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REVIEW ARTICLE

Central auditory processing in bilinguals

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Abstract

Background and Aim: The majority of the world's population is bilingual. Bilingualism is a form of sensory enrichment that translates to gains in cognitive abilities; these cognitive gains in attention and memory are known to modulate subcortical processing of auditory stimuli. Second language acquisition has a broad impact on various psychological, cognitive, memory, and linguistic processes. Central auditory processing (CAP) is the perceptual processing of auditory information. Due to its importance in bilingualism, this study aimed to review the CAP of bilinguals.

Recent Findings: The CAP was studied in three areas: dichotic listening, temporal processing, and speech in noise perception. Regarding dichotic listening, studies have shown that bilinguals have better performance in staggered spondaic word (SSW) test, consonant-vowel dichotic test, dichotic digits test (DDT), and disyllable dichotic test than monolinguals, although similar results have also been reported in SSW and DDT. Regarding temporal processing**,** the results of bilinguals do not differ from those of monolinguals, although in some cases, it is better in bilinguals. Regarding speech in noise perception**,** the results between bilinguals and monolinguals are varied depending on the amount of linguistic information available in the stimuli.

Conclusion: Bilingualism has a positive effect on dichotic processing, no effect on temporal processing, and varied effect on speech in noise perception. Bilinguals have poor performance using meaningful speech and better performance using meaningless speech.

Keywords: Central auditory processing; bilingual; dichotic listening; temporal processing; speech in noise perception

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Introduction

Bilinguals make up more than half of the world's population [1]. There has been a significant increase in the number of studies on how bilingualism affects human language and cognition faculties. The results have shown differences between bilinguals and monolinguals in different areas [2-4]. In bilingualism, two cognitive outcomes are possible; one is that high knowledge and use of two languages affects cognition, regardless of the complexity of the languages (macro level) [5]. For example, it can increase metalinguistic awareness or delay onset of Alzheimer's [6]. Moreover, bilingualism enhances cognitive control and, thus, protects against age-related cognitive decline and postpones the onset of dementia [7]. Another cognitive outcome of bilingualism is that learning two languages affects cognition due to the characteristics of the involved language and how different aspects of the world and life

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are coded by each language [5]. Bilingualism has a direct relationship with cognitive factors such as problem-solving, creative thinking, divergent thinking, independence and concept formation [8]. Anatomical studies have shown that the density of grey matter in the left inferior parietal cortex [9] and asymmetry in the amount of myelinated white matter [10] are higher in bilinguals compared to monolinguals.

In magnetic resonance imaging (MRI) studies, it has been shown that the activation of basic neural circuits is common for first and second language processing, but the level of activity is higher in the second language processing [11]; hence, there is a close relationship between learning different languages and structural, morphological and behavioral changes in the brains of bilinguals [10,12,13]. Learning a second language causes more white matter in the peritoneal region and temporal lobe of the brain. This can be attributed to the effect of further myelination during neural processing, which is essential for learning second language sounds [10]. Studies on bilingualism confirm that second language acquisition has a broad impact on memory and various psychological, cognitive, and linguistic processes. For example, bilinguals have a high ability to focus on the desired information and ignore irrelevant information [14]. They perform better than monolinguals in controlling nonverbal information [15]. Another difference is related to the superior working memory under spatial tests in bilinguals [16]. During other cognitive tasks such as selective attention tasks, the superiority of bilinguals over monolinguals has also been reported [17]. Language engages the dorsal auditory pathway, linked by arcuate fasciculus (AF), and consistent practice to learn a second language can modify the white-matter tract of AF[18]. Koravand et al. showed that bilinguals perform better than monolinguals in subcortical processes, which has been confirmed in electrophysiological tests with speech-auditory brainstem response (speech ABR) [19]. Bilinguals have stronger neural processing of the fundamental frequency of the voice (F0) measured by the frequency-following response (FFR). The F0 is a major cue used for identifying and tracking auditory objects and, thus, is crucial for communication in complex soundscapes [20,21]. Therefore, the study of auditory processing in bilingualism is important. Auditory processing has a cognitive structure based on the input auditory signal, and practically uses its information [12]. Since auditory processing is a term for what we do with what we hear [22], cognitive development makes auditory information functionally useful**.** Auditory processing includes important abilities such as sound recognition, sound localization, attention, analysis, memory, and retrieval of auditory information [12].

