Auditory and Vestibular Research

Variations of stimulus onset asynchrony affect the performance of normal hearing elderly people- the first study by Persian dichotic stimuli

Majid Bershan[1], Hamid jalilvand[1*], Sara Sardari[2], Maryam Yazdi[3]

1. Department of Audiology, School of Rehabilitation, Shahid Beheshti University of Medical Sciences, Tehran, Iran.
2. Parsian audiology clinic, Shahin shahr, Isfahan, Iran
3. Child group growth and development research center, research institute for primordial prevention of non-communicable diseases, Isfahan university of medical sciences, Isfahan, Iran
4.

Majid Bershan: Email:m.bershan@gmail.com ORCID: 0009-0008-4283-2549

Hamid Jalilvand: Email:hamidjalilvand4@gmail.com ORCID: 0000-0002-2351-5918

Sara sardari: Email:sardari.au@gmail.com ORCID:0000-0002-9306-2192

Maryam Yazdi: Email:m.yazdi@mui.ac.ir ORCID: 0000-0003-3961-6702

MB:Study design, acquisition of data, interpretation of the results, and drafting the manuscript; HJ: Study design, interpretation of the results; SS: Study design, interpretation of the results; MZ: Statistical analysis.

- **DITD can be an attractive index for examining dichotic function in elderly people**
- **Dichotic function is clearly impaired in older people compared to younger people**
- **The phenomenon of REA is observed in elderly people with a decline in quality**

Abstract

Background and Aims: Aging leads to noticeable functional changes in central auditory processing and dichotic function. The aim of this study was comparison of dichotic function between young and elderly people, as a factor of Stimulus Onset Asynchrony (SOA).

Methods: Persian syllables were presented dichotically to the participants. The onset time of the concurrent stimuli differed from 0 to 150 ms between the right and left ear. The effects of SOA changes (from 0 to 150 ms) were investigated in 20 normal- hearing young adults (aged 18 to 29 years) and 20 elderly individuals (aged 60 to 75 years) The Binaural **(**Both**)** Ear Correct (BEC%) score, as an indicative of dichotic performance, was measured.

Results: The BEC% scores decreased as SOA was reduced in both groups. However, this decline was more pronounced and significant in the elderly group. In contrast, young adults achieved higher BEC% scores across all SOA levels compared with the elderly individuals.

Conclusion: The reduction in BEC% scores in elderly individuals (particularly at lower SOA levels), indicates a decline in central auditory processing function in this group. This study highlights the impact of aging on central auditory processing and dichotic function, which could be implemented in designing and updating rehabilitative programs.
Keywords: Aging; stimulus onset asynchrony; dichotic function

Introduction

One of the established methods of diagnosis and rehabilitation of central auditory processing disorders are dichotic listening [1] paradigms: presentation of two different competing auditory stimuli to each ear [2]. These stimuli could be presented synchronously (means that the onset time of the stimuli is exactly the same for both ears) or asynchronously (with a time lag at one of the ears). The difference of onset time (stimulus onset asynchrony , SOA) is a key variable of the dichotic listening tasks, which plays an important role in the task results [3]. Under these conditions, the lagging stimulus is often more easily recognized than the leading one. This facilitation in recognition begins at a time gap of approximately 30 ms and peaks around 60 ms[4].

In case of using consonant-vowel (CV) syllables as dichotic stimuli, most participants reveal better scores at the right ear, a phenomenon known as Right Ear Advantage (REA). REA is attributed to the dominance of contralateral auditory pathways and the hemispheric asymmetry of the brain favoring the left hemisphere, which is typically dominant for language processing[5].

A case-control study conducted to explore the effects of aging on dichotic listening performance. Participant were 46 individuals within the age range of 60 to 89 years with no history of neurological disorder or cognitive impairment, and all the participants were of high social class. Forty-five adult individuals (control group) with the age range 32–57 years, with no history of neurological disorders. The elderly group scored significantly depressed scores of dichotic digits' test, especially in the left ear than in the adult group[6].

