Review Article

Review of the Factors Affecting Dichotic Listening

Amir Majidpour[1], Mahshid Moheb Aleaba[2], Maryam Aghamolaei[1], Ahmadreza Nazeri[1*]

[1.] Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[2.] Department of Audiology, School of Rehabilitation, Arak University of Medical Sciences, Arak, Iran

Use your device to scan and read the article online

Citation: Majidpour A, Moheb Aleaba M, Aghamolaei M, Nazeri A. Review of the Factors Affecting Dichotic Listening. Aud Vestib Res. 2022;31(2):74-83.

https://doi.org/10.18502/avr.v31i2.9111

Highlights

- An enhanced right ear advantage (REA) can be observed when the memory load increases
- Men seem to be more lateralized in verbal tasks than women
- Training on focusing the left ear can reduce the REA or increase left ear advantage

Article info:
Received: 04 Aug 2021
Revised: 28 Aug 2021
Accepted: 21 Sep 2021

*** Corresponding Author:**
Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
ahmadrezanazeri49@gmail.com

ABSTRACT

Background and Aim: Dichotic listening (DL) test is a non-invasive method used to study hemispheric asymmetry, hemispheric dominance for language processing, or brain lateralization. In addition to the type, concurrence, and the intensity of stimuli presented to the ears, other factors exist that may have less effect on the DL test results. This review study aims to find these factors.

Recent Findings: The factors that affects the DL included ear advantage, attention, working memory, gender, and top-down and bottom-up factors. These factors were reviewed and discussed in detail so that more precise test results can be obtained. Moreover, due to the significant effects of each factor on the test results, manipulation of these factors was also reviewed.

Conclusion: According to the results of previous studies, ear advantage, attention, working memory, gender, and top-down and bottom-up factors play an important role in the interpretation of DL results; their negligence during the test can affect the outcomes and provide incorrect brain lateralization results.

Keywords: Dichotic listening; ear advantage; top-down; bottom-up; working memory; attention

Introduction

The act of listening is not limited to the detection of acoustic stimuli; it also includes correct decoding, perception, recognition, and interpretation of those stimuli. The central auditory nervous system (CANS) is a very complicated system responsible for recognizing and interpreting a wide range of auditory inputs, ranged from very simple nonverbal acoustic stimuli to highly complicated speech messages. Several underlying neurophysiological and cognitive mechanisms are involved in this process; even very simple auditory events are affected by higher cognitive functions like memory, attention, and learning. Therefore, the interaction between bottom-up and top-down processes determines what is finally experienced by listeners. Hence, one can state that although the analysis of an acoustic signal is initially based on recognition and processing by the CANS, higher-level cognitive and behavioral factors have a significant effect on the listener's ultimate ability to recognize and interpret the acoustic signal [1, 2].

There have been studies conducted on central auditory processing factors using the dichotic listening (DL) technique. The DL technique is the process of receiving different stimuli presented simultaneously to each ear under divided-attention condition. Listeners experience two streams of sound, each localized at the ear to which it is presented. A common result for the verbal stimuli (phonological or linguistic) is that the stimuli presented to the right ear are reported more correctly than to the left ear, which is known as right ear advantage (REA) [3, 4]. In return, a left ear advantage (LEA) is achieved in a dichotic condition with nonverbal stimuli, such as tonal sequences, melodies, or emotional stimuli [5]. The theory of structural model is the most widely supported theory for the ear advantage effect in DL [6]. This theory suggests that DL is associated with brain asymmetry through dominant contralateral auditory pathways, leading to a higher presentation of verbal inputs in the left hemisphere dominant for language. According to this theory, during a dichotic presentation, the contralateral auditory areas of the brain are far more operative; verbal stimuli delivered to the right ear may have a total connection to left-hemispheric processing centers, whereas the stimuli to the left ear is relocated throughout the corpus callosum to reach speech processing region in the left hemisphere. Furthermore, nonverbal stimuli delivered to the left ear have direct access to the processing area of the right hemisphere. It has previously been demonstrated that the REA may be altered systematically by changing the top-down instruction or bottom-up stimulus features. Top-down instruction is commonly accomplished when participants are instructed to concentrate and report from only one ear [3, 7, 8]. Compared to a free-recall condition with no attention (non-forced condition; NF), directing attention to the right ear (forced right attention; FR) tends to increase the REA. On the other hand, the ear advantage progressively diminishes or is even changed when participants are instructed to pay attention to the left ear (forced left attention; FL). The inter-aural intensity difference is changed for manipulation of bottom-up stimulus features [8].

There is a widespread assumption stating gender differences in particular intellectual abilities. Many studies have been conducted to assess this assumption, summarized by Garai and Scheinfeld [9]. Other recent reviews and meta-analyses have shown that men and women have different cognitive abilities. It is now well acknowledged that gender differences affect verbal and spatial abilities. Based on this fact, several explanations have been made for gender differences. Many of them have been investigated; a few of them have been proven wrong and some still remain. It is perplexing that various review studies have reported different findings on gender differences in brain lateralization [10, 11]. Considering these issues and their significant effect on DL, the present study's main goal was to list all of these variables and evaluate their impacts which seems to be essential in this field, because some of these variables or factors may be overlooked during DL evaluations which may lead to misdirection or misinterpretation of the results.