Sensorimotor and cognitive processes are used for auditory and speech perception [23]. In most everyday situations, speech is recognized in the presence of competitive sounds [24]. Speech in noise perception generally entails two processes: a) low-level or bottom-up processing such as primary auditory information processing, and b) high-level or top-down processing such as linguistic and cognitive processes [25,26]. Low-level perception skills include auditory stream segregation followed by identification and recognition of the attended signals [24]. Auditory stream segregation is a phenomenon in which two or more repeating sounds with at least one different acoustic attribute are perceived as two or more separate sound sources [27,28]. There are many high-level auditory processes, two of which are syntactic and phonological processes [24]. Many studies have been conducted on bilingual auditory processing. These studies as well as clinical tests on central auditory processing (CAP) in different bilingual and monolingual individuals highlighted the difference between these people. The difference in the CAP of bilinguals affects the results of clinical tests and auditory rehabilitation programs. Therefore, audiologists, linguists, speech therapists, auditory and speech neuroscientists, cognitive scientists, and other related experts should be aware of the effects and mechanisms of bilingualism. In this study, we aimed to review the CAP of bilinguals.

Methods

In this review study, the search was conducted in Google Scholar, US National Library of

Medicine, PubMed, Science Direct, Medline, and SID databases using Medical Subject Headings (MeSH) keywords including: central auditory processing, bilingual, speech in noise, dichotic listening, temporal processing, and bilingual's auditory processing on related studies published from 1978 to 2020. The results of published articles are classified into three general areas related to CAP, including dichotic listening, temporal processing, and speech in noise perception.

Dichotic listening

In dichotic listening tests, two different auditory stimuli are delivered to both ears simultaneously and the subject is asked to repeat the heard stimuli from one or both ears. When the patient is asked to repeat from only one ear, the task is the separation of inputs, but if s/he is asked to repeat from both ears, the task involves the combination of inputs [29]. Research on dichotic listening in bilinguals has been performed by various tests. One of these tests is the staggered spondaic word (SSW) test [30]. The SSW test has been used to evaluate CAP since the early 1960s. It is used by almost 50% of testers in the United States [31]. It consists of 40 pairs of two-syllable words that are stressed. In this test, the second syllable of the first word and the first syllable of the second spondee are presented simultaneously in each of the four conditions: right non competing (RNC), right competing (RC), left competing (LC), and left non competing (LNC) [32]. This test requires attention, auditory memory, speech ability and evaluation power, in addition to figure-ground skill [33]. Studies using the SSW test on different bilinguals have shown that bilingual people perform better in the SSW test than monolinguals [12,33,34]. Ferreira et al. analyzed auditory behavior in bilinguals under the SSW test compared to monolinguals. The subjects were monolingual speakers of Brazilian-Portuguese language and bilingual speakers of Brazilian-Portuguese and German or Italian languages. Their findings showed that the auditory experience provided by bilingualism improved the performance under the SSW test [34]. The increase in the SSW test score in bilinguals is related to their higher cognitive abilities [33] such as attention that has a positive effect on the ability to decode and recognize messages [34]. However, the results of some studies are against this finding. For example, in Silva's study where the auditory performance of bilinguals fluent in English and monolingual speakers of Brazilian-Portuguese language under SSW test was compared, results showed no differences between the groups [35]. Therefore, it seems that further studies should be conducted using larger sample size and more languages.

Another dichotic test is the consonant-vowel (CV) test. In this test, the stimulus consists of six CV syllables (/ga/, /da/, /ba/, /ka/, /ta/, /pa/) presented in pairs to one ear [36]. This test is used to evaluate the auditory capacity of bilinguals compared to monolinguals. The results have shown that bilinguals have higher CV test scores and more auditory capacity than monolinguals [36]. Studies with disyllable dichotic test have also shown that bilinguals' ability is greater [12], while the studies using dichotic digits test (DDT) have shown contradictory results; some reported higher scores for bilinguals [33,35], while others reported equal scores for bilinguals and monolinguals [12,37]. SSW test has more cognitive load than DDT [35], and requires more language proficiency [34]. This can be the reason for the lack of difference in the results of SSW in some studies. Therefore, depending on the type of test, dichotic studies may report different results for bilinguals compared to monolinguals.

Temporal processing

The auditory temporal processing is defined as the perception of sound or of the alteration of sound within a restricted time interval [38]. Given the temporal resolution required for ordinary conversations at a rate of about 140 words per minute, it is expected that temporal processing is considered in the studies on auditory processing and speech comprehension. New findings link temporal processing of auditory information to areas of the brainstem [29]. Electroencephalography (EEG) studies have shown that, in addition to primary sources in the auditory cortices, sources outside the auditory cortex

designated as non-primary cortical sources are involved in auditory temporal processing. These non-primary sources are within the left and right motor cortices [39]. The common tests for auditory temporal processing are duration pattern sequence (DPS) test, pitch pattern sequence (PPS), frequency pattern test (FPT) and gap-in-noise (GIN) test [40]. Pitch is one of the most important parts of speech information, especially in tonal languages, and helps study the affected mechanisms at different processing levels, because of its phonemic status at the syllable level [41]. Some studies have shown no significant difference in the results of PPS [12,40], DPS [12] and GIN [40] tests between bilinguals and monolinguals. Based on these studies, bilingualism has no notable effect on auditory temporal processing abilities. It may be related to the slight differences between the phonetic and linguistic structures of first and second languages [40]. This issue may indicate the need to study the effect of bilingualism on auditory temporal processes in people with one tonal language and one non-tonal language. Oppitz et al. compared FPT and DPS results of bilinguals and monolinguals. They found that the bilingual subjects performed better in temporal processing tests and suggested that this outcome may be related to the role of the left hemisphere in the analysis of temporal aspects of specific sound stimuli for their discrimination [42]. Some studies have shown that bilingualism does not affect temporal processing [12,40,43], while a study showed that bilinguals have better performance compared to monolinguals in temporal processing [42].