Li and Yang, investigated how older adults' auditory perceptual abilities affected their correct rates and the right ear advantage (REA) in the dichotic listening tasks in two experiments. In Experiment 1, older adults' performance was assessed using dichotic listening tasks based on consonant–vowel (CV) words varying in consonants, vowels, and lexical tones, each presenting distinct auditory perceptual demands. It was found that older adults exhibited decreased correct rates as auditory perceptual demands increased. Moreover, differences in the REA were observed in older listeners, suggesting increased engagement of the hemisphere responsible for acoustic analysis in processing challenging dichotic stimuli. Experiment 2 examined how older individuals' acoustic processing abilities contributed to their dichotic listening performance. It was shown that older adults with acoustic processing abilities comparable to those of younger individuals demonstrated correct rates and REAs similar to those of younger cohorts. These results revealed the no negligible role of acoustic processing in the dichotic listening paradigm and the significance of considering listeners' auditory perceptual abilities in investigating language lateralization using the dichotic listening paradigm [7].

Aging is associated with physiological and functional changes in the central auditory system, which can lead to central auditory processing disorders (CAPD) [8]. Compared to younger individuals, elderly adults often experience greater difficulties in speech perception, especially in noisy environments [9]. Although peripheral hearing loss accounts for many of their auditory challenges, it seems that some of the speech perception difficulties at elderly people stem from age-related decline in cognitive skills, alterations in high-level central auditory processing, or a combination of both [9].

Gelafand et al. investigated the recognition of dichotic CV syllables in young and elderly individuals with stimulus onset delays of 0, 30, 60, and 90 milliseconds. The results showed a significant decrease in overall dichotic scores (both left and right ears) in the elderly compared to the young group, which may reflect age-related decline in auditory system function[8].

Following research on auditory temporal resolution, it has been demonstrated that older adults exhibit poorer temporal resolution than younger adults and require longer silent intervals between stimuli shorter than 250 milliseconds for accurate discrimination[10] .

Even if very few studies have analyzed the relationship between cognitive decline and age-related CAPD, a strong association was highlighted. Therefore, age-related CAPD could be a specific process related to neurodegeneration [10]

The previous studies have focused on the effects of differences in interaural intensity (DIID) on dichotic performance rather than interaural timing differences (DITD). Moreover, given the aging population trend in the world, the present study aims to examine age-related changes in central auditory processing by manipulating stimulus onset timing differences of Persian dichotic stimuli. The primary objective is to assess how temporal asynchrony influences dichotic listening outcomes in the aging population.

Methods

Study Population:

The study population consisted of two age groups: 18 to 29 years (young adults), and 60 to 75 years (older adults). The young group consisted of 20 participants (8 women and 12 men) and the elderly group consisted of 20 participants (6 women and 12 men). Inclusion criteria for the young group included normal hearing thresholds (≤25 dB HL) over the audiometric frequencies (250 to 8000 Hz). In case of the older group, average thresholds should be ≤25 dB HL at 500, 1000, and 2000 Hz in both ears. Additionally, hearing thresholds should be ≤40 dB HL at higher frequencies, and the average threshold difference between ears ≤5 dB HL[11].

Participants were required to have normal immittance audiometry results (Type A tympanogram, static compliance between 0.3–1.6 cc), and normal word recognition scores in both ears. Right-handedness was confirmed using the Edinburgh Handedness Inventory. The exclusion criteria consisted of any history of neurological or psychological disorders, head trauma, memory impairment, cognitive decline (screened via the Persian version of the Mini-Mental State Examination) [12], multilingualism, and uncontrolled hypertension or diabetes.

Data Collection Procedures:

The experimental material involved five lists of meaningless CV Persian syllables, spoken by a female native Persian adult (e.g., /da/, /ga/, /ka/, /cha/, /kha/, /zha/), paired based on their phonological characteristics by a linguist. These CV pairs were presented dichotically with varying Stimulus Onset Asynchrony (SOA) values: 0, 30, 60, 90, and 150 milliseconds.

