Aud Vest Res (2016);25(1):55-62.

RESEARCH ARTICLE

Persian version of the dichotic digit test for children: design and evaluation of the psychometric properties

Vahid Nejati[1,2]*, Farshid Alipour[3], Leyla Jalilvand Karimi[4], Laleh Esfandiari[5]

[1]- Department of Psychology, Faculty of Education and Psychology, Shahid Beheshti University, Tehran, Iran
[2]- Institute for Brain and Cognitive Science, Shahid Beheshti University, Tehran, Iran
[3]- Department of Clinical Psychology, Psychology & Educational Sciences Faculty, Kharazmi University, Tehran, Iran
[4]- Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran
[5]- Department of English Language, Faculty of Foreign Languages and Literature, Science and Research Branch, Islamic Azad University, Tehran, Iran

Received: 28 Oct 2015, Revised: 11 Dec 2015, Accepted: 21 Dec 2015, Published: 28 Dec 2015

Abstract
Background and Aim: Dichotic digit test (DDT) is a valid neuropsychological tool for determining the dominant hemisphere in verbal processing; therefore, the main goal of this research was designing and investigating the psychometric properties of DDT in a sample of Iranian children and then measuring its concurrent validity using the n-back task.
Methods: The present study was a descriptive and psychometric research which was conducted using correlations. 144 children aged between 7-12 years were selected through purposive sampling. To collect data, a DDT which was designed based on the original Persian version of the main dichotic test and validated via the n-back test was also used. Data was analyzed, and the concurrent and descriptive validity of the test was determined using descriptive and inferential statistics as well as correlation and analysis of variance.
Result: Results showed that the DDT has acceptable and valid psychometric properties; the Cronbach's Alpha level of 79% shows the concurrent validity of this test. Meanwhile, with an increase in age, the scores at three measuring scales of this test, i.e. right ear, left ear, and differentiation scale also increased. There was no significant difference between the scores of male and female participants.
Conclusion: It was shown that the DDT which is known to reflect the hemispheric asymmetry in processing verbal information has appropriate psychometric properties among Iranian children, and proved to be applicable in various clinical and research conditions.
Keywords: Dichotic digit test; children; design; psychometric properties; validating

Introduction
Hemispheric asymmetry is one of salient characteristics of the brain. This feature is used to survey normal development of brain hemispheres and investigation of breakdowns in cortical auditory function. Many dichotic tests have been developed to assess cortical auditory processing, one of the simplest and easiest of them to perform is dichotic digit test (DDT), in which different digits are presented to each ear simultaneously. DDT results show left hemisphere dominance for language processing by significantly higher score in right ear over left ear. Since its development by Broadbent and his colleagues, DDT has been used to study

* **Corresponding author:** Department of Psychology, Faculty of Education and Psychology, Shahid Beheshti University, Velenjak, Tehran, 1983963113, Iran. Tel: 009821-29902339, E-mail: v_nejati@sbu.ac.ir

attention and cerebral hemispheric function in both normal subjects and patients who suffer from psychological disorders [1].

Dichotic digit test is considered as a valid method of assessing central auditory pathways. Neuroimaging studies have also supported the validity of this test in evaluation of hemispheric asymmetry. In another words, left hemisphere dominancy in speech has been observed in most normal, right handed people by obtaining higher score in right ear over left ear. In subjects with specific brain lesions or children with learning disabilities (LD) the result is opposite, and left ear score is higher than right ear's [2,3,4]. As previously mentioned, one of the applications of DDT is in the field of psychology to investigate cognitive development and cognitive disorders like dyslexia, schizophrenia, stress disorders, attention deficit/hyper activity disorder (ADHD), Alzheimer's, verbal processing disorder, and working memory [5]. Also plenty of studies were conducted using DDT to measure attention and the ability to shift attention, directing attention and controlling attention [6-9].

One of the most common cognitive tests is n-back task; a task to measure cognitive functions related to executive functions. This test is commonly used as a measuring tool for working memory since it involves both storage and manipulation of information [10]. N-back is mainly based on the paradigm that a range of stimuli (usually visual) is presented to the subject step by step (each step is known as a block), and individual subjects must remember if the new stimulus at a given block coordinates with the previous stimulus at the *nth* block. Different levels of *n* are possible and the more the number of blocks, the more difficult the task will be. As a result, the 1-back block (n=1) is compared with the previous blocks, i.e. the 0-block. For example, in an n-back task, the 3-back block will be compared with the previous third stimuli, and so on. From psychological view point n-back would be a proper test for validating DDT. Therefore, this study was designed to determine the psychometric properties of the Persian version of DDT in Iranian children. It is worth remarking that the Persian version of this test is being validated and designed for the first time and reported through this paper.

