Research Article

Hearing Aid Outcome Measures and Auditory Processing in Elderly Users of Binaural Amplification

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Highlights:

- Dichotic listening deficit in the elderly increases WIN SNR-50
- NDES is a weak but significant predictor of hearing aid satisfaction
- Collectively, WIN SNR-50, and NDES are moderate predictors of hearing aid benefit

ABSTRACT

Background and Aim: Generally, peripheral hearing loss in the elderly is associated with decreased auditory processing ability. Researchers have drawn attention to the role of auditory processing in the success of hearing amplification. The present study investigates the relationship between auditory processing and the benefit and satisfaction of binaural hearing aids in the elderly.

Methods: Forty-seven elderly users (aged 58–85 years) of binaural hearing aids, all of whom presented symmetrically mild to moderate sensory-neural hearing loss, completed the International Outcome Inventory-Hearing Aids (IOI-HA) and Abbreviated Profile of Hearing Aid Benefit (APHAB) questionnaires and the Persian version of Words-in-Noise (WIN), and two-pair Dichotic Digits (DD) tests.

Results: Signal-to-Noise Ratio-50% (SNR-50) and Non-Dominant Ear Score (NDES) collectively explained 16% of the binaural hearing aid benefit variance. NDES accounted for 14% of the variance observed in satisfaction.

Conclusion: Binaural hearing aid benefit and satisfaction in the elderly were not similarly related to auditory processing abilities. NDES alone is a weak but significant predictor of satisfaction and in combination with WIN SNR-50 is a moderate predictor of benefit.

Keywords: Hearing aid; dichotic listening; speech perception in noise; satisfaction; benefit; elderly

Introduction

Aging is often accompanied by a range of sensory, physical, and cognitive impairments [1]. One prevalent chronic health issue among older adults is age-related hearing loss. This decline in auditory function stems from changes in the inner ear sensory and neural structures as well as in the central auditory pathways. As a result, listening difficulty in the elderly arises from both peripheral and central Auditory Processing (AP) impairments [2, 3] and worsens in noisy environments [4]. Age-related changes in AP can manifest as decreased ability in dichotic listening [5, 6] and perception of Speech-in-Noise (SIN) [7, 8]. It is estimated that the signal-to-noise ratio (SNR) required for older adults to recognize speech in noise deteriorates at a rate of 0.18 dB per year [9], and the average SNR-50 increases by approximately 0.4 dB over five years [10].

Hearing aids represent a valuable management strategy for hearing loss. Clinically, outcome measures such as satisfaction and benefit are used after hearing aid fitting, to evaluate the device's effectiveness [11]. Benefit encompasses the anticipated outcomes following hearing aid use, such as reduced activity limitations, decreased listening effort, and improved quality of life. Satisfaction, however, is not solely determined by perceived benefit but also includes factors such as patient expectations, financial and psychological costs, encountered difficulties, and any persisting communication problems [12].

Prescribing hearing aids for elderly individuals with auditory processing disorders poses significant challenges due to their reduced performance, lower satisfaction rates, the adverse effects of combined hearing loss and auditory processing disorder on hearing aid benefit, and a less favorable prognosis for successful hearing aid use [13]. Individuals with these issues often struggle to cope with interfering signals [12].

Previous research has investigated the relationship between AP and hearing aid outcomes, emphasizing the importance of central auditory examination results. Stach et al. found that while auditory processing disorder is not necessarily a contraindication for hearing aid use, individuals with this disorder may be less likely to experience optimal benefits from hearing aid amplification [13]. Gatehouse revealed the importance of the temporal resolution of the auditory system in benefiting from the hearing aid [14]. Givens et al. explored the link between AP skills and hearing aid satisfaction in a sample of 58 hearing-impaired older adults (aged 65–91 years) who had used monaural or binaural hearing aids for at least a year. The researchers utilized Dichotic Digits (DD) and SIN tests to evaluate central auditory and the Profile of Hearing Aid Performance (PHAP) questionnaire to assess satisfaction. Their findings highlighted the importance of incorporating central auditory tasks into hearing aid candidacy evaluations, suggesting that this approach could lead to a better understanding of hearing aid satisfaction among older adults [15].