Methods

In the present review study, a search was first conducted in PubMed, Science Direct, Springer, Elsevier, and Google Scholar databases on articles without limitation in their publication year by using the following keywords: dichotic listening, ear advantage, working memory, attention, gender, top-down and bottom-up factors on dichotic listening. The inclusion criteria were availability of full-texts and being a clinical trial using DL as a base test. The abstracts, case reports, and non-English articles were excluded from the review. Based on these criteria and the study purpose, 25 articles were reviewed, categorized into six main groups (Table 1) including REA, attention, working memory, gender, LEA, and top-down and bottom-up factors.

Right ear advantage

Both brain hemispheres have a homologous anatomical structure. However, in various cases, higher-level cognitive functions are asymmetrically distributed between them [12]. Wernicke [13] and Broca [14] presented one of the most convincing examples of this asymmetry. They found that lesions in the left hemisphere interfere with speech and language perception and production. Kimura published a leading paper in 1967 on the neuroanatomy and neurophysiology of REA [12]. According to her, REA results from the direct access of the right ear to the left hemisphere which is dominant for language processing; this is because of the superiority of the contralateral auditory nerve fibers from the cochlear nuclei to the auditory cortex, whereas the left ear auditory input is transmitted from the right hemisphere (non-dominant) through the corpus callosum to the speech processing area in the left hemisphere. In other words, the auditory input of the right and left ears has direct access to the left and right hemispheres, respectively, through contralateral pathways resulting from suppression or inhibition of ipsilateral stimuli in DL conditions [12, 15, 16]. Pollman et al. found a good correlation between Kimura's model and their study of vascular lesions in the anterior, middle, and posterior areas of the corpus callosum [15]. This model was evaluated and confirmed through the DL paradigm using consonant-vowel (CV) syllables presented in Hugdahl et al.'s study [16].

Conventional DL tests mostly use English CV syllables. The stimuli used in these tests consist of six stop consonants (/b/, /d/, /g/, /p/, /t/, /k/) followed by a vowel (/a/). Dichotic presentation of CV syllables increases the number of syllables reported from the right ear compared to those from the left ear in healthy individuals which results in REA [17]. REA is usually reported during DL tests when a wide range of English stimuli are used, which is an evidence of left-hemispheric lateralization [18]. As the auditory nerve fibers pass through the posterior third of the corpus callosum [17], Pollman et al. predicted that patients with posterior lesions of the corpus callosum (preventing signals from transmitting to the left hemisphere) may have a stronger REA than patients with anterior lesions when the information transferred between the hemispheres remains intact [15].

Several theories have been proposed to explain REA in DL, the most significant of which is theory of structural model. This theory suggests that the input stimuli to each ear are more robust in the opposite hemisphere. Hence, the right ear and its afferent fibers can be more functional in transmitting data to the left hemisphere. The specialization of the left hemisphere for speech processing ends because the right ear speech stimuli are processed faster through the contralateral hemisphere [12]. Studdert-Kennedy and Shankweiler stated that both right and left hemispheres equally process the parameters of speech signals. However, the left hemisphere is more appropriate for extracting linguistic features from auditory inputs, and high-level cognitive functions (e.g., linguistic and semantic engagements) may modulate the perception of low-level signals, which leads to the asymmetric function of the hemispheres [19]. REA in DL is not limited to verbal stimuli. For instance, the physical characteristics of vocal stimuli including intensity can modulate the ear advantage. When suprasegmental information such as pitch is processed, the right hemisphere becomes dominant (LEA). During DL test, the processing of melodies leads to the LEA, while the processing of English syllables leads to the REA, indicating the involvement of the left hemisphere in extracting phonological cues and the contribution of the right hemisphere to the pitch processing [20-22].

The right hemisphere primarily processes suprasegmental information of tones, while the left hemisphere preferentially involves in phonological and lexical-semantic processes. The shift from LEA to REA in DL when the stimulus contains more suprasegmental, phonological, and lexical-semantic information indicates that dichotic listening ear preference depends on hemisphere lateralization during speech listening. Ultimately, one can state that the preference of ear advantage in DL depends on the level of speech and language analyses, which is specialized in both hemispheres [9].

