Auditory and Vestibular Research

# True Vs. Nonsense Word Auditory Memory and Sequencing Performance and Its Relation to Speech Perception in Noise

Somaraj Odeyar[1] and Jim Saroj Winston[1*]

[1]Nitte (Deemed to be University), Nitte Institute of Speech and Hearing (NISH), Mangalore, India

***Corresponding Author-**
Jim Saroj Winston, Assistant Professor, Nitte (Deemed to be University), Nitte Institute of Speech and Hearing (NISH), Mangalore, India, Email: jimaudiology@gmail.com

**ORCID id:**
Somaraj Odeyar: 0009-0007-9517-5928
Jim Saroj Winston : 0000-0001-6835-7346



**Highlights**

- True words show improved auditory memory and sequencing performance
- Auditory sequencing correlates with the speech in noise performance
- True word sequencing scores predict speech perception in noise performance

**Abstract**
**Background and Aim:** Auditory memory and sequencing are vital components of central auditory processing, crucial for functions including speech perception in background noise. This study compared performance in auditory memory and sequencing tasks using true and nonsense words and explored their relation to speech perception in noise abilities.
**Methods:** The study was conducted on 82 participants aged 18 to 24 with normal hearing. The participants completed auditory memory and sequencing tasks using true and nonsense consonant-vowel-consonant-vowel words. Stimuli were organised into three to eight-word sequences and delivered through headphones binaurally. Responses were scored separately for auditory memory and sequencing. Also, the participants were tested for speech perception in the presence of noise by computing the Signal to Noise Ratio required for 50% correct recognition (SNR50).
**Results:** The study findings revealed that the participants performed significantly better on true words than nonsense words in the auditory memory ($t= 24.93$, $p < .001$) and sequencing tasks ($t= 27.25$, $p < .001$). A moderate negative correlation was evident between auditory sequencing and SNR50 for both true ($r = -0.34$, $p = 0.001$) and nonsense words ($r$ -0.29, $p = 0.006$). A subsequent logistic regression revealed that true word auditory sequencing scores can accurately predict speech perception in noise performance.
**Conclusion:** The findings show that cognitive-linguistic scaffolding enhances auditory memory and sequencing, as seen in superior performance for true words. Auditory sequencing predicts speech perception in noise, while auditory memory does not, highlighting the complex link between scaffolding and speech perception in noise.
**Keywords:** Auditory memory; auditory sequencing; speech in noise; cognitive-linguistic processing

## Introduction

Auditory memory and sequencing (AMS) represent fundamental cognitive processes that form the cornerstone of human auditory perception and language comprehension, enabling individuals to temporarily store, organise, and manipulate auditory information (1,2). The efficiency of AMS mechanisms significantly influences an individual's capacity to follow complex verbal instructions, comprehend narratives, acquire new vocabulary, and ultimately navigate spoken language processing challenges (3). Deficits in AMS have been consistently associated with a spectrum of developmental and acquired communication disorders, including specific language impairment, dyslexia, and auditory processing disorder (4). Emerging evidence suggests that AMS capacities may play an even more critical role in suboptimal listening conditions, where they serve as compensatory mechanisms for degraded auditory input (5).

The theoretical framework for understanding AMS has been significantly shaped by Baddeley and Hitch's multicomponent model of working memory (6). Baddley's model postulates dynamic interactions between four specialised subsystems: the central executive (responsible for attentional control and cognitive coordination), the visuospatial sketchpad (handling visual and spatial information), the phonological loop (dedicated to speech-based information maintenance and manipulation), and the episodic buffer (integrating information across modalities). The phonological loop is particularly of interest to the field of auditory memory research as it enables the temporary retention and manipulation of verbal information, forming the cognitive substrate for language comprehension and production.

Traditional clinical assessments of AMS have predominantly employed meaningful verbal stimuli, including digits, words and sentences (7-9). While meaningful verbal stimuli are ecologically valid, they automatically activate the cognitive-linguistic scaffolding networks associated with lexical knowledge, semantic associations, and prior experience, potentially masking fundamental deficits in auditory processing through top-down compensatory mechanisms. In response to these methodological concerns, researchers have increasingly advocated using nonsense word paradigms in AMS assessment (10). Nonsense words are linguistically neutral stimuli, typically conforming to the phonotactic rules of the target language while lacking semantic content, providing a more precise measure of phonological processing by minimising the contribution of lexical and semantic memory systems (10, 11).