Each list (except for the 150 ms SOA list, which had 12 pairs) included 18 dichotic syllable pairs. Across all lists, 84 pairs were presented, with 6 diotic pairs in each list used solely for familiarization purposes and excluded from analysis. All syllables were recorded by a female speaker using constant pitch and intensity. SOA adjustments were made using Cool Edit Pro v2.1 (Syntrillium Software Corporation, USA) Paired syllabic stimuli were developed and normalized by Sardarī et al.[13] .

Stimuli were delivered binaurally via headphones at the comfortable listening level (60 dB SPL). Calibration was performed according to ANSI standards. A 4-second interval was provided between each stimulus pair for response registration. Half of the items were randomly presented first to the right ear, and, the other half, to the left ear. Participants were instructed that they would hear syllables from both ears simultaneously or alternatively, and were asked to repeat everything they heard. Responses were recorded on custom-designed answer sheets.

After data collection, the following metrics were calculated for each list: Right Ear Correct (REC), Left Ear Correct (LEC), Unilateral Ear Correct (UEC, correctly identified items by either ear), and the Binaural Ear Correct (BEC, correctly identified items by both ears). These results were expressed as percentages.

To eliminate the learning effects, all six syllables were initially played as a practice trial.

Results

The normality of quantitative variables was verified using graphical tools (e.g., Q-Q plots), and no deviation from normal distribution was observed. Therefore, parametric tests were employed to evaluate study hypotheses.

A significant difference was found between young and older adults in all SOA conditions. In every condition, young adults showed significantly higher BEC% than older adults ($P < 0.05$) (Figure 1). Repeated measures ANOVA showed that the mean BEC% varied significantly across different SOA values regardless of group ($P < 0.05$), and that BEC% increased with increasing SOA.

A statistically significant difference was also observed in the mean percentage of Unilateral Ear Correct (UEC%) between the elderly and young groups across all levels of Stimulus Onset Asynchrony (SOA). In all conditions, the elderly group demonstrated a significantly higher mean UEC% compared with the younger group ($P < 0.05$). Figure 2 illustrates the Bonferroni confidence intervals for each condition in the two groups. The difference between the groups becomes more pronounced at higher SOA values.

The mean LEC% was higher in the elderly group compared to the young group in all conditions, except at the SOA of 30 ms. A statistically significant difference in mean LEC% between the young and elderly groups was observed at SOA levels of 60 and 150 ms (Fig 3).

The mean REC% at the SOA level of 150 ms was higher in the elderly group compared to the young group (58.20 ± 25.30 vs. 0.00 ± 0.00). However, at lower SOA levels, the young group showed higher REC% values. For example, at the SOA of 60 ms, the REC% was significantly higher in the young group than in the elderly group (69.60 ± 18.51 vs. 58.20 ± 9.11) (Fig 3)

Table 1 shows the mean difference between the percentage of correct responses for the right and left ears. As shown, in both age groups, the average percentage of correct responses was higher for the right ear, with this difference being more pronounced in the young group. Regardless of age group, a general right ear advantage was observed across the total sample. This advantage was statistically significant at all SOA values except for 90 ms ($p < 0.05$).

Discussion

The present study implemented natural Persian CV pairs to investigate the impact of the synchrony of stimuli on the dichotic speech perception. Regarding the great impact of age on the cognitive functions, we divided the subjects into two age groups. Hence, it would be possible to observe the interactive effect of age and stimulus asynchrony on the dichotic function.

The percentage of correct responses from both ears for each stimulus—representing the main index of complete dichotic performance—revealed significant differences between the age groups. For all SOA levels, older subjects demonstrated significantly less BEC% scores than younger ones, which could be related with the decline in dichotic performance.