Attention

It is a common experience for many people to cope with various auditory signals at the same moment. This phenomenon is known as the cocktail party effect, in which different auditory streams are generated from several speakers, and the listener has to focus his/her attention on a particular stimulus [23]. In a DL condition, two different stimuli are presented simultaneously, one to the right ear and one to the left ear. In this situation, the resulting REA seems to result from the left-hemispheric dominance for speech and language processing [24]. DL is one of the most frequent and non-invasive techniques for evaluating hemispheric lateralization in clinical and experimental studies. Dichotic presentation of the stimuli may increase the error in lateralization across trials due to shifting attention to the right or left ear. Hence, a forced-attention condition in dichotic paradigms has been introduced where the individual is asked to pay attention to stimuli only in one ear to control the attention effect [23]. So far, it has been assumed that the same underlying attentional and cognitive processing are involved in focusing attention on the right-ear or left-ear

Table 1. Trial characteristics of included studies

Study (author, year)	Participants, age (y), mean (range)	Methods	Finding
		Right ear advantage	
Kimura, (1967) [12]	120 participants	Dichotic digits test	The right hemisphere's superiority in melodic-pattern perception is reflected in greater identification of melodies arriving at the left ear, while the left hemisphere's predominance in speech is reflected in more robust recognition for words arriving at the right ear.
Pollmann et al., (2002) [15]	10 participants with a partial lesion of corpus callosum (6 male, 4 female), (20-66 years), (45±16.19 years) 11 voluntary participants as controls group include 7 male and 4 female (21-66 years), (45±16.23 years)	Dichotic CV syllables test	1) Differences in the distribution of auditory callosal fibers across inter-species 2) Left ear suppression was caused by splinum lesions. 3) Lesions of the corpus callosum anterior to the splenium did not affect laterality scores.
Hugdahl et al., (1999) [16]	12 right-handed male subjects (20–30 years)	CV syllables test	1) DL performance and PET data show the asymmetry effects of the dichotic mode of stimulus presentation. 2) There are activation biases in the temporal lobe, left inferior frontal lobe, right dorsolateral prefrontal cortex, left occipital lobe, and cerebellum.
Studdert-Kennedy et al., (1970) [19]	12 participants, 7 female and 5 male (18–26 years)	Dichotic CVC syllables test	In both hemispheres, the primary auditory system has been equipped to extract the auditory characteristics of a speech sign.
Prete et al., (2016) [20]	400 right-handed participants (19–36 years)	Auditory imagery	In brain asymmetry, the left hemisphere's dominant involvement in auditory imagery may lead to significant lateral biases in mental imagery.
Prete et al., (2018) [21]	50 volunteer participants, 31 females, 19 male (22.79±0.41 years)	Dichotic CV syllables	The use of bilateral HF tRNS in the treatment of language deficits to modulate fundamental speech processing pathways.
Prete et al., (2020) [22]	200 participants, 99 females and 101 males (18–40 years)	Auditory imagery task, during dichotic listening	When describing negative emotional content, the right hemisphere's dominance for negative emotions balances the left hemisphere's dominance for language, resulting in hemispheric asymmetry.
		Attention	
Kompus et al., (2012) [23]	113 healthy participants, 62 male, 51 female (29.3±8.3 years)	fMRI dichotic CV syllables	The left inferior prefrontal gyrus and caudate nucleus were active in the FL condition, while the right inferior frontal gyrus and caudate nucleus were activated in both the FL and FR conditions, as well as in the non-instructed (NF) baseline condition.
Toga et al., (2003) [24]	-	-	Brain mapping and other approaches, as well as ontogeny, phylogeny, and genetic determinants of brain asymmetry, hold a lot of potential for examining factors that control cognitive specialization in the brain.
		Working memory	
Kimura, (1961) [6]	71 participants	Dichotic digits test	1) Both temporal lobes engage in elaborating activity in the same side's auditory receiving area. 2) The left temporal lobe is particularly important in identifying language information in the audio modality.
Penner et al., (2009) [25]	30 German-speaking volunteer participants (28.10±7.6 years)	Dichotic CV syllables test	Working memory mechanisms responsible for increased REA are addressed in hemispheric asymmetry via top-down and bottom-up techniques.
Geffen, (1978) [29]	48 right-handed participant, 24 male and 24 female	Dichotic digits test	Control of directed attention (that improves with development) and left hemisphere specialization for speech processing are used to determine success in dichotic verbal listening (that remains constant).
Tylor et al., (1982) [30]	48 participants, 24 male and 24 female (17–27 years, mean age=21)	Nonsense syllables presentation monaurally	1) The underlying processes that cause asymmetries in other patterns may be comparable to those that cause asymmetries in monaural REA. 2) The intrinsic processing of the monaural approach may be partly responsible for its limited REA dependability.