Speech perception in noise (SPIN) represents a complex real-world skill that draws upon multiple cognitive and perceptual resources. AMS plays a pivotal compensatory role when auditory signals are degraded (9). In this line, the review by Akeroyd (5) highlights a significant relationship between performance in phonologically loaded tools of working memory and the ability to segregate target speech from competing noise after accounting for peripheral hearing loss. However, little is known regarding how phonological processing alone contributes to understanding speech in noisy environments.

The present study was designed to systematically investigate three fundamental questions regarding AMS and its relationship to SPIN. First, we aimed to quantify performance differences between true and nonsense word AMS tasks, thereby elucidating the magnitude and nature of cognitive-linguistic scaffolding effects in auditory processing. Second, we sought to examine the differential relationships between these AMS measures and Speech perception in noise abilities, testing the hypothesis that nonsense word performance would show stronger associations with speech perception in noise abilities due to their greater reliance on core auditory sequencing mechanisms. Third, we employed advanced statistical modelling techniques to determine whether AMS measures could reliably predict SPIN performance, with particular attention to how these predictive relationships vary as a function of stimulus type (true vs. nonsense words).

## METHODS

### Participants

A cross-sectional study was conducted using a convenience sampling technique to recruit the participants from an undergraduate and postgraduate student population of the parent university in the Dakshina Kannada district, Mangalore, Karnataka. The sample size was estimated using pilot data (N = 20), which revealed a moderate effect size (d = 0.65). A power analysis ($\alpha = 0.05$, power = 80%) indicated a requirement of 64 participants. The study enrolled 84 participants (45 females; age M ± SD = 20.67 ± 1.56 years) to compensate for possible exclusions.

Participants were chosen based on normal audiological and otological history. Pure-tone thresholds were required to be less than 15 dB HL for octave frequencies (250–8000 Hz for air conduction and 250–4000 Hz for bone conduction) (12), and speech identification scores greater than 90% under both quiet and noise environments. Normal middle ear status revealed by Type 'A' tympanogram with intact ipsilateral acoustic reflexes elicited by broadband noise at 1 kHz. Transient Evoked Otoacoustic Emissions (TEOAEs) levels were greater than noise by a minimum of 6 dB at three successive frequencies, suggesting normal outer hair-cell functioning. Cognitive function was screened by the Mini-Mental State Examination (MMSE) (13), and only participants with no cognitive impairments were recruited. Further, all participants passed the Screening Checklist for Auditory Processing Disorders in Adults (SCAP-A) (14).

### Auditory Memory and Sequencing Tasks

The participants completed true and nonsense word AMS tasks. The true words were chosen from validated English word sets in the Revised Auditory Memory and Sequencing Test in Indian-English, developed by Yathiraj, Vanaja, and Muthuselvi at the All India Institute of Speech and Hearing, Mysuru, in 2012.. The words had a consonant-vowel-consonant-vowel (CVCV) pattern and were arranged in varying sequence lengths of three to eight words with a gap of 500 milliseconds between the words. Concomitantly, nonsense words obeying the structure of CVCV were adopted from lists developed at the parent institute as part of an unpublished dissertation (15). From the original 25 lists, the nonsense words were randomly selected, and those words were systematically combined into sequences utilising Audacity 3.0. Sequences of three to eight words were arranged with a gap of 500 milliseconds between the words, congruent with common auditory memory and sequencing tests (16).

Procedure

The investigation was conducted in two stages. The first stage was to quantify the SPIN abilities by computing the threshold signal to noise ratio required for a 50% correct speech recognition (SNR50) in an acoustic-controlled environment. The subjects were presented with speech stimuli masked by various background noise levels using the Smriti-Shravan software (17). The noise level was varied systematically through an adaptive procedure to establish the SNR at which the subjects could correctly identify 50% of the speech material.

In the second phase, the Auditory Memory and Sequencing Test was administered to measure the subject's ability to repeat and recall word sequences in the correct order. The test was administered in a treated sound room per ANSI S3.1 (2008) permissible noise levels (18). Participants completed the AMS tests involving true and nonsense words. The participants were instructed to listen carefully and repeat the words in the exact order they heard them. The memory and sequencing subtests with 118 words each were responded to using an audio recorder. For marking, every word reproduced correctly earned 1 point for the memory component, and every word repeated in sequence correctly earned 1 point for the sequencing component. Hence, the maximum possible score was 118, separately for memory and sequencing.