For both age groups, there was an inverse relationship between the BEC% and the amount of SOA, i.e., the more complex was the task, the lower scores were acquired by all of the participants. However, the between- group difference of BEC% was more pronounced at shorter SOAs- as the most considerable difference was observed at SOA = 0 ms (when paired CVs were presented simultaneously). At this level, the older group’s performance reached its lowest point compared with the young group.

The best performance belonged to the younger adults at SOA = 150 ms; at which, all of them repeated the stimuli correctly, indicating complete dichotic perception. In contrast, at the same SOA, older adults repeated fewer than half of the stimuli correctly (BEC% <50%).

These findings align with a study by A. Martini et al., which reported significantly weaker dichotic performance in older adults compared with younger participants [14]. Similarly, with decreasing SOA, both groups showed reduced correct responses, although this decline was more prominent in the elderly group, whose performance deteriorated by a steeper rate than the younger group.

Gelfand et al. also reported reduced overall dichotic scores among older participants, consistent with the present findings [8]. Moreover, Studdert-Kennedy et al. observed that reductions in SOA were associated with declines in correct responses, particularly among older adults [15].

According to the findings, significant differences were observed in the mean UEC% between the elderly and young groups at all SOA levels. In all conditions, elderly participants demonstrated higher UEC% than younger ones ($P < 0.05$). This can be attributed to the lower rate of BEC% and, to some extent, the higher frequency of incorrect responses in the elderly, further suggesting a decline in their dichotic processing ability.

At SOA = 150 ms, UEC% in the young group was close to zero, since BEC% reached 100% at that level—meaning all stimuli were correctly identified in both ears. The most notable difference in UEC% between the groups was at this same SOA level, with a U.E.C% of 47.40 ± 28.23 (Mean ± SD) observed in the elderly group. As SOA decreased and BEC% declined among young participants, their UEC% increased. Consequently, the stark advantage observed in the elderly group at higher SOA levels diminished at lower SOA values.

As shown in Figure 4 the average LEC% in elderly participants were higher than that in younger participants across all SOA conditions—except at SOA = 30 ms. Notably, statistically significant differences were observed at SOA = 60 ms and 150 ms, with the elderly showing higher average LEC% values. In contrast, the younger group showed higher average REC% at lower SOA levels.

Finally, the difference between REC% and LEC% , shows that correct responses were generally higher for the right ear in both age groups, with this asymmetry being more pronounced in younger adults. A right ear advantage (REA) was observed regardless of age group. This advantage was statistically significant across all SOA conditions, except at SOA = 90 ms ($p < 0.05$).

The presence of a clear REA in both young and elderly groups strongly support the structural model of right ear dominance proposed by Kimura and colleagues[5]. Similar findings were reported by Martini et al.[14]. Although the REA was observable in both age groups, it was more prominent in younger adults.

Several theories have been proposed to describe the observed fading of REA in older people. Some age-related auditory difficulties—such as speech perception in noisy environments—are attributable to peripheral deficits (e.g., damage to hair cells or dysfunction in the stria vascularis). However, central auditory processing is also independently affected by aging. In animal studies, age-related changes in the central auditory system were observed as reduced neuron counts and behavioral alterations. In humans, Magnetic Resonance Imaging (MRI) studies have revealed brain atrophy in white and gray matter, along with ventricular enlargement. Additionally, alterations in certain brain metabolites have been observed in older adults. MRI results also show clear differences in central auditory system activity between young and elderly individuals [16]. Moreover, the age-related disruption of interhemispheric information processing could be a basis for some auditory deficits in the elderly [9].

Based on the Hemispheric Asymmetry Reduction in Older Adults (HAROLD) model, proposed by prefrontal activity during cognitive performances becomes less lateralized in older adults than the younger. Hence, in spite of the normal physiology of the human brain, in which, the left hemisphere handles the language function, both hemispheres are recruited for lingual processes. It may be a compensatory mechanism of the brain to overcome the age-related decline of highly lateralized functions- simply, the brain calls the right hemisphere to conquer the cognitive load of task [16].