Methods

This study was analytical and psychometric conducted using correlations.144 children both male (n=72) and female (n=72), aged between 7-12 years were selected through purposive sampling: subjects had bilateral normal hearing thresholds (0-15 dB HL) at frequencies of 500 Hz to 8000 Hz. All subjects had cognitive ability to understand instructions (able to indicate right and left side). Also researchers asked their teacher to confirm that none of children had language or behavioral difficulties or poor academic achievement. Subjects were individually tested under lab conditions and under the supervision of the researchers. They were instructed on the DDT procedure by presenting some sample items. After assuring that subjects had learned the procedure, the test was conducted. The process of designing the Persian version of the test was adopted from Hugdahl's original design [8]. The digits and syllabi were presented in an additive way from two letter digits to five letter digits which were recorded by an adult Persian native-speaker female. Children were exposed to the stimuli using headphones. Subjects were presented the words or digits simultaneously and after each presentation, they were asked to repeat whatever they heard. 40 items were presented to the subjects. Both digits of each item were spoken monotonically and with the same rhythm. The stimuli were presented simultaneously because during simultaneous presentations of auditory signals, the dominant hemisphere has a more processing power and is more active; hence, comparing the responses of two ears makes it possible to determine the dominant hemisphere. After reporting the words by each subject, words were written down and three scales were measured: the left ear scale (all the correct answers heard from the left ear), the right ear scale (all the correct answers heard from the right ear), and the laterality dominant scale (the

Table 1. Results of the Pearson test for the dichotic digit test indices, the reaction time for correct answers, and the number of correct answers in n-back test

	Reaction time for correct answers	Number of correct answers
Right ear scale	0.100	0.188*
Left ear scale	0.049	0.025
Differentiation scale	0.183*	0.087

*p<0.05

differentiation scale) [11].

$$\text{Right ear advantage (REA)} = \frac{\text{Right ear score} - \text{Left ear score}}{\text{Right ear score} + \text{Left ear score}} \times 100$$

For validating Persian version of DDT as a tool for assessing cognitive functions like working memory, n-back was used. In this research, the computer version of n-back task on two levels of n and 0 was used in which 120 numbers including 1-9 were presented on the screen pseudo-randomly in the time period intervals of 2 seconds. Each number was presented for 1500 msec, and after 500 msec of its fading, the next number was emerged on the screen. Numbers were presented pseudo-randomly in a way that one third of the responses were correct. Performance on this task was measured based on the correct response rate minus the sum of error rates and unanswered cases. The final total score, error rates, and the response time for the correct responses were recorded. The primary goals of applying the n-back task in this study was measuring the concurrent validity of the Persian DDT and showing the relationship between cognitive functions, brain hemispheres, and the DDT. This paper also aimed to evaluate the working memory using n-back test and measuring the verbal working memory using the DDT and exploring the relationship between these two tests.

The Persian DDT that was designed in this study was derived from Hugdahl's original DDT [8]. In this test, a number of words were presented to individual subjects in fixed pauses. Next, the tape recorder was switched off and the subjects were expected to repeat what they have heard. Different words were presented through each side of the headphone. Words were recorded monotonously using a female Persian voice. All words were recorded in the same rhythm and tone. As the stimuli, 40 pairs of words were presented to the subjects simultaneously through both ears. Performance on this test was rated based on three properties: the left ear scale (all correct responses from the left ear), the right ear scale (all correct responses from the right ear), and the differentiation scale [11]. At the beginning, the Kolmogorov-Smirnov test was used to compare the three scales, and results showed a normal distribution of data on the three scales.

$$\text{Left ear advantage (LEA)} = \frac{\text{Left ear score} - \text{Right ear score}}{\text{Left ear score} + \text{Right ear score}} \times 100$$

The differentiation scale is shown in + and – forms in which + represents the left ear relative dominance and – represents the right ear (relative?) dominance [12].

