganglia—have been implicated in language switching. The ACC communicates with other brain regions via the caudatus, which then modulates the activity of the prefrontal cortex according to Abutalebi. “The role of the caudatus in language switching has also become apparent also in bilingual patients with lesions in this area. They either switch between languages pathologically or else one of the languages is blocked completely”, he added.

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The functions of these brain regions have been elegantly differentiated in an experiment by Jubin Abutalebi together with David Green from the University College London, UK, and other colleagues [7]. They investigated neuronal activity during language switching in trilingual participants, taking relative language proficiency into account. The researchers found that switching between languages increased activity in the ACC, regardless of proficiency. In contrast, activity in the basal ganglia varied with language proficiency. Switching from the most to the least proficient language induced the largest response. This is consistent with the model, as the demand on

language selection is expected to be largest when switching to the least proficient language. Finally, activity in the prefrontal cortex did not vary with language switching, conceivably because it plays a role in the sustained inhibition of a language that is not in use.

Of course, there is more than one way of being bilingual. Some have learned both languages early in childhood, whereas others learned their second language later in life. Some bilinguals are very proficient in their second language, others are not. Some master languages as diverse as English and Chinese, others speak more similar languages, like Spanish and Catalan or Cantonese and Mandarin. Some use both languages every day, some don’t. “All of these different demands of language use are going to create different demands on the brain. The outcome is bilinguals who reveal different consequences of language experience”, Kroll said. For example, Kroll and her colleagues showed that different neuronal circuits are used for language inhibition in different language tasks [8]. Thus, different ways of using language may train different brain regions and thereby impact on the cognitive advantage.

Surprisingly though, the age of acquisition does not seem to be a crucial factor. “We do not see any difference between bilinguals that have learned their second language early or late. But proficiency does make a large difference. You can benefit from bilingualism only if you speak two languages very well”, Abutalebi explained. “We have preliminary data saying that mastering two similar languages is even more effective in training the brain. This is possibly because more attention is required to keep them apart”, said Abutalebi.

Last but not least, the context in which languages are used can vary widely. Some bilinguals, depending on social circumstances, switch a lot. There are entire bilingual communities, such as Catalonia or Luxemburg, where people frequently switch between languages. For other bilinguals, languages are used quite separately. Many immigrants, for example, use one language at home and one at work. According to Abutalebi, there is a link between cognitive benefit and switching. “The more you switch, the better”, he said. “We assume that bilinguals that code-switch frequently are the better multitaskers”.

The connection between switching and cognitive advantages is still a hypothesis. But there is some evidence. For example, Anna Soveri from Abo Akademi University in Turku, Finland, and her colleagues investigated whether frequency of language switching, age of second language acquisition or the amount of language use in Finnish-Swedish bilinguals impacted on their performance in a number executive function tasks [9]. They found the strongest correlation between language switching and performance in a set-shifting task, in which participants view a number-letter combination and made judgments either about the number or about the letter, depending on where on the screen the number-letter pair appeared. Bilinguals that frequently switch language in their everyday life were more adept at switching between the two tasks.

Of course, being bilingual comes at a cost. Children learning two languages simultaneously are delayed in terms of vocabulary in each of their languages, although their total vocabulary is comparable to their monolingual peers. Bilinguals also experience some linguistic drawbacks as adults. Mastering more than one language may hamper lexical access and lead to more tip-of-the-tongue experiences. But the advantages clearly outweigh the disadvantages—particularly in Alzheimer's disease, the cognitive gains of bilingualism become apparent. A cognitive reserve, built up by bilingual brain training, can make a difference between being able to lead an autonomous life or not. "Learning a second language is a good preventive measure against Alzheimer's disease. This is much more important than the discussion about possible advantages or disadvantages

in early childhood", Abutalebi said. Initial symptoms of Alzheimer's disease may show up as much as 5 years later in bilinguals as compared to monolinguals [10]. "Acetylcholinesterase inhibitors postpone the onset of the disease for about 1 or 2 years. Being bilingual is much more effective than any current medication. But it still has not yet received the appropriate attention", Abutalebi added.

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While for a long time educators had been advised to not confuse children with two languages, science has meanwhile debunked this idea. Most scholars agree that bilingualism leads to brain changes that bear a cognitive benefit. Research is now proceeding to provide a more detailed analysis of this advantage. "We don't yet know what it is specifically bilinguals do that produces these changes in the brain", said Kroll. "There are many different ways in which bilinguals have to solve conflict and one of the goals in the ongoing research is to try to understand the consequences are of each of these types of language conflict for cognition".

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