Study (author, year)	Participants, age (y), mean (range)	Methods	Finding
Gender			
Buffery, (1972) [34]	-	-	-
Hiscock, (1995) [7]	-	-	-
Voyer, (1996) [11]	-	-	Variations in cognitive ability between men and women are caused by differences in laterality. As a consequence, sex differences in laterality may be the source of cognitive sex disparities.
Left ear advantage			
Bethmann et al., (2007) [40]	30 participant German-speakers, 15 male, 15 female (26±6 years)	Dichotic listening fMRI	1) A dichotic listening test cannot identify language laterality in single subjects. 2) According to fMRI data, more than 90% of right-handed adults have left dominant language processing.
Fernandez et al., (2006) [41]	14 children with intractable seizures (13.23±2.29 years)	FDWT fMRI	In pre-surgical patients, the FDWT may give a fast and accurate assessment of lateralization.
Schmithorst et al., (2013) [37]	13 participants (7–14 years)	Diffusion tensor imaging fMRI	LEA may be anticipated by sensory and attentional impairments.
Hugdahl et al., (1997) [42]	13 participants (10–19 years)	Dichotic CV syllables test	The ear advantage in dichotic condition may create artificial left-right classifications which don't match the data's real grouping.
Westerhausen et al., (2018) [36]	-	Dichotic listening with verbal stimuli	When employing the dichotic-listening technique, careful consideration of these variables should be at the core of any experimental design in order to create the best testing environment for assessing laterality and prevent confounding in between-participant and between-group evaluations.
Top-down and bottom-up			
Westerhausen et al., (2009) [8]	35 participants, 19 male and 16 female, (19–35 years), (23.08±3.3 years))	Dichotic CV syllables test	The top-down and bottom-up manipulations are intertwined and should not be considered separate.
Hugdahl et al., (2008) [44]	33 participants, 17 male and 16 female, (21–39 years), (24.8±4.9 years)	Dichotic CV syllables test	When listening to CV syllables in dichotic state, the REA can tolerate an interaural intensity differential of 9 dB before producing a substantial LEA.
Bloch et al., (1989) [3]	18 male participants	Dichotic CV syllables test	The effects of relative sensory intensity are the same in forced attention and split attention conditions.
Tallus et al., (2007) [45]	20 participants, 13 female, 7 male (21–35 years)	Dichotic CV syllables test	The ear advantage was substantially influenced by the interaural intensity difference in the expected manner.

CV; consonant- vowel, DL; dichotic listening, PET; positron emission tomography, CVC; consonant-vowel-consonant, HF; high frequency, tRNS: transcranial random noise stimulation, fMRI; functional magnetic resonance Imaging, FL; forced left, FR; forced right, NF; non-forced, REA; right ear advantage, FDWT; fused dichotic words test, LEA; left ear advantage

stimuli. This assumption has recently been challenged. One of the clear downsides of this assumption is the distinction between FR and FL attention conditions in clinical populations. Patients with schizophrenia, post-traumatic stress disorder, attention deficit hyperactivity disorder, Alzheimer's disease, and Huntington's disease have poor selective attention through the left ear such that they report fewer stimuli from the left ear, while their function in the FR attention condition is normal. Such difference can also be observed in healthy older adults. Youth and older people do not differ significantly in their function under the FR attention conditions; however, the older people are less able to pay attention to the left-ear stimuli under this condition. Therefore, although two FR and FL attention conditions may have a similar effect on the ear advantage, attention to the right- and left-ear stimuli seems to cause distinct cognitive processes [24]. It has been proposed that, under the FR condition, the participants are required to repeat the robust auditory inputs, while under the FL condition, they need to process a weak input in the presence of a competing and more robust stimulus. Both FR and FL conditions need selective attention, where the FL condition requires more processing to select a weaker stimulus [23, 24]. Thus, under the FL condition, one can assume that the brain should use more networks to successfully respond to the weaker stimuli where perceptually salient speech stimuli from the right ear are in conflict with them. It is believed that subcortical brain structures including the striatum and the prefrontal cortex play an essential role in cognitive control. Hence, FL performance is associated with the contribution of the frontostriatal network. This helps explain why the above-mentioned clinical patients have poor selective FL performance [23].

Working memory

As mentioned before, according to Kimura's structural model, the REA observed in DL tests usually shows the left hemisphere's advantage in speech processing and the superiority of contralateral auditory pathway in signal transmission [12]. There are some contradictions in the results of many DL studies regarding phonological lateralization and speech processing compared to Kimura's reports [6], because Kimura did not use phonological stimuli and speech perception paradigms; instead, he used a task developed by Broadbent in 1954 containing three pairs of single-digit numbers presented in rapid sequence and the subjects were asked to immediately repeat as many digit numbers as they could remember in a free-recall condition [6, 25, 26]. Hence, the task used in Kimura's study was actually a working memory task with 6-digit stimuli (3 to the right ear and 3 to the left ear), and the participants were likely used the phonological loop to span the time interval between the presentation of the stimuli and reporting of a series of numbers. The results of her studies showed a marginal REA. Indeed, most of participants could repeat all six stimuli correctly, indicating a ceiling effect. Hence, the functions where DL stimuli are expected to tap may not be exclusively associated with speech perception and language processing [25]. This is consistent with neuroimaging studies which have reported strong activity of the medial prefrontal cortex during DL. High-level cognitive functions such as working memory, are also affected by this brain region [27, 28].

If verbal DL tasks such as dichotic presentation of CV syllables, depend on working memory. The magnitude of REA in dichotic assessment should be changed by manipulating memory parameters such as memory load and serial position effect. Hence, it is assumed that REA in DL depends on the number of stimuli that the participant should remember as well as the order of their presentation. Since the participants split their attention between both ears while simultaneously keeping track of a growing number of stimuli, a working memory task is highly required. The increased use of top-down cognitive processes is reflected in the greater demand for executive functions [25]. As memory load increases, the need for bottom-up processing increases due to the anatomical structure of the auditory pathways. Thus, the question is whether REA is enhanced as memory load increases or not [29, 30]. Penner et al. Examined the possibility of improved REA by increasing working memory load. They used a DL task in three working memory load conditions on 30 participants. Their findings indicated that higher working memory load results in improved REA [25]. The mechanisms that lead to these outcomes have been discussed in terms of top-down and bottom-up approaches and hemispheric asymmetries [25, 31]. Therefore, the degree of lateral asymmetry is affected by the number of items in acoustic memory [29].