Statistical analysis:

Data from the study were analysed using descriptive and inferential statistical analysis, using Jeffrey's Amazing Statistics Program (JASP) version 0.19.1.0 (19). The Shapiro-Wilk test was employed to determine the normality of auditory memory and sequencing data. Auditory memory and sequencing performance between true and nonsense words were compared with the Student t-test. The Pearson correlation test was also conducted to determine the correlation between SNR50 and auditory memory and sequencing performance for true and nonsense words. Further, the sample was divided into two groups based on the median SNR50 score of -3.34 dB, with the low SNR50 group (≤-3.34 dB) representing better speech-in-noise performance and the high SNR50 group (>-3.34 dB) representing poorer performance. The group differences in SNR50 scores was confirmed using a nonparametric Mann-Whitney U test (U=1763.00, p<0.001, rank-biserial correlation(rrb)=1.00). Finally, a logistic regression test was performed to identify if SNR50 significantly predicts performance in sequencing and auditory memory tasks using true and nonsense words.

**RESULTS**

The present study used true and nonsense words to compare AMS performance in young adults. Furthermore, the study examined the correlation between the SNR50 scores and AMS to determine how these auditory processing abilities are associated.

*Performance Differences in Auditory Memory and Sequencing: True Words vs. Nonsense Words*

The Shapiro-Wilk test was conducted to assess the normality of the data. The results indicated that true and nonsense word auditory memory ($p = 0.37$) and auditory sequencing ($p = 0.37$) were not significantly different from a normal distribution.

[Figure 1]

The distribution of scores and paired comparisons are visually represented in Figure 1a, illustrating the shift in memory performance between true and nonsense words. A Student's t-test was conducted to compare auditory memory performance between true and nonsense words. The results revealed a statistically significant difference between true and nonsense words in auditory memory ($t(82) = 24.93$, $p < .001$, Cohen's $d = 2.37$).

Figure 1b displays the raincloud plot of scores and paired comparisons for auditory sequencing performance. A Student's t-test revealed significantly better sequencing ability for true words compared to nonsense words ($t(82) = 27.25$, $p < .001$, Cohen's $d = 2.99$). The findings suggest that participants demonstrated significantly higher auditory memory and sequencing ability for true words than nonsense words.

*Correlation between SNR50 and auditory memory and sequencing scores*

Figure 2 shows the scatter plots for the correlation between TWAM (a), NWAM (b) and SNR50. The trend line suggests that higher TWAM and NWAM scores are associated with lower (better) SNR50. A Pearson's correlation test was conducted to examine the statistical significance of the relationship between SNR50 and auditory memory performance for both true and nonsense words. The results indicated no significant correlation between SNR50 and true word auditory memory ($r (82) = 0.05$, $p = 0.62$, $|r| = 0.11$), as well as SNR50 and nonsense word auditory memory ($r (82) = -0.17$, $p = 0.11$, $|r| = 0.11$).

[Figure 2]

For the auditory sequencing scores, Pearson's correlation revealed a significant weak to moderate negative correlation between SNR50 and true word auditory sequencing ($r (82) = -0.34$, $p = 0.001$, $|r| = 0.11$), as well as SNR50 and nonsense word auditory sequencing ($r (82) = -0.29$, $p = 0.006$, $|r| = 0.11$). The correlation was stronger for true word auditory sequencing than nonsense word auditory sequencing.

*Auditory Memory and Sequencing Measures as Predictors of SNR50 Performance*

Figure 3a represents the descriptive details of the high and low SNR50 groups as divided based on the median value of -3.34 dB. A binary logistic regression was conducted to evaluate whether auditory memory and sequencing scores for true and nonsense words could significantly predict SNR50 groups.

[Figure 3]

The null model ($M_0$), which contained no predictors, served as the baseline for comparison. Model $M_1$ included true word auditory memory (TW AM), and $M_2$ added true word auditory sequencing (TW AS), while $M_3$ added nonsense word auditory memory (NW AM). Model $M_4$ further included nonsense word auditory sequencing (NW AS). Model $M_5$ introduced interaction terms TW AM × TW AS. The final model ($M_6$) included NW AM × NW AS interaction (Figure 3b & c).

