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Cognitive Benefits of Bilingualism across the Lifespan

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Abstract: This paper reviews the effects of bilingual learning on human cognitive abilities and compiles relevant research results. The cognitive advantages of bilinguals over monolinguals are revealed through the exploration of memory, attention regulation and cognitive switching. In addition, the article analyses in depth the close connection between language and cognition, as well as the impact of bilingual learning at different ages, especially on children. Finally, the impact of bilingual learning on brain mechanisms is explored, highlighting the importance of left-right brain coordination and networked representation of language functions. These studies provide an important theoretical and practical basis for a deeper understanding of the benefits of bilingual learning.

The impact of bilingual learning on human higher cognitive abilities has been extensively studied in the past decades (Bialystok, 2009).[2] Since Peal & Lambert (1962) verified that bilinguals have significant advantages in intelligence levels compared to monolinguals, bilingual cognitive advantages have been confirmed in more domains, such as memory, attention regulation, cognitive switching, learning strategies, metacognitive abilities, and many others.[16] Over the past decade or so, the bilingual cognitive advantage in the field of creative thinking has also been supported by a growing body of experimental evidence from scholars (Leikin, 2013).[13-14]

As the economy becomes more globalized, bilingualism is becoming an increasingly common phenomenon. It is estimated that half of the world's population speaks two or more languages (Grosjean, 2012), and the benefits and acquisition costs of bilingualism are becoming an important area of research in cognitive science in the context of globalization.[11] Previous research has extensively explored the effects of bilingual experiences on executive functioning, finding that bilinguals perform significantly better than monolinguals in attentional control, inhibitory control, cognitive control, cognitive switching, and conflict monitoring (Prior & MacWhinney, 2010), tasks that require the involvement of executive functions that modulate attentional resources to obtain relevant information and ignore distracting information (Poulin- Dubois, Blaye, Coutya, & Bialystok, 2011).[17][18] Bilinguals who switch between two languages for long periods of time require executive functions to select the target language and suppress interference from the inactive language, thus showing a significant bilingual cognitive advantage effect on executive functions (Costa & Sebasti án-Gall és, 2014).[8]

1. A study of the relationship between language and cognition

1.1 Language and Thinking

According to psychology of language research, language is "a set of symbols and principles that unite those symbols that can be communicated and understood". Only through the use of language can people engage in complex abstract thinking, and thinking is the core structural component of the cognitive psychological process, so thinking and language must be closely related. In China, learning and using foreign languages (especially English) has become an important part of school education and even social education, and a significant number of Chinese people are able to use two or even more different languages. Of course, due to regional and educational differences, there are still a considerable number of people in China who only speak one language. So, are there any differences in the cognitive psychology of monolinguals and bilinguals, and what are the psychological advantages and disadvantages of learning multiple languages? This cannot but be a major question that must be considered in modern foreign language teaching. Some research findings have found that bilinguals perform more intelligently in solving insightful tasks compared to those who use only one language. This is because the use of different languages can lead to changes in the way a person perceives the world around him or her, thus helping to enhance the person's thinking process and problem-solving skills. Language is an important part of human society for communication and can have an equally important impact on an individual's development and self-actualization. Other studies have found that mastering more than two languages helps individuals achieve greater success in today's world and helps improve cognitive functions, such as being more cognitively flexible and creative, thus making them smarter and more intelligent. A thinking study done by Indian scholars showed that bilinguals have more divergent thinking than monolinguals when it comes to solving epiphanic problems. The researchers presented the subjects with three epiphanic and three non-epiphanic problems. It was found that monolinguals were better at solving non-epiphanic problems than epiphanic problems, and late bilinguals showed a similar tendency, while early bilinguals were better at solving epiphanic problems. The results of this study provide supportive evidence for early bilingualism. In addition, this study found that bilingual children outperformed monolingual children in terms of academic achievement and social performance. The author suggests that this may be related to the greater use of English for everyday communication in India, which may not be appropriate for all countries and cultures. However, in this day and age when Chinese society is becoming increasingly international, there is no doubt that mastery of multiple languages has a positive effect on facilitating international social communication and even on enhancing individual social values.

