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REVIEW ARTICLE

Speech perception in noise mechanisms

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Abstract

Background and Aim: It will be discussed about five mechanisms in relation to speech in noise perception; including neural encoding and decoding, centrifugal pathways, pitch perception, asymmetric sampling in time and cognitive skills. These mechanisms are related to each other and each is important to recognize speech in noise. In this article, we have tried to rely on the latest studies to describe the mechanisms as mentioned. In the end, we will refer to word in noise training.

Methods: In this review study, the articles related to speech perception in noise published in Google Scholar, PubMed, Scopus and Springer database, were collected and investigated. Keywords include speech in noise and related words.

Conclusion: It can be concluded that mentioned mechanisms have a considerable effect on speech in noise perception. It should be noticed that word in noise training cause these mechanisms to improve by covering some of them.

Keywords: Speech in noise; word in noise training; hearing in noise; speech perception

Introduction

Speech perception in noise (SPIN) is one of the most important challenges for people with peripheral hearing loss. In most cases, people with normal audiometry results suffer from speech understanding in noisy environment; including patients with central auditory processing disorder (CAPD), learning disability (LD), attention deficit/hyperactivity disorder (AD/HD) and aged people (generally over 65 years) [1-5].

Adults who have problem in perceiving speech in noise (SIN), complain about listening fatigue, hearing without understanding the meaning, the discomfort of the presence of background noise and the lack of understanding of conversation in the presence of competing sounds [6]. SPIN is most serious issue in children because the major steps of learning are done in noisy environments during childhood [1,7,8]. But even normal children require more signal to noise ratio (SNR) in order to understand speech than what adults need.

The outcomes associated with defect of SPIN include academic failure which have related destructive effects on communications [7-10]. This has led to a considerable attention on this subject around the world. The purpose of these studies is to understand the mechanisms of SPIN and provide rehabilitation strategies to improve them.

Although there is no agreement on this case, it is essential to answer these two critical questions:

What is the mechanism of SPIN? And what are the strategies to improve these skills?

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Methods

In this article, the studies and theories about SPIN discovered over the past several decades (from 1971 to now) and particularly the mechanisms of SPIN and related improvement solutions have been reviewed. For this purpose, publications in PubMed, Scopus, Springer and Google Scholar were used. Keywords such as word in noise training, Speech Perception, Hearing in Noise and Speech in Noise were used in order to search through the database. The collected data were analyzed and articles related to the topic, were finally extracted.

Finally, our references were limited to the articles on mechanisms of speech perception in challenging environments and available solutions in order to improve perception of speech.

In this section, we have explained the required mechanisms of SPIN which have been verified.

Neural encoding and decoding

Auditory encoding and decoding are the main factors of speech perception. It's clear that one who has low ability of decoding, receives less information from speech in a noisy environment than a quiet place. One of the acoustic aspects affecting speech perception in a noisy environment is the spectro-temporal characteristic of consonants which have less intensity [1,11]. Thus, neuron's ability of decoding this limited information is so essential for recognizing speech [3,12].

The ability of neural decoding at subcortical and cortical levels is required to understand speech in the presence of noise [3,13,14]. For instance, patients with learning disabilities have deficits in SIN. Many studies on LD patients have used cABR by presenting speech stimuli in the background noise. This studies have proved that the auditory-evoked responses recorded in this situation would indicate abnormalities [1,12,14-16]. In fact, the presence of noise results in a distortion in the neural response time and alters wave latencies in LD patients, whereas the noise presentation only reduces the amplitude of the waves in normal people. These abnormalities are due to the poor ability of brainstem and subcortical pathways to decode spectro-temporal characteristics of the incoming sound in LD patients [1,16].

Moreover, we are aware that cortical p1-n1 waves can represent some aspect of auditory processing such as frequency and time encoding in addition to representing the development of the central auditory system [17,18]. Anderson et al. proved that p1-n1 complex amplitude was reduced in people with low ability of SPIN [19].

To summarize, the noise can disturb specific acoustic characteristics of speech (spectro-temporal quick changes) and robust neurological function is required to overcome this challenge. Since noise will reduce synchronization and the number of respondent neurons to speech, it causes an effect similar to reducing effecttive intensity of signal [13].