Taken together, in line with the former research, the results of the present study reinforced the relation of aging and functional changes in the central auditory system. These changes were clearly reflected in the poorer dichotic performance of elderly participants compared with the young adults. These findings could be implemented at designing and verification of rehabilitative plans for the elderly people. Regarding the growing population of older adults around the world, the future rehabilitative plans must consider the above- mentioned alterations of function, to elevate their quality of life.

Conclusion

This study investigated the effect of stimulus onset asynchrony (SOA) of Persian dichotic syllables on dichotic listening performance in elderly individuals with normal hearing thresholds. The presentation of dichotic syllable lists at varying SOAs (ranging from 0 to 150 ms) revealed that the percentage of Binaural (both-ear) correct (BEC%) responses, decreased with shorter SOAs in both groups. However, the rate of decline was steeper in the elderly group, and across all SOA levels, younger adults demonstrated higher BEC% values than older adults. These findings suggest that the diminished dichotic performance in elderly participants may be linked to central auditory processing deficits associated with aging.

Furthermore, in both age groups, correct responses were more frequent in the right ear. The difference in correct response rates between the right and left ears was more pronounced in younger adults. In other words, the Right Ear Advantage (REA) was present in both groups but diminished with age. This clear REA supports Kimura's structural theory of right ear dominance, as confirmed by both the young and elderly participants.

The research study was approved by the Ethics Committee of Shahid Beheshti University of Medical Sciences, Tehran, Iran.
(IR.SBMU.RETECH.REC.1399.1316)

REFERENCES

1. Mahdavi ME, Rezaeian M, Zarrinkoob H, Rezaeian M, Akbarzadeh A. Effect of a Dichotic Interaural Time Difference Program on Dichotic Listening Deficit of Children with Learning Difficulty. J Am Acad Audiol. 2021;32(5):295-302. [DOI:10.1055/s-0041-1728753]
2. Hugdahl K, Andersson L. A dichotic listening study of differences in cerebral organization in dextral and sinistral subjects. Cortex. 1984;20(1):135-41. [DOI:10.1016/s0010-9452(84)80030-1]
3. Moncrieff DW, Wertz D. Auditory rehabilitation for interaural asymmetry: preliminary evidence of improved dichotic listening performance following intensive training. Int J Audiol. 2008;47(2):84-97. [DOI:10.1080/14992020701770835]
4. Berlin CI, Hughes LF, Lowe-Bell SS, Berlin HL. Dichotic right ear advantage in children 5 to 13. Cortex. 1973;9(4):394-402. [DOI:10.1016/s0010-9452(73)80038-3]
5. Hugdahl K. Fifty years of dichotic listening research - still going and going and…. Brain Cogn. 2011;76(2):211-3. [DOI:10.1016/j.bandc.2011.03.006]
6. Tawfik, S.M., Shafik, N.A. Effects of aging on dichotic listening ability. Egypt J Otolaryngol. Egypt J Otolaryngol. 2022;38:40. [DOI:10.1186/s43163-022-00228-8]
7. Li Y, Yang X. Auditory perceptual ability affects dichotic listening performance in older adults. Laterality. 2024;29(4):429-61. [DOI:10.1080/1357650X.2024.2420408]
8. Gelfand SA, Hoffman S, Waltzman SB, Piper N. Dichotic CV recognition at various interaural temporal onset asynchronies: effect of age. J Acoust Soc Am. 1980;68(5):1258-61. [DOI:10.1121/1.385117]
9. Martin JS, Jerger JF. Some effects of aging on central auditory processing. J Rehabil Res Dev. 2005;42(4 Suppl 2):25-44. [DOI:10.1682/jrrd.2004.12.0164]