1.2 Brain mechanism of bilingual learning

According to modern brain science research, the human brain can be divided into four main functional areas, namely the frontal, parietal, occipital and temporal lobes. The main functions of the frontal lobe are motor, memory, planning, reasoning and judgment, impulse control, etc. The Broca's area, which is well known to psychologists, is located in the frontal lobe. If this area is damaged, even if the articulatory organs are normal, a person cannot communicate and communicate verbally (even if he or she can understand the language expressed by others normally). The parietal lobe is responsible for the processing and integration of various types of somatosensory information (e.g., touch, pain, etc.), and is also related to functions such as language and memory. The occipital lobe is mainly related to visual processing, while the temporal lobe, which processes auditory information, is mainly divided into auditory processing, and Wernicke's area, which is indispensable for understanding language, is located in the temporal lobe area. In addition, the human brain is

composed of two hemispheres, the left and right, which are connected by the corpus callosum, and this special structure makes their functions different. The left hemisphere of the human brain is responsible for language, mainly related to grammar and phonology, while the right hemisphere is mainly related to the emotional and spatial properties of nonverbal stimuli. It is obvious that language is closely related to the brain, and language acquisition and bilingual education cannot be studied without studying brain functions. However, there is still a lot of controversy as to how the left and right hemispheres of the human brain are specifically associated with language and which language activities depend on which neural mechanisms.

2. The effect of bilingual training on different age groups

2.1 Children

From the early 1900s to the early 2000s, it was believed that bilingualism had negative side effects on children's intellectual development. Many researchers believed that bilingual children often had to think in one language and speak another, and as a result they became mentally uncertain, confused, and even mentally retarded. Many studies have concluded that bilingualism has negative side effects on intellectual development. However, earlier studies lacked explanatory results because they did not control for variables such as socioeconomic status, parental occupation, length of residence of the child, and cultural differences in testing. The results of this study were compared with those of French-English bilingual and French monolingual children matched for age, gender, and socioeconomic status. The results found that bilingual children scored significantly higher than monolingual children on non-verbal IQ tests and on total IQ tests.

Several researchers have successively found experimentally that proficient bilingual children exceed monolingual children in cognitive flexibility, creativity, meta-linguistic awareness, concept formation, visual-spatial ability, analogical reasoning, categorization skills, and field independence. There were no significant differences between the century-old and monolingual children. This suggests that the advantage of attentional control shown by bilingual children in verbal tasks is cross-sectional, but is influenced by the level of language proficiency. Only when children were highly proficient in both languages could the attentional control advantage be demonstrated in different domains. Moreover, the fact that the unskilled bilingual children in this study were less proficient in their first language than in their second language may suggest that the level of proficiency in the first language also influences the transfer of attentional control dominance from the verbal processing domain to the nonverbal domain. Most subsequent studies have concluded that bilingualism promotes the development of certain cognitive abilities in children. The debate has shifted from whether bilingualism facilitates or interferes with cognitive development to the stage at which bilingualism has a positive effect and the extent and degree of that effect.

Recent researchers have placed more emphasis on exploring the effects of bilingual learning on children's cognitive functioning. It is proposed that language processing consists of two components-analysis of linguistic representations and attentional control of representations. The former refers to the analysis or reconstruction of the mental representation of language. The latter refers mainly to the selective attention to different representations or different aspects of representations, which is performed in real time. The importance of these two components is different in different language tasks. A word size judgment task was set up in which monolingual and bilingual children were asked to determine which word was larger in and such a word pair. To perform this task correctly, children had to ignore the size of the object to which the word referred and selectively direct their attention to the length of the word itself, i.e., children were required to selectively control their attention. It was found that bilingual children were better able to recognize that word size was different from object size and therefore answered the question correctly. Using the same task, first-grade English-speaking

children who had been learning Italian for several months also showed word awareness advantages.

Bialystok examined the effects of bilingual learning on children's meta-linguistic awareness using a grammaticality judgment task. She asked children to make judgments only about syntactic violations among sentences that included syntactic violations but were semantically sound and those that were semantically but syntactically sound. Determining whether a sentence violated syntax required more analysis of syntactic structural representations, whereas determining whether a sentence violated semantics required subjects to ignore the irrationality of the sentence's meaning and pay selective attention to the sentence's syntax. In the task requiring attentional control, both very proficient and non-fluent bilinguals performed significantly better than monolingual children, but in the task requiring representation analysis, only very proficient bilinguals outperformed monolingual children. In the case of English-Spanish bilinguals, it was found that they outperformed monolingual children on tasks requiring attentional control, such as evaluating and correcting sentences. The above studies suggest that bilingual children show an advantage in attentional control on verbal tasks compared to monolingual children.