Pitch perception

The fundamental frequency (F0) of the speaker is an important factor for SPIN because speech components can be grouping across frequency and over time by which helps to identify speaker [20-22]. Studies have shown that listeners would like to pay attention to F0 in the presence of noise and to use other information superimposed on that (pitch, formants) [23]. Many behavioral studies verified that the pitch perception (determined by low harmonics) can be considered as a significant factor on improving SPIN.

Two studies done separately by Anderson et al. and Song et al. provided new information regarding this subject. They concluded based on cABR results that those listeners who show robust representation of F0, have greater ability in SPIN [3,24]. Thus, subcortical decoding of pitch results in a variation of SPIN in different listeners.

Asymmetric sampling in time (AST)

Asymmetric sampling in time theory which was stated for the first time by people, refers to this fact that asymmetry of hemispheric neural oscillations is a basic biological factor simplifying speech perception [25].

As we know the left and right auditory cortices are specialized to process acoustic features at different time scales, such as those conveyed by speech, simultaneously. Converging evidence suggests that slow, low-frequency temporal features (~200ms; 3-7Hz; syllables) are biased to right hemisphere auditory cortex, whereas fast, high-frequency temporal features (~20-50ms; 20-50Hz; phonemes) are biased leftward [26,27].

Thompson et al. tested this theory in 2015. They believed that sampling in cerebral hemispheres asymmetrically cause speech perception in challenging environments to be simplified. They divided the children based on the SPIN abilities into two groups including Top SPIN and Bottom SPIN. Subsequently, 32 channels electroencephalography (EEG) done on these children. It was concluded that high-frequency cortical oscillatory activity was more left lateralized for children who were better perceivers of speech in noise [28].

Centrifugal pathways

Centrifugal pathways were discovered by Held for the first time in 1893. In fact these are pathways in auditory system which have been innervated from higher levels to lower ones [29]. Olivocochlear bundle (OCB) is one of the most important pathways extending from superior olive to hair cells. This was discovered for the first time by Rasmussen [30]. It is suggested that the OCB helps protect cochlea from acoustic trauma, involved in selective attention and also assists in the detection of signal in noise [31]. Winslow and Sachs suggested that the electric stimulation of OCB (Most the medial branch) would be able to cause masking in single auditory nerve to reduce [32]. It was also noted in subsequent studies that OCB stimulation could lower the detection thresholds of tones in noise, commonly about 5dB [31]. Kim et al. verified that MOC had a direct relation to the ability of SPIN [33].

Pathways which lead to cochlear nuclei could be pointed out among other centrifugal pathways. The majority of these inputs arise from superior olivary complex (SOC), reticular formation and inferior colliculus. A role for the cholinergic input to the cochlear nucleus in the discrimination of signals in noise was shown in behavioral experiments by Pickles and Comis [34].

The auditory cortex is a rich source of centrifugal fibers to the inferior colliculus (IC) and medial geniculated body (MGB). The corticofugal fibers can affect frequency-specific processing, temporal processing, and representation of sound location and also enhance stimulus adaptation that helps system to respond to novel stimuli and improving the quality of signal [31].

There was a considerable finding in the Anderson et al. about cortical waves. In this study, the n2 wave amplitude became low while providing signal in the presence of noise in those who had better ability to recognize speech in noise than the others. That was due to increasing the inhibitory effect of higher levels reducing the noise effect and improving the speech signal quality [19].

Cognitive skills

Arlinger et al. published an article titled "the emergence of cognitive hearing science" in which they concluded that "auditory system and cognitive functions are so integrated" [35]. The main cognitive functions consist of attention, short-term memory and working memory [7]. Cognitive functions are considered compensatory mechanisms of auditory system in some cases such as hearing loss, the lack of spectro-temporal encoding and sensory input [36]. It has been suggested in several studies that there is a relation between attention and auditory memory with SPIN [37]. The results of brain imaging suggest that the thickness and volume of the prefrontal cortex -that has a lot of connections with attention and memory area- are correlated to the ability of SPIN [38]. On the other hand, studies done on patients who have deficit in attention and auditory memory, verify that these patients have a deficit in SPIN as well [39,40].