Davidson et al. conducted a systematic review of the association between auditory behavioral measures and hearing aid satisfaction in adults with hearing loss. Their review demonstrated that speech perception in noise ability had the strongest correlation with hearing aid satisfaction, emphasizing the significance of evaluating speech understanding in noisy environments during hearing rehabilitation [16]. In a subsequent study, Davidson et al. provided preliminary evidence for incorporating measures of hearing aid self-efficacy and gap detection ability into the assessments of long-term hearing aid satisfaction following fitting. Their findings underscore the importance of long-term outcome evaluations after hearing aid adjustments, suggesting ways for targeted rehabilitation beyond hearing aid provision [11]. These studies highlight the importance of assessing auditory processing abilities in predicting the efficacy of hearing aids. However, not all aspects of AP have been comprehensively investigated. Nowadays, the AP status of older adults is often overlooked during hearing aid consultations, selection, and fitting.

To the best of our knowledge, Words-in-Noise (WIN) results have not been used to predict the outcome of hearing aids. Additionally, the studies that have examined dichotic listening have not reported detailed results and ear scoring has not been based on ear dominancy. This study was conducted to further investigate the role of auditory processing abilities in the satisfaction and benefit of binaural hearing aids in the elderly. Our research employed both free and directed recall conditions in dichotic listening which is not reported in similar studies on hearing aid outcome prediction. The next goal of the present study was to determine the SNR at different noise intensity levels (SNR growth/rollover) and its relationship with dichotic listening.

Methods

Study design and participants

The current study was conducted with a cross-sectional descriptive-analytical design. Persian participants were selected non-randomly from the patient files available in a private audiology clinic. The inclusion criteria included the following: age of 58–85 years (70.85±6.80); history of using binaural hearing aids for at least 6 months (self-reported hearing aid use and perceived benefit demonstrate a degree of stability by six weeks post-fitting [12]); lack of history of ear and brain surgery, use of ototoxic drugs and narcotics, Alzheimer's disease and cognitive impairment, sensorimotor problems, history of any neurological and psychological problems, head injury, and addiction; Montreal Cognitive Assessment (MoCA) questionnaire score ≥26; mild to moderate bilateral sensorineural symmetric hearing loss(ear difference ≤15 dB in 500–4000 Hz) with a WRS of >70%.
By considering type I (alpha) and II (beta) errors of 0.05 and 0.2 (power=80%) respectively and the effect size of 0.4, the sample size was determined to be 47 people.
All participants had been fitted with binaural hearing aids (receiver in the canal/behind the ear/completely in the canal) of the same brand by a skilled audiologist.

Measures

Hearing aid satisfaction and benefit were assessed face-to-face using the Persian version of Abbreviated Profile of Hearing Aid Benefit (APHAB) [17] and International Outcome Inventory-Hearing Aids (IOI-HA) [18] questionnaires. The Persian version of the WIN test [19] including 105 monosyllabic words was conducted binaurally to determine SNR-50. Prior to the experiment, the participants' Uncomfortable Loudness Levels (UCLs) were determined to ensure that the presentation levels of the WIN stimuli remained below their individual UCL thresholds. The first list (35 words) of this test was performed at the level of 60 and the next two lists were administered at the intensity levels of 70- and 80-dB HL, respectively.
Three 25-item lists of the Persian two-pair DD were constructed using a digitized file of the Persian randomized dichotic digits test [20]. The ear with the higher score in the free recall condition was defined as the dominant ear. In order to involve more cognitive abilities (attention and memory) in dichotic listening, the response task was not limited to free recall, and directed recall (pre-cued and post-cued) was also investigated. The ear scores for the two-pair DD test in free and directed recall conditions were averaged. Considering the cut point of 90% for the ear scores in the free recall mode, participants were classified into normal and abnormal groups. The abnormal group was further divided into unilateral and bilateral sub-groups.