The use of distinct beginning consonant sounds for the right- and left-ear stimuli on each trial may influence the REA, which is a potential limitation in clinical studies [25]. Rimol et al. realized that having distinct beginning consonant sounds in the right and left ears results in more significant REA when the right-ear stimulus was an unvoiced syllable and lower REA was resulted when a voiced syllable was used, compared to having the same consonant sound in both ears which resulted in moderate REA [32]. Therefore, compared to a typical CV-syllables scenario, simply adding trials with varied beginning consonant sounds can have little effect on the overall REA [25, 32].

Gender

The idea that gender differences in brain lateralization may affect cognitive patterns has been studied for 40 years [9, 10, 33], since Levy's study in 1972 [33]. Indeed, it may not be coincidental that men perform better in tasks engaged the right hemisphere (visual-spatial tasks), while women outperform men in tasks involving the left hemisphere (verbal tasks). Levy expected that men show more lateralization in verbal and non-verbal tasks than women; however, Buffery et al. predicted more lateralization in women than in men [34]. Levy stated that men have more left-hemisphere advantage in verbal processing, including reading words displayed on a computer screen or repeating dichotically presented syllables. Moreover, men have more right-hemisphere advantage over women in nonverbal tasks such as comparing geometric shapes rotating on a computer screen [33]; however, Buffery et al. predicted gender differences in the opposite direction [34]. A study was conducted by Hiscock et al. based on these two hypotheses. They carried out a comprehensive review of studies on auditory lateralization and gender differences published in six neurophysiology journals. Although monaural tasks were included in their review, their bulk data were DL tasks found in 92 out of 141 (65.2%) available studies. According to them, gender differences were found in only 43 of 141 (35.5%) DL studies, and most of which reported greater lateralization in men than in women. As a result, Hiscock et al. concluded that moderate gender differences in lateralization might be found at population level [7]. Their results supported Levy's theory [35]. Voyer in a meta-analysis of gender differences in perceptual asymmetry, included 396 effect sizes drawn from 266 studies on visual, auditory, and tactile lateralization in 1994. In their review, only the auditory modality was considered. Based on their analyses, there was a significant gender difference in the lateralization effect size such that men showed more lateralization effects than women. This supported the results of Hiscock et al. [11]. The studies showed that the small population-level difference regarding lateralization in men compared to women might be due to the gender effects on the inherent top-down and bottom-up factors in DL [10, 11].

Left ear advantage

In a typical DL task, two different acoustic stimuli are presented at the same time through headphones, one to the right and one to the left ear. Using verbal stimuli, participants usually report more stimuli delivered to the right than to the left ear. This precise mechanism of this process is still unclear. There is valid claim that REA reflects the left hemisphere's dominance for speech and language processing. As a result, perceptual laterality and the preference for the right-ear stimuli seem to reflect underlying asymmetry in processing between the left and right hemispheres. Unlike many phenomena that may be seen only in western societies, it seems that the REA can be taken into account as a phenomenon of human perception on a global scale [36]. Not all people show REA in DL tasks. About 15–20% of right-handed people show no ear advantage or may even show LEA during the evaluations. The prevalence of LEA in children is high as 20%. It is common in children with learning, language, reading, and phonological problems [37].

DL tests are included in the test batteries because abnormal results can be found in the presence of auditory processing disorder. As a result, an LEA may suggest a sensory deficit, which is related to the right-hemisphere dominance. The etiology of right-hemispheric language dominance and ear advantage are not well known. Attention or other supramodal factors can be responsible for some of these ear advantages [36, 37]. The effect of LEA under the FL condition shows cognitive control and inhibition, which needs to detect the correlation between neuroanatomical and neurophysiological aspects of behavioral effects [17]. Thomsen et al. used functional magnetic resonance imaging (fMRI) with contrast agents and found significant activation of the anterior cingulate cortex, middle frontal gyrus, and inferior parietal lobe under the FL condition; however, no significant activations were observed under the FR condition [27]. This indicates neuroanatomical correlates of LEA under the FL condition in cortical regions, which are found when there are cognitive control and inhibitory responses [17].

The prevalence of right-hemisphere dominance is 1–5% [38, 39]. Moreover, DL studies using speech stimuli in normal adults and patients with epilepsy [40-43] have confirmed that REA can predict the left-hemisphere advantage, but LEA cannot be an indicator of the right-hemisphere advantage [37]. After more than five decades of research in this area, there is still no comprehensive study that can show LEA on a group basis using a verbal DL task. The magnitude of REA may vary between groups. The remarkable point is the emergence of this advantage from childhood to an older age. This advantage can be found in both genders and both right- and left-handed people [36].