10. Sardone R, Battista P, Panza F, Lozupone M, Griseta C, Castellana F, et al. The Age-Related Central Auditory Processing Disorder: Silent Impairment of the Cognitive Ear. Front Neurosci. 2019;13:619. [DOI:10.3389/fnins.2019.00619]
11. Ashrafi M, Adel Ghahraman M, Mohammadkhani G, Jalaie S, Sadjedi H. The Effects of Dynamic Spatial Hearing Rehabilitation Combined with Transcranial Electrical Stimulation on Speech Perception in Noise in Elderly Men: A Randomized Clinical Trial. Crescent J Med Biol Sci. 2021;8(4):283-95.
12. Gharaeipour M, Andrew MK. Examining Cognitive Status of Elderly Iranians: Farsi Version of the Modified Mini-Mental State Examination. Appl Neuropsychol Adult. 2013;20(3):215-20. [DOI:10.1080/09084282.2012.688228]
13. Sardari S, Pourrahimi AM, Talebi H, Mazhari S. Symmetrical electrophysiological brain responses to unilateral and bilateral auditory stimuli suggest disrupted spatial processing in schizophrenia. Sci Rep. 2019;9(1):16454. [DOI:10.1038/s41598-019-52931-x
14. Martini A, Bovo R, Agnoletto M, Da Col M, Drusian A, Liddeo M, et al. Dichotic performance in elderly Italians with Italian stop consonant-vowel stimuli. Audiology. 1988;27(1):1-7. [DOI:10.3109/00206098809081568]
15. Studdert-Kennedy M, Shankweiler D, Schulman S. Opposed Effects of a Delayed Channel on Perception of Dichotically and Monotically Presented CV Syllables. J Acoust Soc Am. 1970;48(2B):599-602. [DOI:10.1121/1.1912179]
16. Cabeza R. Hemispheric asymmetry reduction in older adults: the HAROLD model. Psychol Aging. 2002;17(1):85-100. [DOI:10.1037//0882-7974.17.1.85]

Figure 1. Comparing mean Right Ear Correct **% and 95% Bonferroni confidence intervals between young and old groups in different** Stimulus Onset Asynchrony **level**