Statistical analysis

Data distribution was compared to the normal using the Shapiro-Wilk test. Depending on the distribution of the data, parametric or non-parametric statistical tests were used to detect the relationship between the variables. Simultaneous and stepwise multiple linear regression was also used to determine the predictive model of the dependent variables. The P value less than 0.05 was considered statistically significant.

Results

Dichotic digits

The results of the two-pair DD in the free recall condition were normal in six (12.8%) and abnormal in 41 (87.8%) participants. A unilateral dichotic deficit was seen in 24 and a bilateral dichotic deficit in 17 participants. The right ear was dominant in 70.2% of the participants and the left ear in 23.4%. 6.4% did not show an ear advantage. Table 1 contains dominant and non-dominant ear scores.

Words-in-noise

Binaural SNR-50 in three presentation levels of 60-, 70-, and 80-dB HL are shown in Table 2. The mean SNR-50 at 60 dB HL was significantly higher than the mean SNR-50 at 70- and 80-dB HL ($p<0.001$). The average of SNR-50 at 70- and 80-dB HL was considered as WIN SNR-50.

Words-in noise and dichotic digits

The mean SNR-50 of the participants showing bilateral dichotic deficit was significantly higher than the mean SNR-50 of those with normal DD ($p<0.05$). At 80 dB HL, the participants with abnormal DD scores neededSNR-50 of 12.12±3.48 dB that was significantly higher than SNR-50 of 7.45±3.33 dB of the participants showing normal DD score ($p<0.05$) (Figure 1), indicating SNR-50 reduction due to increased presentation level has ceased in the group with dichotic listening deficit. Further analysis was performed to adjust the hearing threshold. However, the mean PTA (500–2000 Hz) did not show a significant difference between the participants with normal ear scores and the subgroups of unilateral and bilateral abnormal ear scores, $F_{(2,44)}=2.68$, $p=0.08$).

Hearing aid outcome measures

Hearing aid global benefit

Calculation of multiple linear regression for the predictor variables revealed a moderate collective significant effect between the WIN SNR-50, NDES, DES, and APHAB, ($F_{(2,44)}=4.23$, $p=0.021$, $R^2=0.16$, $R^2adj=0.12$), (Figure 2). The individual predictors were examined further and indicated that WIN SNR-50 ($t=2.745$, $p=0.009$) and NDES ($t=2.025$, $p=0.049$) were significant predictors (Table 3), and DES was a non-significant predictor in the model.

Hearing aid satisfaction

Results of the multiple linear regression indicated that there was a weak collective significant effect between the WIN SNR-50, NDES, DES, and IOH-HA, ($F_{(1,45)}=7.43$, $p=0.009$, $R^2=0.14$, $R^2adj=0.12$), and NDES alone was determined as a significant predictor of hearing aid satisfaction (Figure 3 and Table 3).

Discussion

The present study was conducted to further investigate the relationship between auditory processing abilities and the satisfaction and benefit of hearing aids in the elderly. The main aim of this study was to answer the question of whether the ear score in dichotic listening to digits and WIN SNR-50 alone or collectively can be useful in predicting the satisfaction and benefit of binaural hearing aids in the elderly with mild-to-moderate sensorineural hearing loss. The findings could contribute to increased awareness of AP measures during hearing aid consultations, selection, and fitting.

The studies on the prediction of hearing aid outcomes from dichotic listening abilities are not consistent. In contrast to several observations [15, 21-23] in the Davidson et al study, DD alone was not determined as a significant predictor of hearing aid satisfaction and benefit [11]. The results of our statistical analysis revealed that NDES can play a role in predicting the satisfaction and benefit of binaural hearing aids in the elderly. Unlike the previous studies [15, 22, 23], in the present study, the ear score of DD was not based on the right and left ears. We calculated the ear score based on ear dominancy to avoid mixing the results of dominant and non-dominant ears in statistical calculations. 23.4% of the participants showed the left ear advantage and in five of them, the right ear deficit varies from 42–100% in free recall condition. When both NDES and SNR-50 were used collectively to predict hearing aid benefit, a stronger relationship appeared compared to the individual effect for predicting hearing aid benefit. However, the results of SNR-50 individually and collectively with NDES were not a significant predictor of satisfaction and only NDES alone was a weak but significant predictor of satisfaction (Figure 3). These results suggest that if auditory processing results are combined, it can more powerfully predict hearing aid outcomes, although this was not true for binaural hearing aid satisfaction in the elderly.