If bilingual children's attentional control over language processing is facilitated by bilingual learning, then this facilitated general cognitive ability should be cross-domain and generalized and can be demonstrated in other cognitive tasks. To examine whether the attentional control advantage of bilingual children is generalized, et al. explored the ability of skilled bilingual children, unskilled bilingual children with low second language proficiency, and monolingual children to solve nonverbal problems. In both studies, they designed a sorting task, a block design task, a horizontal plane task, and a juice task. The former tasks required children to sort objects according to different criteria and dimensions, or to assemble blocks into certain shapes, and to draw a horizontal surface according to the tilt of a clear bottle containing water. To successfully complete these tasks, children must ignore task-irrelevant information and selectively direct their attention to task-relevant information. The juice task required children to judge the strength of the liquid based on the ratio of water to juice, which required them to analyze the information. It was found that proficient bilinguals scored significantly higher than unskilled bilinguals and monolingual children on nonverbal tasks requiring high levels of attentional control, but there was no significant difference between bilinguals and monolingual children in solving nonverbal problems requiring high levels of analysis. This suggests that the attentional control advantage bilingual children exhibit in verbal tasks is cross-domain, but is influenced by the level of language proficiency. Only when children were highly proficient in both languages could the attentional control advantage be demonstrated in different domains. Moreover, the fact that the unskilled bilingual children in this study were less proficient in their first language than in their second language may suggest that the level of the first language also influences the transfer of attentional control dominance from the verbal processing domain to the nonverbal domain.

Cognitive neuroscience research has demonstrated that individual growth experiences such as second language acquisition and reading training, as well as changes in growth environment such as family economic situation and family harmony, can have a plastic effect on brain structure and function. Humans have a more advanced brain, and language is considered a uniquely human function. Early studies found that the left hemisphere is primarily responsible for verbal behavior in humans. Among other things, studies of children with brain injury have demonstrated more severe language impairment in children with left hemisphere brain damage. So what exactly are the brain mechanisms underlying language development in children? First, studies in recent years have found that the left hemisphere is not solely responsible for human language behavior; both the left and right hemispheres are involved in the comprehension and processing of language. Studies have demonstrated that the right hemisphere of the brain is also activated during the task of processing and analyzing the phonology of sentences. Second, recent studies have shown that the implementation of language functions in the brain is supported by neural networks. Relatively traditional theories suggest that the

realization of language functions in children is mostly the responsibility of a single functional area, independent of each other and divided into multiple distinct language areas. However, there are also researchers who are gradually recognizing that higher cognitive activities like language are realized by a neural network composed of different brain areas together. The formation of human language neural networks can be divided into two stages: from birth to 3 years of age, when the temporal lobes on both sides of the brain develop rapidly in infants and children; and from 3 years of age to adulthood, when functional selection and connectivity in the brain gradually develop and gradually network. Again, some studies suggest that the development of the child's brain can predict, to some extent, its language development. The study of the amygdala by Ortiz-Mantilla et al. found that for early children, the larger the volume of the left amygdala and the smaller the right amygdala, the better their language skills. In addition, it has been shown that differences in language activity during infancy and differences in the level of brain activity can predict the ability to read and write language at a later time. In general, the study of brain mechanisms of language development in children has important implications for early childhood education.

Mechelli et al. in 2004 assessed second language reading, writing, speech comprehension and output in 22 native Italian speakers.[15] The results of the study showed that learning a second language increased the density of gray matter in the left inferior parietal cortex. Moreover, changes in gray matter density are influenced by the learner's ability to learn and the age of language acquisition. A 2017 study of blind children by Bedny showed that the cortex once thought to process visual information was used by blind children to process auditory information, a finding that validates the great plasticity of children's brains.[1] Scholars implemented the experiment in blind adults as well and found that people who became blind as adults had difficulty calling on the brain's visual cortex in the same way as patients with congenital blindness. This suggests that children's brains are more plastic than adults'.

2.2 Youth

The earliest studies of bilingual experience affecting executive functioning began with inhibitory control, which is commonly expressed as an ability to select and preserve task-relevant information during task processing and the ability to ignore interfering information (Botvinick, Braver, Barch, Carter, & Cohen, 2001).[5] Inhibitory control typically includes interference inhibition and response inhibition (Robertson, Manly, Andrade, Baddeley,&Yiend,1997).[19] The former achieves conflict resolution through attentional control by selecting task-relevant stimuli and ignoring interfering stimuli; the latter primarily inhibits behavioral responses that do not meet current needs (Bunge, Dudukovic, Thomason, Vaidya,&Gabrieli,2002).[6] The classical paradigms of interference inhibition are the Stroop paradigm, the Flanker paradigm, and the Simon paradigm, with later researchers using more variations of the classical paradigm, such as one researcher who found that bilinguals have an advantage over monolinguals in recognizing font colors through the Stroop color naming task (Coderre & vanHeuven,2014).[7] Bialystok,Craik and Luk (2008) studied young subjects using the Stroop paradigm and found that the Stroop effect was smaller for bilinguals;[3] young bilinguals showed faster response times to conflict tasks than monolinguals in the Simon paradigm; middle-aged bilinguals also showed a bilingual dominance effect in the Flanker paradigm (Emmorey, Luk, Pyers, & Bialystok, 2008).[9]