Speech in noise perception

As mentioned before, speech in noise perception is done through two general processes: low-level or bottom-up processing such as primary auditory information processing, and high-level or top-down processing such as linguistic and cognitive processes [25]. Auditory tests in the presence of noise are used in many studies as a clinical and research tool [44-47]. Based on the amount of linguistic information, various tests have been designed to assess speech in noise perception, some of which have been used for comparing bilinguals and monolinguals. In a study by Krizman et al., before testing the speech in noise perception, tone in noise detection in bilinguals was carried out using backward masking and tone tracking. In their study, bilinguals had better performance than monolinguals. Researchers believed that the ability to perceive a tone embedded in noise is related to cognitive mechanisms [48]. This supports the hypothesis that bilinguals have higher cognitive abilities [33]. Krizman et al. and Kraus and White-Schwoch using the words in noise test showed no difference between bilinguals and monolinguals [20,48]. In sentence-based tests including hearing in noise test and quick speech in noise test which are common clinical tests for assessment of speech in noise perception, bilinguals scored lower [2,48-50]. Studies on different levels of noise showed that with increasing noise (decreesing signal-to-noise ratio), bilinguals' performance is more affected than that of monolinguals and report lower scores, but the silent mode of their performance is equal [50]. Other studies have shown that bilinguals have poorer performance under hearing-in-noise test when the test material is related to a second language [51].

Based on the above mebtioned studies, it can be said that bilinguals have poorer performance under speech in noise perception tests compared to monolinguals, and its exact mechanism is not clear. Of course, the studies depend on the amount of linguistic information in the stimuli; when there is no linguistic information in the stimulus (pure tone), bilinguals perform better than monolinguals [48]. In other words, bilinguals in their second language have the ability to understand speech at low-frequency noises [52].

Discussion

The existence of structural, anatomical [10,53], functional, and physiological [21,54] differences between bilinguals and monolinguals, as well as differences in their cognitive abilities [14], indicate the differences in their CAP. Since the volume of the corpus callosum is higher in bilinguals than in monolinguals [55] and the relationship between the two hemispheres is important for dichotic abilities, it is scientifically logical

and we can argue that bilinguals' dichotic listening abilities are higher compared to monolinguals and have better performance in CV test, disyllable dichotic test, DDT and SSW test [12,33-36]. Some studies, however, showed their equal performance in DDT and SSW test [12,35,37]; therefore, the type of test is important and more studies using DDT and SSW test are needed. Temporal information is generally processed in the subcortical parts [40], auditory cortex, and non-primary pathways [39]. Despite the differences in the plasticity of bilingual and monolingual individuals [6,21,56], in studies on temporal processing with existing tests, no significant difference was reported between the two groups [12,40,43,57], and one study even reported better performance of bilinguals in temporal processing [42].

In speech in noise perception studies, the complexity of tests makes it more difficult to predict the results due to the simultaneous integration of several important issues: whether or not the used speech material is meaningful, the presence of noise, the ability to control the interfering factor for perception, and test materials in a second language rather than in the first language of a bilingual are the main factors that can cause different results. Therefore, studies have been conducted using different speech-in-noise perception tests [12,40,48,58-60]. Bilingualism, in addition to structural differences in myelination [10], plasticity, and the volume of different parts of the nervous system, seems to make reasonable and expected differences in CAP. A study even suggested that the knowledge of multiple languages improves supra-threshold auditory processing [61].

Conclusion

The cognitive and neural advantages in bilingual people highlight the need to consider how bilingualism improves the activity of the brain and affects the related processes including central auditory processing. Bilinguals perform better than monolinguals in dichotic listening tests; however, in some dichotic tests (dichotic digit test and staggered spondaic word) similar results have been reported. Auditory temporal processing in bilinguals does not differ from that of monolinguals, although in some cases it is better in bilinguals. In speech in noise perception, the results of studies vary depending on the speech material used to test. In a meaningless speech (non-sense syllable), the scores of bilinguals are higher than those of monolinguals, while in a meaningful speech, the scores of bilinguals are lower. Numerous studies have shown the differences between bilinguals and monolinguals, and some studies have noted that, by using suitable tools and methods, they can differentiate between monolinguals with linguistic damage and bilinguals with typical growth.

Conflict of interest

The authors state that there was no conflict of interest.

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