The importance of SIN evaluations in rehabilitation counseling, hearing aid selection, and adjusting hearing aid specifications is emphasized by researchers, and its association with satisfaction has been confirmed in a systematic review [16]. In the present study, WIN SNR-50 alone or together with the NDES had a significant role in predicting the benefit of binaural hearing aids in the elderly. However, Davidson et al could not find a significant relationship between Listening in Spatialized Noise-Sentences (LISN-S) results and binaural hearing aid satisfaction in the elderly [11]. Walden and Walden found that SNR loss in the QuickSIN test provided the best predictors of hearing aid success in daily living [24].

The detrimental effects of peripheral hearing loss on WIN SNR-50 have been established [25, 26]. In Nasiri et al. study, it was shown that the WIN SNR-50 of 20–28-year-old normal-hearing adults for the test used in the current study has an average of 2.56 dB (Central SNR) [26]. The elderly in the present study needed an average of 11.69 dB, (Table 2); Therefore, 9.13 dB of total SNR can be attributed to aging and peripheral hearing loss. The interaction of central and peripheral SNR may not be so simple, and it may interact with the amplification and noise reduction strategies in hearing aids. The development of outcome prediction models beyond the existing questionnaires may help to better understand hearing aid satisfaction and benefit.

Our study did not find a significant association between benefit and satisfaction in the elderly. It seems that the determinants of satisfaction are not always the same as the determinants of benefit [27, 28]. For instance, Cox

et al. found that the greater the hearing problems of a hearing-impaired person without hearing aids, the higher the level of satisfaction with hearing aids [28]. Furthermore, Grunditz and Magnusson, in their research, compared speech intelligibility in noise under aided and unaided modes and investigated the relationship between the monosyllabic word comprehension and IOI-HA questionnaire results. They found no significant correlation between overall questionnaire scores and differences in the two above conditions. It suggests that while both tests assess hearing aid usage, they capture different aspects of the rehabilitation process, emphasizing the value of using multiple measures to validate hearing aid fitting [29]. However, the NDES was a determining variable for both satisfaction and benefit. Weakness of the NDES can be considered as an indicator of decreased interhemispheric integration. It may be concluded that elderly people who have better binaural integration have simultaneously higher satisfaction and benefit from binaural hearing aids.
The results of the present study are consistent with the studies exploring the relationship between AP ability and hearing aid success [14, 15, 21, 24, 30]; However, unlike Sameti et al study [23] conducted on elderly users of monaural hearing aid, SIN was not found to be a significant predictor of the satisfaction.
In this study, only the binaural SNR-50 was determined. It is recommended to conduct a study that also measures the monaural SNR-50 to investigate the relationship between these measures to the benefit and satisfaction of binaural hearing aids in the elderly. Binaural SNR is higher than monaural SNR in cases of binaural interference [31].

Conclusion
The binaural words-in-noise signal-to-noise ratio-50, combined with the score of the non-dominant ear in two-pair dichotic digits, is a moderate predictor of the benefit of binaural hearing aids in the elderly. Binaural hearing aid satisfaction could be weakly predicted based on non-dominant ear score. This study underscores the importance of evaluating auditory processing abilities during rehabilitation counseling, hearing aid selection, and fitting.

Ethical Considerations

Compliance with ethical guidelines
This study was approved by the Research Ethics Committee of Shahid Beheshti University of Medical Sciences (IR.SBMU.RETECH.REC.1402.576).

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Authors' contributions
NF: Study design and acquisition of data; statistical analysis, interpretation of the results, drafting the manuscript; MEM: Study design and supervision, interpretation of the results, and critical revision of the manuscript; HJ: Interpretation of the results, and validation the final revision of the manuscript; AAB: Statistical analysis. All authors discussed the results and contributed to the final manuscript.

Conflict of interest
The authors declare that they have no conflict of interest.