Top-down and bottom-up factors

As mentioned before, it has been proven that REA can be manipulated by changing instructions (top-down approach) and stimulus characteristics (bottom-up approach). Top-down approach is often used by instructing the participant to focus only on the auditory stimuli delivered to one ear. Individuals in a NF condition need to repeat the stimuli easily and clearly heard from any ear, while under FR attention condition, their REA score usually increases compared to the NF condition. Training the individuals under FL attention condition reduces the REA or even can increase the LEA. The manipulation of bottom-up factors includes the change of stimulus intensity presented to the ears [8]. Hagdual et al., revealed that changing the intensity of stimuli can change the ear advantage. The gradual reduction in the intensity of left-ear stimuli at 3 dB and keeping the intensity of the right-ear stimuli constant, increase the REA linearly, while a gradual decrease in the intensity of right-ear stimuli and keeping the intensity of left-ear stimuli constant results in a linear decrease in REA leading to LEA [44].

Since both top-down and bottom-up manipulations affect the REA in DL using verbal stimuli, some questions arise: What are the combined effects of these manipulations? Does the increase of the stimulus's intensity in one ear (bottom-up factor) abolish the ability to manipulate and transfer the ear advantage to the other ear by training the individual to focus attention on one ear (top-down factor)? Can the cognitive control (top-down factor) overcome the intensity of the two competing stimuli (bottom-up factor)? Which factor (top-down or bottom-up) has more power to overcome the other? [8]. Bloch and Hellige performed a DL study to perceive how these two factors interact with each other. They used three intensity conditions (equal stimulus intensity in both ears, and the stimulus intensity in one ear>10 dB in other ear) during three different attention conditions (NF, FR, and FL). According to them, there was no significant relationship between altering attention and intensity, indicating that the effects of top-down and bottom-up factors seems to be independent of each other [3]. Tallus et al. applied Bloch and Hellige's method with an intensity difference of 15 dB between the ears. Their study showed a significant relationship between attention and intensity level, and the effect of attention was more negligible when the focus was on the same ear while the intensity was different. Thus, it seems that the interactions between top-down and bottom-up factors relies on the level of stimulus intensity [45]. A research was conducted by Westerhassen et al. to resolve this contradiction, where a DL test was performed on 35 right-handed individuals with normal hearing. The stimuli were changed by varying bottom-up factors. The stimuli intensity difference varied from –21 dB HL in favor of the left ear to +21 dB HL in favor of the right ear. The top-down factors were manipulated at three different attention conditions (NF, FR, and FL). A considerable interaction was found between top-down and bottom-up manipulations in terms of ear advantage. Their results revealed that the directing attention was reduced when the intensity difference favored the attended ear. Therefore, bottom-up intensity and top-down attention manipulation should not be considered independent from each other, but rather interacting factors in a DL situation during the manipulation of the ear advantage [8].

Conclusion

Dichotic listening (DL) tests are common due to their non-invasiveness and detecting the hemisphere dominant for language processing, where different stimuli are delivered simultaneously to the ears. Based on the previous studies, factors such as the ear advantage, working memory, attention, top-down and bottom-up factors should be considered in addition to the type, intensity, and concurrence of stimuli. The results of DL studies can be affected and the probability of obtaining contradicting results can increase if these factors not been taken into account. The ear advantage in DL depends on the level of speech analysis and the type of used stimulus which are specialized in each hemisphere. Attention conditions seem to involve different cognitive processes when presenting stimuli to the ears; in the forced left (FL) condition, people need to process a weak stimulus in the presence of a more competitive stimulus, and the brain has to use more areas of the hemisphere to receive and respond to the speech stimuli successfully. As memory load increases, bottom-up processing is needed because of the anatomical structure of the auditory pathways. Hence, an enhanced right ear advantage (REA) can be observed when the memory load increases. Regarding the gender effects, men seem to be more lateralized in verbal tasks compared to women. Forced attention to the right ear usually increases the REA compared to the non-forced (NF) condition. Training to focus on the left ear reduces the REA or even can increase left ear advantage (LEA).

Ethical Considerations

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Authors' contributions

AM: Study design, drafting the manuscript; MMA: Drafting the manuscript; MA: Critical revision of the manuscript; AN: Study design, revised and supervision the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

References

[1] Bellis TJ. Assessment and management of central auditory processing disorders in the educational setting: from science to practice. 2nd ed. San Diego: Plural Publishing; 2011.