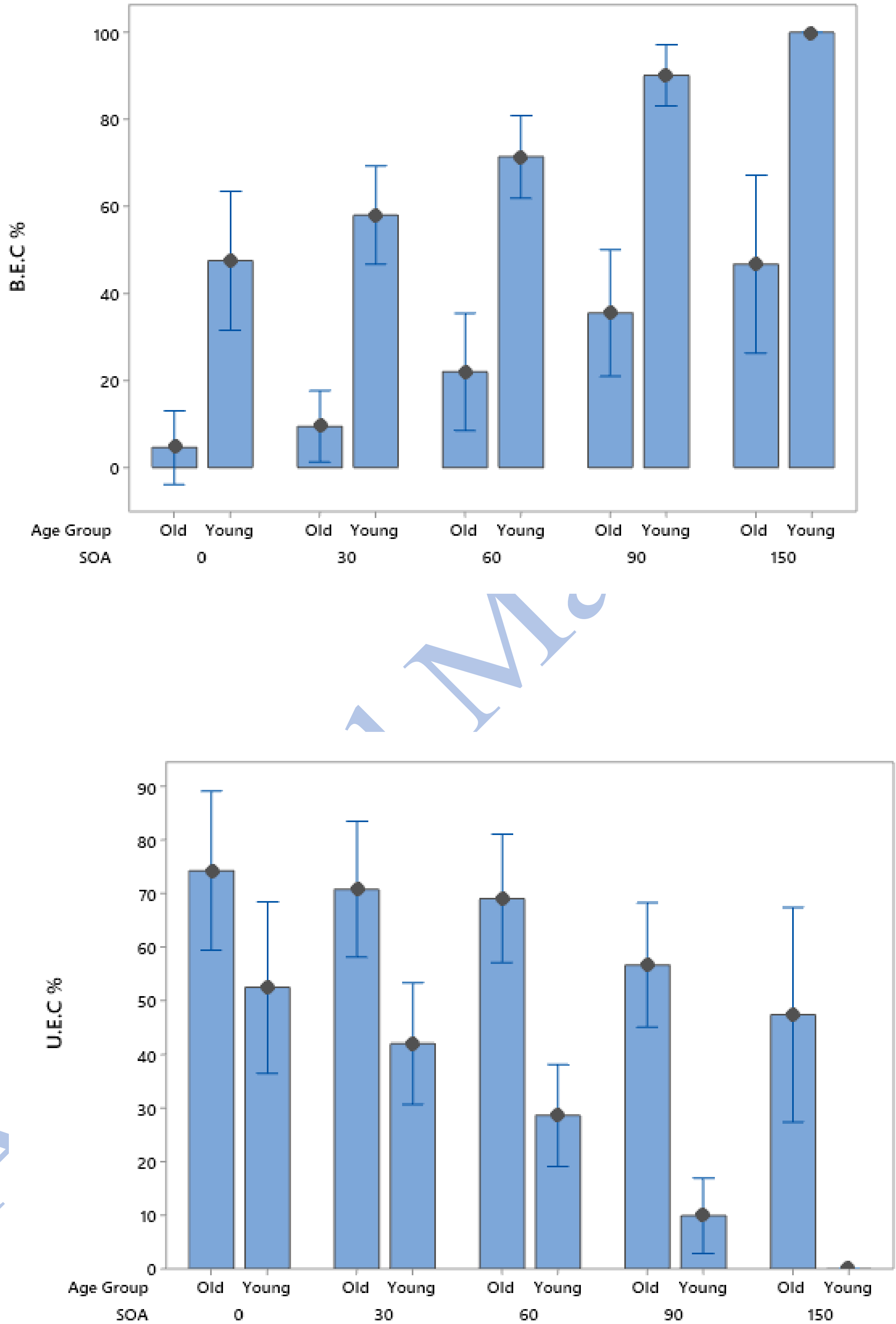

Figure 2. Comparing mean Unilateral Ear Correct **% and 95% Bonferroni confidence intervals between young and old groups in different** Stimulus Onset Asynchrony **level**