Results

Of the 144 children who participated in this study, 72 males and 72 females were selected. The age range was 7-12 and from each age group 12 males and 12 females were selected. The Cronbach Alpha was 0.79. To show the concurrent validity of the test, the n-back test was used (Table 1). As shown in Table 1, the right ear response rates have significant positive correlation with the number of correct responses and the differentiation scale is positively correlated with the response time for correct responses. In the following, the rates of all the three properties are given for both males and females in the six age groups (Table 2).

Table 2. Mean and standard deviation of the three scales in the dichotic digit test for both male and female across six age groups

		Mean (SD)		
Scales	**Age group**	**Male**	**Female**	**Overall score for both sexes**
Right ear scale				
	7	13.92 (4.29)	14.17 (4.89)	14.04 (4.50)
	8	14.08 (5.88)	17.81 (4.08)	15.63 (5.25)
	9	15.93 (5.57)	17.17 (4.72)	16.50 (5.11)
	10	22.08 (6.79)	21.50 (6.30)	21.46.(6.52)
	11	21.17 (3.90)	26.67 (10.06)	24.37 (7.22)
	12	25.42 (8.77)	25.67 (6.81)	25.46 (7.42)
Left ear scale				
	7	19.67 (7.37)	19.42 (6.80)	19.54 (5.50)
	8	22.00 (7.37)	19.17 (8.03)	20.58 (7.67)
	9	20.00 (7.67)	20.67 (6.84)	20.33 (7.11)
	10	23.83 (6.54)	18.50 (5.50)	21.17 (6.51)
	11	19.83 (6.39)	25.75 (7.42)	22.79 (7.41)
	12	24.33 (5.34)	22.25 (5.91)	23.29 (5.61)
Differentiation scale				
	7	-1.25 (24.30)	-1.08 (16.77)	-1.17 (20.42)
	8	-1.00 (21.98)	-0.83 (12.83)	-0.92 (17.60)
	9	-0.33 (21.91)	1.75 (14.95)	0.71 (18.38)
	10	1.58 (18.95)	6.00 (23.31)	3.79 (20.90)
	11	9.83 (17.73)	13.08 (26.75)	11.46 (22.25)
	12	12.42 (22.56)	16.50 (21.68)	14.46 (21.74)

One-way analysis of variance (ANOVA) was used to show the age and gender effect on the scores of the three scales of DDT and to determine its discriminant validity. While the results demonstrated that the effect of gender on the scores was not significant, the age effect was significant (Table 3).

Significant difference is found between different age groups in terms of the right ear rate and the differentiation rate. In order to find out which age groups differ from each other, the post hoc test of Tukey was applied to show between group comparisons.

Table 4 shows that there is a significant difference between the right ear and the differentiation rates. Because of this ability of the Persian version of DDT in discriminating different age groups, it is shown that this test has acceptable discriminant validity, too. One-way analysis of variance (ANOVA) was also used to investigate the effect of gender on the three scales of the DDT; however, the results showed no significant gender effect. Fig. 1 shows response rates on the three scales for each of the six age groups. This Figure also illustrates that the higher the age, the more

Table 3. Results of the one-way analysis of variance for age groups in the dichotic digit test

	Statistical Indicators	Total squares	Degrees of freedom	Mean square	f	p
Right ear scale						
	Between Groups	2750.396	5	550.079	14.04	
	Within Groups	5405.042	138	167.39		0.001
	Total	8155.438	143			
Left ear scale						
	Between Groups	257.951	5	51.590	1.151	
	Within Groups	6185.375	138	44.822		0.337
	Total	6443.326	143			
Differentiation scale						
	Between Groups	5366.889	5	1073.378	2.607	
	Within Groups	56812.006	138	411.681		0.028
	Total	62178.889	143			

increase in the differentiation, left and right ear rates is resulted.

Discussion

Analysis of the factors showed that our DDT is valid and has separate factor loads. As the children's age increase, their scores in all of the three scales also increase. The differentiation scale, which is a criterion for brain lateralization, increases as the age goes up. In none of the three properties, the effect of gender was significant. These findings are in line with the results from Hirnstein et al. [13], Knecht et al. [14], and Voyer [15].