Thus it can be concluded that higher levels of cognitive function can reinforce bottom-up pathways by influencing up-down and also cause the quality of the signal to improve [7,41].

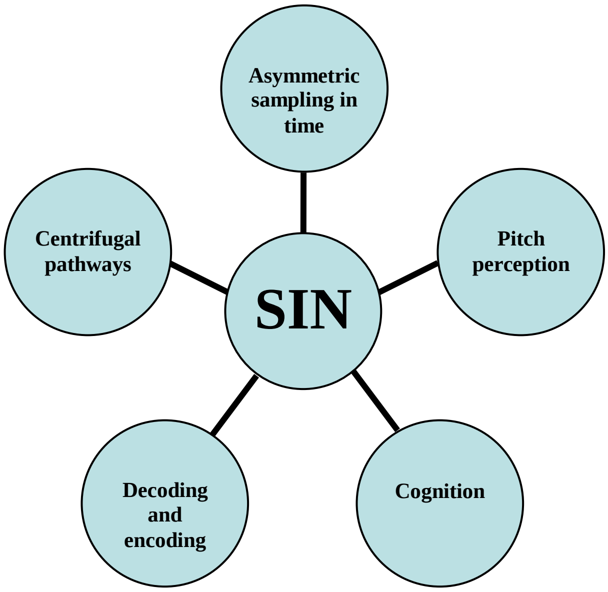

Fig. 1. Mechanisms that involved in speech perception in noise, AST; asymmetric sampling in time, SIN; speech in noise.

Improvement mechanisms

The improvement mechanisms of SPIN can be easily understood by knowing about the inability causes of speech recognition in noise. Many procedures have been suggested to improve this ability. In several studies, the effects of auditory training, music therapy and cognitive training on improving SPIN, have been shown [1,7,12,37,42-48]. These methods cause SPIN to improve by increasing neural firing, improve timing representation and optimization of up-down pathways.

We will continue with word in noise training (WINT). That's because this exercise is thoroughly unique to auditory system and also is adaptive to buffalo method. It has become so popular among audiologists [44].

Word in noise training (WINT)

Central auditory training programs has been considered much more seriously than the past. One of these programs is WINT that was mentioned as one of the most important exercises in buffalo model. WINT is commercially available in two forms of WINT1 and WINT3. WINT3 has a high flexibility advantage over WINT1. It means that audiologist is able to follow his plans by changing SNR, stop or proceeding the program. The basic procedure for both program is essentially the same.

WINT contains two tracks. One track is made up of 600 primary level words that are divided into 60 subgroup of 10 words each. The other track is multitalker, eight speaker babble. Eight subgroups are presented in one session. The first 10 items are given with no noise and speech presented at 62dBHL. The next subgroup started with a SNR of about +12dB. Then on each subsequent sub list, noise increased 2dB until the SNR is zero.

The effect of WINT on the auditory ability of children with auditory processing disorder (APD) included in tolerance-fading memory (TFM) group, has been clearly observed [44,49].

It's seems that Katz and Burge were the first who provided use of speech training in presence of noise to increase the ability of SPIN. 49 learning disabled (LD) children were trained during eight sessions that each took 30 minutes. Finally their SPIN ability were improved [50].

Speech in noise training were proposed by Ferre under the title of "desensitization exercise". He presumed that having patients do these exercises will desensitize them to noise and will improve their speech comprehension. Although the last results didn't represent any improvement in children [42].

In the same year, another study was done on children with central auditory processing disorder (CAPD). Masters et al. verified that desensitization to noise training is able to improve SPIN among the children who have been classified as TFM according to buffalo classification [47].

Conclusion

Many studies have been conducted about the mechanisms of SPIN. The growing trend of research indicates the importance of SPIN in speech perception, language skills, communication and learning. Among theme several studies have been conducted to find out mechanisms of SPIN (such as the summary of findings discovered in Fig. 1). These include: auditory decoding and encoding, pitch perception, asymmetric activities of the hemispheres and cognitive functions. These are factors which can affect SPIN.

Word in noise training (WINT) supports the major centers involved with SPIN in order to gain a better understanding by improving the subcortical neural decoding, cognitive functions and relation between them by centrifugal pathways. It's recommended to use this training clinically to improve the abilities of patients who suffer from SPIN.

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