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Table 1. The scores of dominant and non-dominant ears for the two-pair dichotic digits test (free recall) in the participants categorized as normal and abnormal groups

	Pure tone average (500–2000 Hz) of both ears		Dominant ear score		Non-dominant ear score	
	Mean(SD)	Min-max	Mean(SD)	Min-max	Mean(SD)	Min-max
Normal dichotic digits (n=6)	44.58(7.81)	30-55	96.33(2.66)	94-100	93.33(3.72)	90-100
Unilateral dichotic deficit (n=24)	43.12(8.02)	25-55	94.33(3.76)	90-100	56.17(26.62)	0-86
Bilateral dichotic deficit (n=17)	48.68(6.91)	35-55	77.65(9.33)	54-86	49.53(21.42)	12-82

Table 2. The signal-to-noise ratio-50% for Persian words-in-noise test in the participants categorized as normal and abnormal groups for dichotic digits ear score (free recall)

	Normal dichotic digits		Unilateral dichotic deficit		Bilateral dichotic deficit		All	
Presentation level (dB HL)	Mean(SD)	Min-max	Mean(SD)	Min-max	Mean(SD)	Min-max	Mean(SD)	Min-max
60 (list #1)	15.33(6.09)	6.00-20.40	16.90(5.15)	2.80-25.20	18.24(4.73)	8.40-25.20	17.18(5.09)	2.80-25.20
70 (list #2)	10.13(4.31)	4.40-14.80	11.53(4.01)	1.20-18.80	13.20(3.49)	6.80-18.00	11.96(3.92)	1.20-18.80
80 (list #3)	7.47(3.33)	2.80-12.40	11.27(3.94)	2.80-18.00	13.06(3.65)	4.40-18.80	11.43(4.08)	2.80-18.80
WIN SNR-50 (average of the lists 2–3)	8.80(3.66)	3.60-13.60	11.40(3.49)	2.00-16.40	13.13(3.31)	6.00-18.00	11.69(3.64)	2.00-18.00

HL; hearing level, WIN SNR-50; words-in-noise signal-to-noise ratio-50%

Table 3. Prediction of hearing aid satisfaction and benefit using dichotic ear scores and words-in-noise signal-to-noise ratio-50%

Outcome measures (Persian)	Prediction variables	R	B	β	SE	95.0% confidence interval for B: Lower bound	Upper bound
APHAB (benefit)	**Non-dominant ear score**	0.401	0.18	0.31	0.09	0.001	0.365
	Words-in-noise SNR-50		1.78	0.42	0.649	0.473	3.088
IOI-HA (satisfaction)	**Non-dominant ear score**	0.346	0.07	0.38	0.027	0.019	0.129

R; coefficient of multiple correlation, B; unstandardized regression coefficient, β; standardized regression coefficient, SE; standard error, APHAB; abbreviated profile of hearing aid benefit, SNR-50; signal-to-noise ratio-50%, IOI-HA; international outcome inventory-hearing aids