Since 60 years ago when the DDT was originally used to measure the attention of air traffic controllers, this test has been used for various purposes, e.g. predicting the addictive drug use of the youth [15], measuring the amount of attention in adults [16], measuring attention and cognitive control in schizophrenia [17], evaluation of the working memory, measuring the amount of attention and the ability to control attention in Alzheimer patients [16], measuring the amount of inhibition and cognitive flexibility [18], predicting recognition emotion, predicting the cognitive capabilities of the frontal lobe, predicting negative emotion in depression [19], diagnosing auditory processing disorders in children, and finally evaluating the effectiveness of cognitive rehabilitative programs [20]. The precise power of the dichotic digit test in discriminating/differentiating the dominant hemispherewas supported by several magnetic resonance imaging (MRI) studies, and electroencephalogram studies [21].

Processing auditory information entails the combination of stimuli from both ears. Broadbent was the first scholar who found out that in normal individuals, when information arrives at the two ears simultaneously, the input to the right ear will be restored better. Later studies have shown the dominance of the left hemisphere in verbal processing. As compared with the handedness questionnaire which is proved to be an inefficient tool to show hemispheric dominance, the dichotic digit test is more valid. This claim is supported by concurrent validity from related MRI studies. With the increase in age, the higher differentiation rate between the hemispheres is observed. Longitudinal studies have also supported these results [4], in that, along with the increase in age and with the development and evolution of brain structures, both male and

Table 4. Post hoc Tukey test for the right ear scale and the differentiation scale between the six age groups

Age		Right ear scale		Differentiation scale	
		Difference between means (SD)	p	Difference between means (SD)	p
7	8	-1.58 (1.80)	0.952	-0.25 (5.85)	1.000
	9	-2.45 (1.80)	0.750	-1.87 (5.85)	1.000
	10	-7.70 (1.80)	0.001	-4.95 (5.85)	0.958
	11	-9.95 (1.80)	0.000	-12.62 (5.85)	0.266
	12	-11.41 (1.80)	0.000	-15.62 (5.85)	0.089
8	7	1.53 (1.80)	0.952	0.25 (5.85)	1.000
	9	-0.87 (1.80)	0.997	-1.62 (5.85)	1.000
	10	-6.12 (1.80)	0.012	-4.70 (5.85)	0.966
	11	-8.37 (1.80)	0.000	-12.37 (5.85)	0.287
	12	-9.83 (1.80)	0.000	-15.37 (5.85)	0.098
9	7	2.45 (1.80)	0.750	1.87 (5.85)	1.000
	8	0.87 (1.80)	0.997	1.62 (5.85)	1.000
	10	-5.25 (1.80)	0.048	-3.08 (5.85)	0.995
	11	-7.50 (1.80)	0.001	-10.75 (5.85)	0.447
	12	-8.95 (1.80)	0.000	-13.75 (5.85)	0.183
10	7	7.70 (1.80)	0.001	4.95 (5.85)	0.958
	8	6.12 (1.80)	0.012	4.70 (5.85)	0.966
	9	5.25 (1.80)	0.048	3.08 (5.85)	0.995
	11	-2.25 (1.80)	0.814	-7.66 (5.85)	0.780
	12	-3.70 (1.80)	0.318	-10.66 (5.85)	0.456
11	7	9.95 (1.80)	0.000	12.62 (5.85)	0.266
	8	8.37 (1.80)	0.000	12.37 (5.85)	0.278
	9	7.75 (1.80)	0.001	10.75 (5.85)	0.447
	10	225 (1.80)	0.814	7.66 (5.85)	0.780
	12	-1.45 (1.80)	0.966	-3.00 (5.85)	0.996
12	7	11.41 (1.80)	0.000	15.62 (5.85)	0.089
	8	9.83 (1.80)	0.000	15.37 (5.85)	0.098
	9	8.95 (1.80)	0.000	13.75 (5.85)	0.182
	10	3.70 (1.80)	0.318	10.66 (5.85)	0.456
	11	1.45 (1.80)	0.996	3.00 (5.85)	0.996