[2] Weihing J, Musiek FE. Dichotic Interaural Intensity Difference (DIID) Training. In: Chermak GD, Musiek FE, editors. Handbook of Central Auditory Processing Disorder Comprehensive Intervention; Vol 2. 2nd ed. San Diego: Plural Publishing; 2014. p. 225-42. [DOI:10.1055/s-0035-1564458]

[3] Bloch MI, Hellige JB. Stimulus intensity, attentional instructions, and the ear advantage during dichotic listening. Brain Cogn. 1989;9(1):136-48. [DOI:10.1016/0278-2626(89)90049-3]

[4] Westerhausen R. A primer on dichotic listening as a paradigm for the assessment of hemispheric asymmetry. Laterality. 2019;24(6):740-71. [DOI:10.1080/1357650X.2019.1598426]

[5] Hugdahl K, Wester K. Dichotic listening studies of hemispheric asymmetry in brain damaged patients. Int J Neurosci. 1992;63(1-2):17-29. [DOI:10.3109/00207459208986657]

[6] Kimura D. Some effects of temporal-lobe damage on auditory perception. Can J Psychol. 1961;15:156-65. [DOI:10.1037/h0083218]

[7] Hiscock M, Israelian M, Inch R, Jacek C, Hiscock-Kalil C. Is there a sex difference in human laterality? II. An exhaustive survey of visual laterality studies from six neuropsychology journals. J Clin Exp Neuropsychol. 1995;17(4):590-610. [DOI:10.1080/01688639508405148]

[8] Westerhausen R, Moosmann M, Alho K, Medvedev S, Hämäläinen H, Hugdahl K. Top-down and bottom-up interaction: manipulating the dichotic listening ear advantage. Brain Res. 2009;1250:183-9. [DOI:10.1016/j.brainres.2008.10.070]

[9] Garai JE, Scheinfeld A. Sex differences in mental and behavioral traits. Genet Psychol Monogr. 1968;77(2):169-299.

[10] Voyer D. Sex differences in dichotic listening. Brain Cogn. 2011;76(2):245-55. [DOI:10.1016/j.bandc.2011.02.001]

[11] Voyer D. On the magnitude of laterality effects and sex differences in functional lateralities. Laterality. 1996;1(1):51-83. [DOI:10.1080/713754209]

[12] Kimura D. Functional asymmetry of the brain in dichotic listening. Cortex. 1967;3(2):163-78. [DOI:10.1016/S0010-9452(67)80010-8]

[13] Wernicke C. [Der Aphasische Symptomencomplex: Eine Psychologische Studie Auf Anatomischer Basis]. Breslau Cohn und Weigert; 1874. German.

[14] Broca P. [Remarques sur le siège de la faculté du langage articulé, suivies d'une observation d'aphémie (perte de la parole)]. Bull Soc Ana Paris. 1861;6:330-57. French.

[15] Pollmann S, Maertens M, von Cramon DY, Lepsien J, Hugdahl K. Dichotic listening in patients with splenial and nonsplenial callosal lesions. Neuropsychology. 2002;16(1):56-64. [DOI:10.1037//0894-4105.16.1.56]

[16] Hugdahl K, Brønnick K, Kyllingsbrk S, Law I, Gade A, Paulson OB. Brain activation during dichotic presentations of consonant-vowel and musical instrument stimuli: a 15O-PET study. Neuropsychologia. 1999;37(4):431-40. [DOI:10.1016/S0028-3932(98)00101-8]

[17] Musiek FE, Chermak GD. Auditory neuroscience and central auditory processing disorder: an overview. In: Musiek FE, Chermak G, editors. Handbook of central auditory processing disorder auditory neuroscience and diagnosis; Vol 1. 2nd ed. San Diego: Plural Publishing; 2013. p. 3-16.

[18] Mei N, Flinker A, Zhu M, Cai Q, Tian X. Lateralization in the dichotic listening of tones is influenced by the content of speech. Neuropsychologia. 2020;140:107389. [DOI:10.1016/j.neuropsychologia.2020.107389]

[19] Studdert-Kennedy M, Shankweiler D. Hemispheric specialization for speech perception. J Acoust Soc Am. 1970;48(2):579-94. [DOI:10.1121/1.1912174]

[20] Prete G, Marzoli D, Brancucci A, Tommasi L. Hearing it right: evidence of hemispheric lateralization in auditory imagery. Hear Res. 2016;332:80-6. [DOI:10.1016/j.heares.2015.12.011]

[21] Prete G, D'Anselmo A, Tommasi L, Brancucci A. Modulation of the dichotic right ear advantage during bilateral but not unilateral transcranial random noise stimulation. Brain Cogn. 2018;123:81-8. [DOI:10.1016/j.bandc.2018.03.003]

[22] Prete G, Tommasi V, Tommasi L. Right news, good news! The valence hypothesis and hemispheric asymmetries in auditory imagery. Lang Cogn Neurosci. 2020;35(4):409-19. [DOI:10.1080/23273798.2019.1659990]

[23] Kompus K, Specht K, Ersland L, Juvodden HT, van Wageningen H, Hugdahl K, et al. A forced-attention dichotic listening fMRI study on 113 subjects. Brain Lang. 2012;121(3):240-7. [DOI:10.1016/j.bandl.2012.03.004]

[24] Toga AW, Thompson PM. Mapping brain asymmetry. Nat Rev Neurosci. 2003;4(1):37-48. [DOI:10.1038/nrn1009]

[25] Penner IK, Schläfli K, Opwis K, Hugdahl K. The role of working memory in dichotic-listening studies of auditory laterality. J Clin Exp Neuropsychol. 2009;31(8):959-66. [DOI:10.1080/13803390902766895]