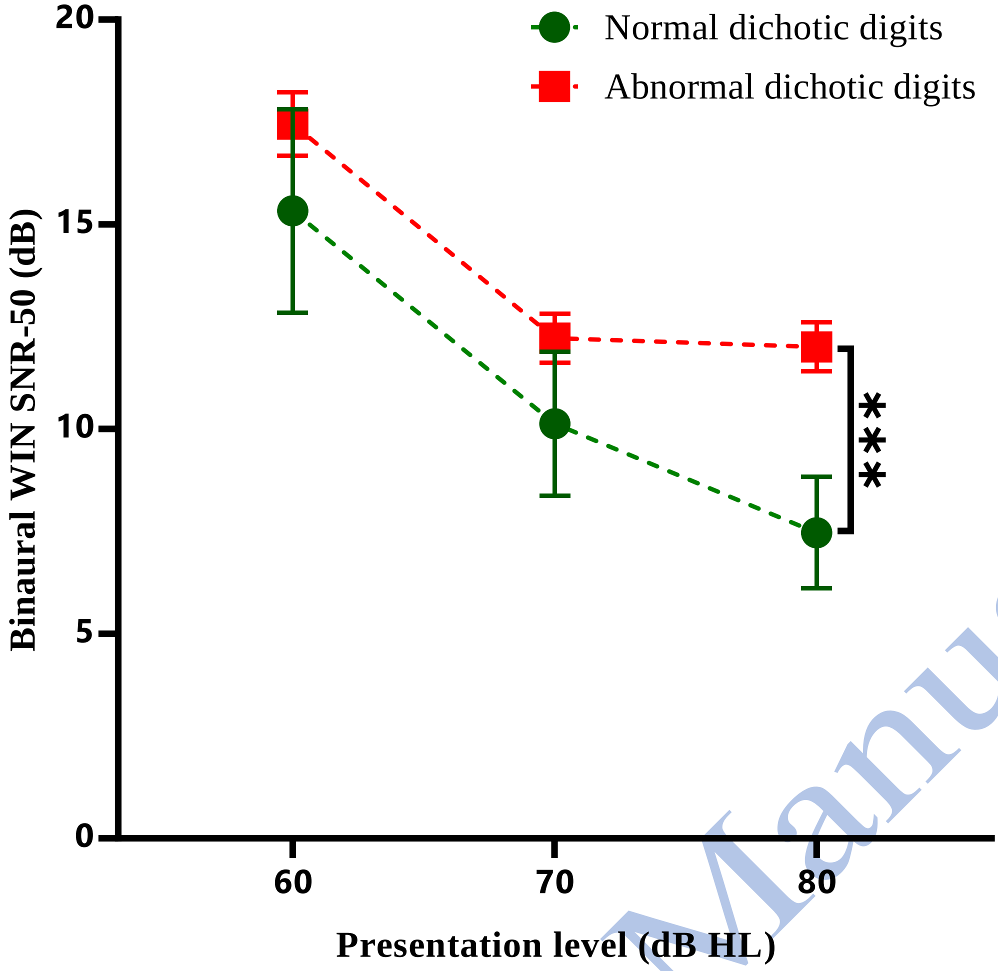

Figure 1. Mean and standard error of binaural words-in-noise signal-to-noise ratio 50% in presentation levels of 60, 70, and 80 in the participants categorized as normal and abnormal groups for dichotic digits ear score. WIN; words-in-noise, SNR-50; signal-to-noise ratio-50%