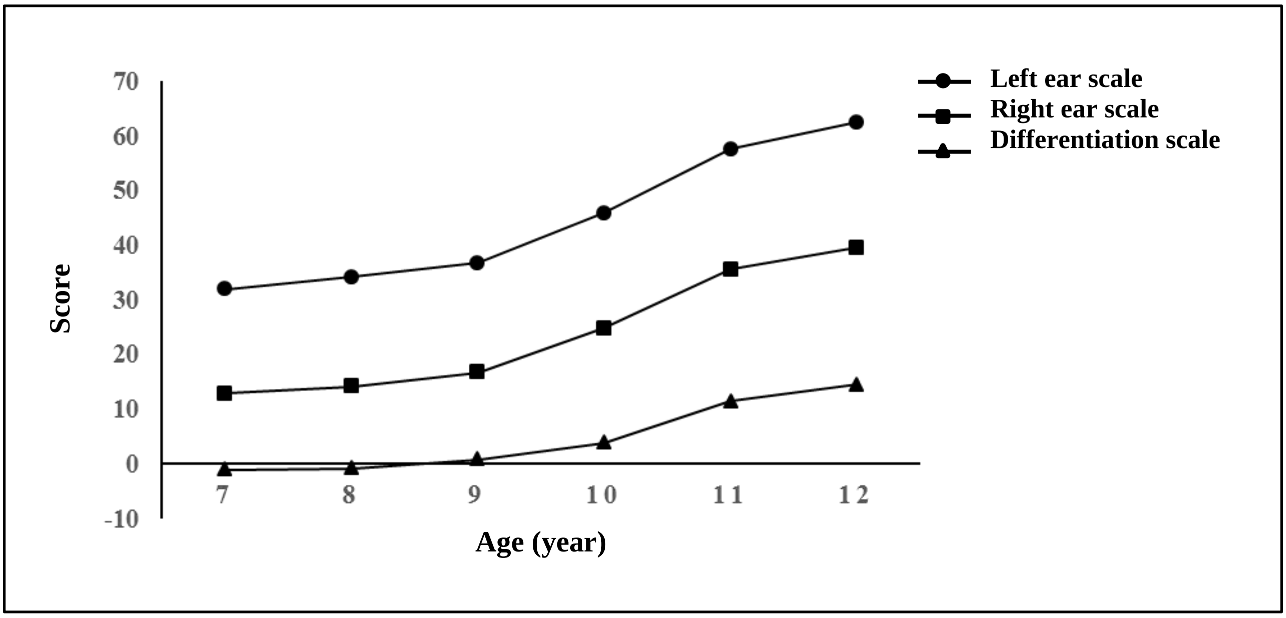

Fig. 1. Scores of each age group in the three scales.

female subjects show higher differentiation and right and left ear rates in this test. There is no doubt that biological and psychological factors have effect on age differences. With the increase in age and consequently the increase in basic cognitive skills, children performed better on this test. It is widely accepted that the left hemisphere has advantages over the right one in cognitive abilities. In a six-year longitudinal study by Wasserman et al. [16] on children, it was found that children with lower right ear (left hemisphere) rates have shown greater vulnerability to the consumption of addictive drugs. The ability to control the attention to selective stimuli and inattention to extraneous stimuli is one of the criteria of adaptability and efficient cognitive functioning in individuals. Auditory input is one of these stimuli. DDT can measure this ability in individuals pretty well. This test can even assess the auditory direction and its related disorders [22]. It also serves well in measuring LD in children. Throughout the literature, children with LD have consistently shown less differentiation, less attention and lower attention control for left hemisphere in comparison with normal children [23]. This test has also been investigated in studies on the auditory hallucinations of schizophrenic individuals and the results showed that auditory hallucinations were accompanied by left hemisphere malfunctioning and lower right ear rates. Low right ear rates are observed in individuals with analytic experiences which indicate the possibility of the emergence of depression symptoms due to the lack of left hemisphere dominance [24].

Conclusion

Our study in Persian version of the DDT is a valid neuropsychological test, and considering its adaptation with Persian language and culture, it is appropriate for various clinical and research conditions. This test is noninvasive and financially economical; another advantage of this test is its easy and simple application. The Persian version of DDT is a highly valid non-invasive neurocognitive and psychological tool which can be applied in measuring cognitive abilities; however, some of its applications have not been recognized yet. Future studies can focus on different populations with various disorders and cognitive abilities. Another possible area of research using our test would be measuring the concurrent validity of this test along with other types of listening tests as well as diagnosing verbal comprehension disorders.