[26] Broadbent DE. The role of auditory localization in attention and memory span. J Exp Psychol. 1954;47(3):191-6. [DOI:10.1037/h0054182]

[27] Thomsen T, Rimol LM, Ersland L, Hugdahl K. Dichotic listening reveals functional specificity in prefrontal cortex: an fMRI study. Neuroimage. 2004;21(1):211-8. [DOI:10.1016/j.neuroimage.2003.08.039]

[28] Jäncke L, Shah N. Does dichotic listening probe temporal lobe functions? Neurology. 2002;58(5):736-43. [DOI:10.1212/WNL.58.5.736]

[29] Geffen G. The development of the right ear advantage in dichotic listening with focused attention. Cortex. 1978;14(2):169-77. [DOI:10.1016/S0010-9452(78)80042-2]

[30] Taylor HG, Heilman KM. Monaural recall and the right-ear advantage. Brain Lang. 1982;15(2):334-9. [DOI:10.1016/0093-934X(82)90063-3]

[31] Aboitiz F, Ide A, Olivares R. Corpus callosum morphology in relation to cerebral asymmetries in the postmortem human. In: Zaidel E, Iacoboni M, editors. The parallel brain: the cognitive neuroscience of the corpus callosum. 1st ed. Cambridge: MIT Press; 2003. p. 33-46.

[32] Rimol LM, Eichele T, Hugdahl K. The effect of voice-onset-time on dichotic listening with consonant-vowel syllables. Neuropsychologia. 2006;44(2):191-6. [DOI:10.1016/j.neuropsychologia.2005.05.006]

[33] Levy J. Lateral specialization of the human brain, behavioral manifestations and possible evolutionary basis. In: Kiger JA, editor. The biology of behavior: Proceedings of the thirty-second annual biology colloquium. Corvallis: Oregon State University Press; 1972.

[34] Buffery AW, Gary JA. Sex differences in the development of perceptual and linguistic skills. In: Ounsted C, Taylor DC, editors. Gender differences: their ontogeny and significance. 1st ed. London: Churchill; 1972. p. 123-57.

[35] Warnick B, Inch ES. Critical thinking and communication: The use of reason in argument. 2nd ed. New York: Macmillan College; 1994.

[36] Westerhausen R, Kompus K. How to get a left-ear advantage: A technical review of assessing brain asymmetry with dichotic listening. Scand J Psychol. 2018;59(1):66-73. [DOI:10.1111/sjop.12408]

[37] Schmithorst VJ, Farah R, Keith RW. Left ear advantage in speech-related dichotic listening is not specific to auditory processing disorder in children: A machine-learning fMRI and DTI study. Neuroimage Clin. 2013;3:8-17. [DOI:10.1016/j.nicl.2013.06.016]

[38] Knecht S, Dräger B, Deppe M, Bobe L, Lohmann H, Flöel A, et al. Handedness and hemispheric language dominance in healthy humans. Brain. 2000;123 Pt 12:2512-8. [DOI:10.1093/brain/123.12.2512]

[39] Loring DW, Meador KJ, Lee GP, Murro AM, Smith JR, Flanigin HF, et al. Cerebral language lateralization: evidence from intracarotid amobarbital testing. Neuropsychologia. 1990;28(8):831-8. [DOI:10.1016/0028-3932(90)90007-B]

[40] Bethmann A, Tempelmann C, De Bleser R, Scheich H, Brechmann A. Determining language laterality by fMRI and dichotic listening. Brain Res. 2007;1133(1):145-57. [DOI:10.1016/j.brainres.2006.11.057]

[41] Fernandes MA, Smith ML, Logan W, Crawley A, McAndrews MP. Comparing language lateralization determined by dichotic listening and fMRI activation in frontal and temporal lobes in children with epilepsy. Brain Lang. 2006;96(1):106-14. [DOI:10.1016/j.bandl.2005.06.006]

[42] Hugdahl K, Carlsson G, Uvebrant P, Lundervold AJ. Dichotic-listening performance and intracarotid injections of amobarbital in children and adolescents: preoperative and postoperative comparisons. Arch Neurol. 1997;54(12):1494-500. [DOI:10.1001/archneur.1997.00550240046011]

[43] Hund-Georgiadis M, Lex U, Friederici AD, von Cramon DY. Non-invasive regime for language lateralization in right and left-handers by means of functional MRI and dichotic listening. Exp Brain Res. 2002;145(2):166-76. [DOI:10.1007/s00221-002-1090-0]

[44] Hugdahl K, Westerhausen R, Alho K, Medvedev S, Hämäläinen H. The effect of stimulus intensity on the right ear advantage in dichotic listening. Neurosci Lett. 2008;431(1):90-4. [DOI:10.1016/j.neulet.2007.11.046]

[45] Tallus J, Hugdahl K, Alho K, Medvedev S, Hämäläinen H. Interaural intensity difference and ear advantage in listening to dichotic consonant-vowel syllable pairs. Brain Res. 2007;1185:195-200. [DOI:10.1016/j.brainres.2007.09.012]