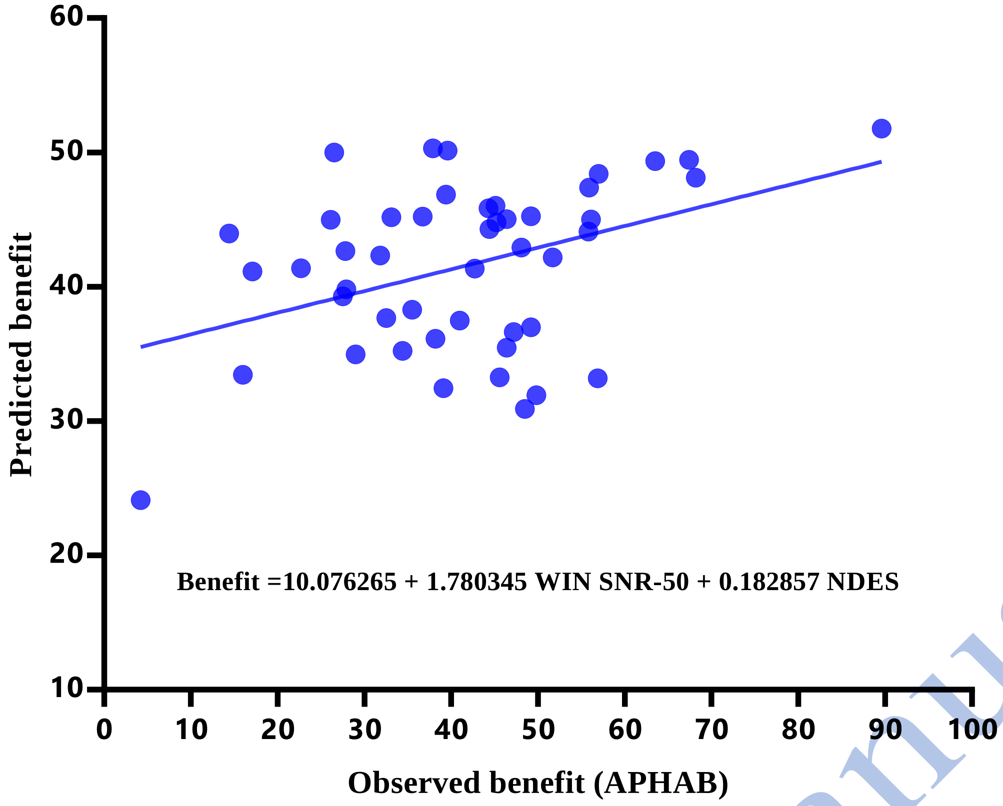

Figure 2. Regression line displaying the connection between observed and predicted hearing aid global benefit based on binaural words-in-noise signal-to-noise ratio-50% and dichotic digits non-dominant ear score. WIN; words-in-noise, SNR-50; signal-to-noise ratio-50%, APHAB; abbreviated profile of hearing aid benefit

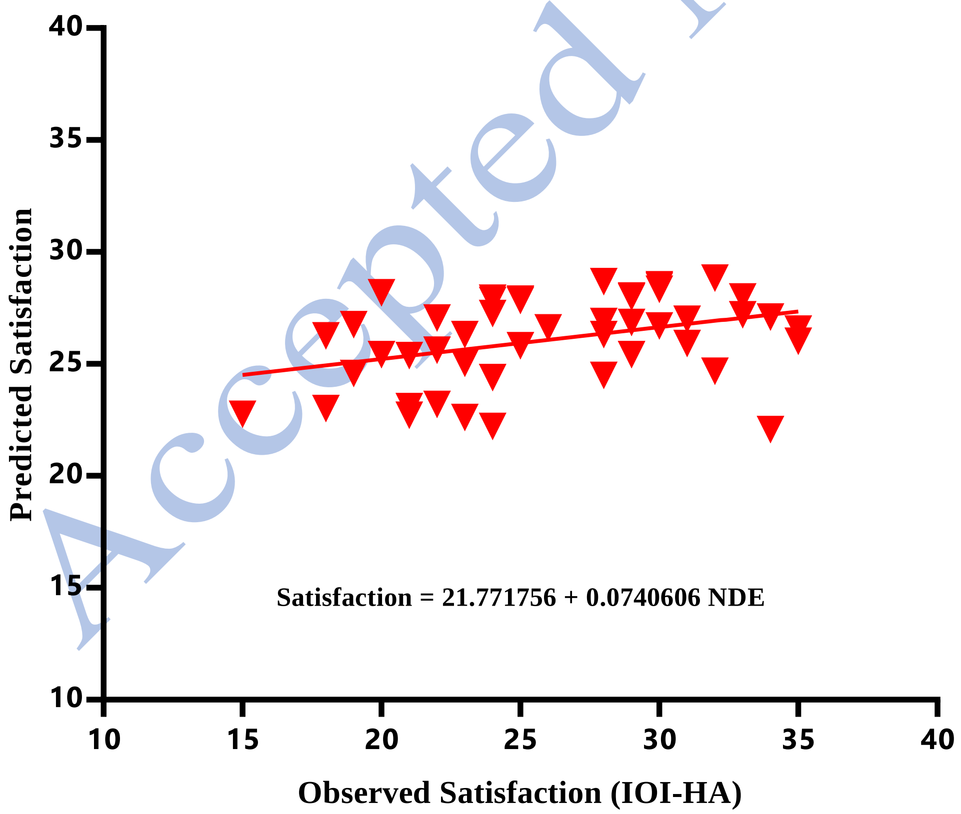

Figure 3. Regression line displaying the connection between observed and predicted hearing aid satisfaction based on dichotic digits non-dominant ear score. NDES; non-dominant ear score, IOI-HA; international outcome inventory-hearing aids