Although a few researchers have argued that bilinguals do not have a significant advantage in cognitive switching (Paap & Greenberg, 2013), more experimental results favor bilinguals' switching ability over monolinguals, e.g., Prior and MacWhinney (2010) used a cue-task switching paradigm to experiment with college subjects and found that bilinguals had a Hernández, Martin, Barceló, and Costa (2013) tested the switching ability of Spanish bilingual and monolingual college students using

an intermittent cue switching task with two types of task cues, implicit and explicit, and found that the restart cost was smaller for bilinguals with implicit cues.[12][18][20] Garbin et al. (2010) studied Spanish monolinguals and Spanish-Catalan bilinguals using a nonverbal conversion task and found that bilinguals exhibited lower conversion costs.[10] National scholars using the Wisconsin Card Sorting Task (WCST) in Chinese-English bilinguals also found a significant advantage in bilinguals' switching ability.

2.3 Elderly

Only recently have researchers begun to look at the relationship between the phenomenon of bilingualism and cognitive control in middle-aged and older adults. Existing research has found that, consistent with studies of children, proficient bilinguals have greater cognitive control in middle-aged and older adults. Furthermore, studies have found that bilingualism slows the decline of cognitive control in older adults.

Zied et al. conducted a comparative study of bilingual inhibitory control in middle-aged bilinguals and older bilinguals, and found that unskilled bilinguals showed a decrease in bilingual inhibitory control with age while skilled bilinguals showed no change in bilingual inhibitory control with age.[21]

They selected two groups of subjects, one group of young subjects with an average age of one year and one group of older subjects with an average age of one year. In these two groups, there were three types of bilingual proficient bilinguals, French dominant bilinguals, and Arabic dominant bilinguals. These subjects were tested by reading the presented color words, the color of the color words, and translating them in turn. The results showed that the older group performed the same as the younger group in the translation task. The French-dominant bilinguals were slower in translating Arabic and the Arabic-dominant bilinguals were slower in translating French, while the differences between the two tasks were not significant for the skilled bilinguals, The Arabic-dominant bilinguals were slower to respond when naming in French. This suggests that there is more interlingual interference among unskilled bilinguals. In all kowtowing conditions, older proficient bilinguals responded faster compared to French-dominant and Arabic-dominant bilinguals, and this phenomenon was also found in middle-aged bilinguals. These findings suggest that the inhibitory control of bilingualism decreases with age in unskilled bilinguals and does not change with age in skilled bilinguals. This suggests that controlling for both languages may improve the efficiency of bilingual inhibitory mechanisms.

A study by Bialystok et al. found that bilinguals were more able to perform controlled processing and that bilingualism slowed the decline of cognitive control in older adults.[3-4] The study used two experiments to compare the Simon test scores of middle-aged and older mono- and bilinguals. The results found that the Simon effect was significantly smaller for bilinguals than for monolinguals, and the Simon effect was smaller for the middle-aged group than for the older group. In the first experiment, subjects with comparable educational backgrounds were selected and divided into two groups according to age: middle-aged and older, with half of the bilinguals and half of the monolinguals being proficient bilinguals. The Simon effect was found to be smaller in the middle-aged group compared to the older group and smaller in the bilinguals compared to the monolinguals. This result suggests that in adults, cognitive control declines with age and that bilinguals have more cognitive control than monolinguals. Considering that the overall response time of the subjects in the first experiment was longer and the Simon effect was larger, the sample of subjects in the second experiment was expanded by selecting 94 subjects and increasing the difficulty of the Simon test: from 28 to 192 in Experiment 1; adding a baseline condition, i.e., presenting the color block in the middle of the screen, eliminating the conflict between target and response positions; and increasing the number of color blocks by A condition for examining working memory was added. The results, in addition to validating the results of Experiment 1, revealed that bilinguals responded much faster

than monolinguals in the conditions requiring more inhibitory control and working memory. This suggests that bilinguals have better inhibitory control and working memory than monolinguals. Inhibitory control and working memory declined with aging, so that monolinguals' inhibitory control and working memory declined more rapidly than bilinguals' with aging.

3. Conclusion

Bilingual users have: better cognitive control, higher thinking flexibility, better performance in dealing with related tasks such as switching, inhibition and conflict monitoring. No matter what age, whether the elderly or children, can enjoy these benefits. Compared with children using a single language, bilingual children have multiple advantages in visual space and verbal working memory. The cognitive and neurological benefits of using two languages will continue from childhood to old age, because the brain can process information more effectively and avoid cognitive decline.

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