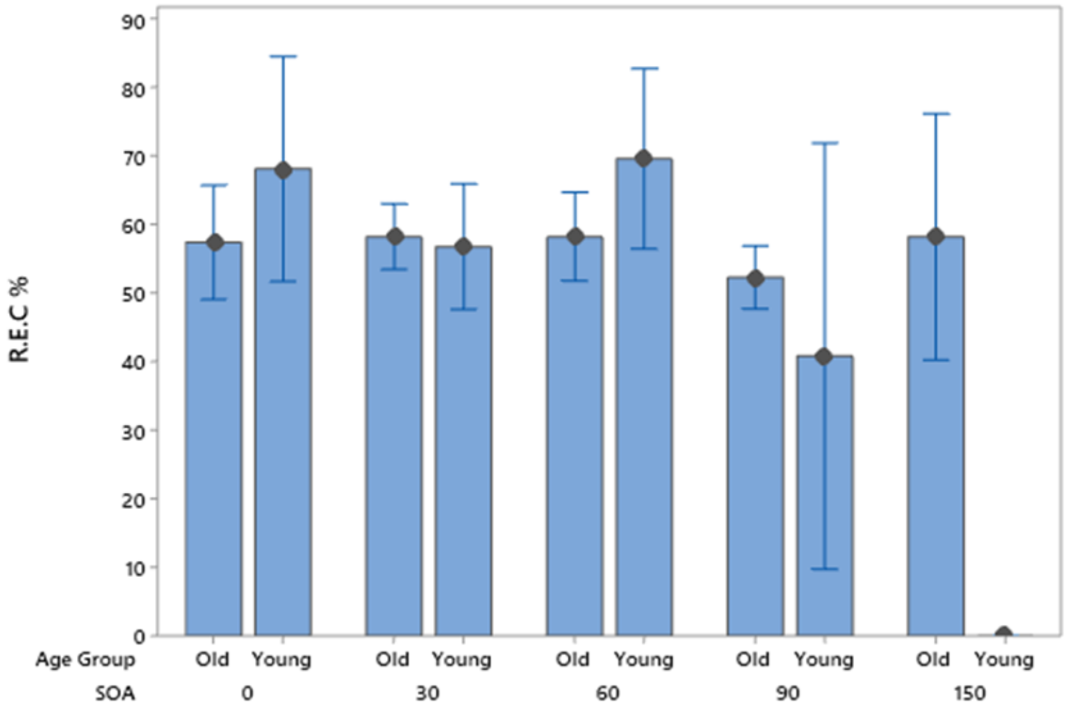

Figure 3. Comparing mean right ear correct % and 95% Bonferroni confidence intervals between young and old groups in different stimulus onset asynchrony level

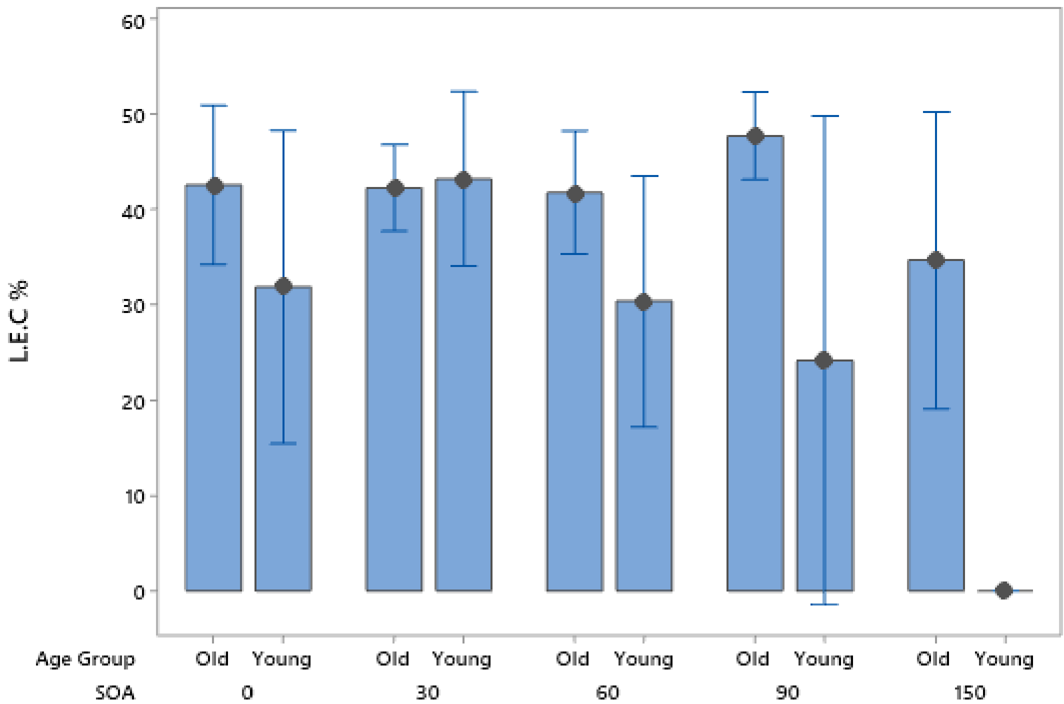

Figure4. Comparing mean left ear correct **% and 95% Bonferroni confidence intervals between young and old groups in different** Stimulus Onset Asynchrony **level**

Table 1. Mean difference of Right ear score compared to Left ear

	Young		Old		Total	
SOA	Mean difference±SD	P*	Mean difference±SD	P**	Mean difference±SD	P**
0	36.20±46.20	0.002	14.80±23.48	0.011	25.50±37.76	<0.001
30	13.50±25.76	0.03	15.90±12.94	<0.001	14.70±20.16	<0.001
60	39.20±37.02	<0.001	16.40±18.21	0.001	27.80±31.03	<0.001
90	16.60±63.58	0.257	4.50±12.93	0.136	10.55±45.70	0.152
150	0.00±0.00	—	23.50±40.97	0.019	11.75±30.97	0.021

** paired samples t-test