REFERENCES

1. Broadbent DE. Perception and communication.1st ed. London: Pergamon Press; 1958.
2. Hugdahl K. Dichotic listening and language: overview. In: Wright JD, editor. International encyclopedia of the social & behavioral sciences. 2rd ed. Amsterdam: Elsevier; 2015. p. 357-67.
3. Gazzaniga MS, Ivry RB, Mangun GR. Cognitive neuroscience: the biology of the mind. 3rd ed. New York: W.W. Norton & Company; 2008.
4. Moncrieff DW. Dichotic listening in children: age-related changes in direction and magnitude of ear advantage. Brain Cogn. 2011;76(2):316-22.
5. 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.
6. Abosch A. Handbook of functional neuroimaging of cognition: Roberto Cabeza, Alan Kingstone (Eds.), The MIT Press, 2001, GBP 41.50, ISBN: 0-262-03280-5. J Chem Neuroanat. 2004;27(4):283-4.
7. Hugdahl K. Fifty years of dichotic listening research - still going and going and…. Brain Cogn. 2011;76(2):211-3.
8. Hugdahl K, Westerhausen R, Alho K, Medvedev S, Laine M, Hämäläinen H. Attention and cognitive control: unfolding the dichotic listening story. Scand J Psychol. 2009;50(1):11-22.
9. Moore DR, Ferguson MA, Edmondson-Jones AM, Ratib S, Riley A. Nature of auditory processing disorder in children. Pediatrics. Pediatrics. 2010;126(2):e382-90.
10. Hjelmervik H, Westerhausen R, Osnes B, Endresen CB, Hugdahl K, Hausmann M, et al. Language lateralization and cognitive control across the menstrual cycle assessed with a dichotic-listening paradigm. Psychoneuroendocrinology. 2012;37(11):1866-75.
11. Emanuel DC, Ficca KN, Korczak P. Survey of the diagnosis and management of auditory processing disorder. Am J Audiol. 2011;20(1):48-60.
12. Chen YN, Mitra S, Schlaghecken F. Sub-processes of working memory in the N-back task: an investigation using ERPs. Clin Neurophysiol. 2008;119(7):1546-59.
13. Hirnstein M, Westerhausen R, Korsnes MS, Hugdahl K. Sex differences in language asymmetry are age-dependent and small: a large-scale, consonant-vowel dichotic listening study with behavioral and fMRI data. Cortex. 2013;49(7):1910-21.
14. 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.
15. Voyer D. Sex differences in dichotic listening. Brain Cogn. 2011;76(2):245-55.
16. Wasserman GA, Pine DS, Workman SB, Bruder GE. Dichotic listening deficits and the prediction of substance use in young boys. J Am Acad Child Adolesc Psychiatry. 1999;38(8):1032-9.
17. Bouma A, Gootjes L. Effects of attention on dichotic listening in elderly and patients with dementia of the Alzheimer type. Brain Cogn. 2011;76(2):286-93.
18. Hugdahl K, Nygård M, Falkenberg LE, Kompus K, Westerhausen R, Kroken R, et al. Failure of attention focus and cognitive control in schizophrenia patients with auditory verbal hallucinations: evidence from dichotic listening. Schizophr Res. 2013;147(2-3):301-9.
19. Saetrevik B, Specht K. Cognitive conflict and inhibition in primed dichotic listening. Brain Cogn. 2009;71(1):20-5.
20. Gadea M, Gómez C, González-Bono E, Espert R, Salvador A. Increased cortisol and decreased right ear advantage (REA) in dichotic listening following a negative mood induction. Psychoneuroendocrinology. 2005;30(2):129-38.
21. Hämäläinen H, Soveri A, Tallus J, Laine M, Tuomainen J, Nyberg L, et al. Training of executive functions: a dichotic listening (DL) study. Int J Psychophysiol. 2010;77(3):224-5.
22. Ikeda Y, Yahata N, Takahashi H, Koeda M, Asai K, Okubo Y, et al. Cerebral activation associated with speech sound discrimination during the diotic listening task: an fMRI study. Neurosci Res. 2010;67(1):65-71.
23. Falkenberg LE, Specht K, Westerhausen R. Attention and cognitive control networks assessed in a dichotic listening fMRI study. Brain Cogn. 2011;76(2):276-85.
24. Obrzut JE, Mahoney EB. Use of the dichotic listening technique with learning disabilities. Brain Cogn. 2011;76(2):323-31.