Model $M_2$ showed a statistically significant improvement over the null model ($\Delta\chi^2 = 7.27$, $df = 2$, $p = 0.01$), suggesting that the combination of TW AM and TW AS better fit the data. In terms of model fit statistics, Model $M_6$ demonstrated the lowest Akaike Information Criterion (AIC= 120.18) and the highest pseudo $R^2$ values (Nagelkerke $R^2 = 0.15$), indicating that it accounted for the greatest proportion of variance in SNR50 group classification among all models tested, despite the relatively modest explained variance.

Analysis of individual predictors revealed that true word auditory sequencing (TW AS) was the only statistically significant variable across multiple models. In Model $M_2$, TW AS was positively associated with membership in the better SNR50 group (Estimate = 0.09, SE = 0.04, $z = 2.54$, $p = 0.01$). This effect remained significant in Model $M_3$ ($p = 0.01$) and Model $M_4$ ($p = 0.03$), highlighting the potential importance of true word sequencing ability in predicting speech-in-noise performance (Figure 3d). In contrast, TW AM, NW AM, and NW AS were no significant predictors in any models ($p > 0.1$). Additionally, neither of the interaction terms included in Models $M_5$ and $M_6$ reached statistical significance ($p > 0.3$), suggesting no meaningful interaction between memory and sequencing abilities for either stimulus type.

**Discussion**

This study tested the effect of true and nonsense words on auditory memory and sequencing and the interaction between SNR50 and auditory memory and sequencing skills.

*True vs. Nonsense Word Auditory Memory and Sequencing Performance*

As per the results, participants' memory of true words was significantly better than nonsense words. As per well-established working memory models, these findings align with the hypothesis that lexical familiarity enhances auditory memory performance (20). Long-term memory's existing phonological and semantic representations enable correct words to be encoded, stored, and retrieved faster than nonsense words.

Baddeley's working memory model identifies the phonological loop as a short-term storage facility for verbal information, subject to linguistic familiarity (20). True words are aided by lexical and semantic representations already present, allowing for improved processing and retrieval. Nonsense words do not have standard representations and need more cognitive resources in encoding, which can explain their poorer recall performance. Such findings are also in line with Baezzat et al.'s study, where it was found that phonological familiarity plays a significant role in auditory memory retention (21).

The findings also corroborate Cowan's embedded processes model, which emphasises the activation of long-term memory and control of attention resources in word recall (22). It posits that authentic words provide superior memory functioning because pre-existing knowledge cues demand fewer processing resources for remembering.

In contrast, nonsense words are novel and lack background associations, requiring more mental effort from working memory and decreasing recall accuracy.

Moreover, research on the effects of phonological similarity has shown that familiarity with the phonemes enhances rehearsal efficiency within the phonological loop (12). Familiar words are practised and remembered better than unfamiliar nonsense words because they contain phonological structures similar to those of familiar words. Evidence supporting the premise that lexical storage representations enhance verbal working memory performance is provided by this phonological benefit (23). In addition, lexical processing research has shown that long-term memory activation strongly impacts auditory recall (24). In their report, the larger recall of real words can also be attributed to the consolidation of brain networks responsible for word detection and retrieval through constant exposure to familiar word shapes. The present finding is also consistent with the results of Majerus et al., who demonstrated that lexical knowledge significantly enhances verbal information memory, particularly with immediate recall tasks (25).

*Relationship between SNR50 and performance in Auditory Memory and Sequencing Tasks*

The present study investigated the interplay between speech perception in noise (SNR50) and auditory memory/sequencing performance using linguistically distinct stimuli (true words vs. nonsense words. Results demonstrated dissociation between memory and sequencing systems: while AS exhibited a moderate negative correlation with SNR50, AM showed only weak, nonsignificant associations, irrespective of linguistic alignment. The finding aligns with Baddeley's working memory model, wherein the phonological loop - specialised for speech sequence maintenance would be disproportionately taxed by noise degradation compared to the episodic buffer's item memory functions. The stronger TWAS correlation ($\Delta r = 0.05$) further supports Cowan's embedded-processes theory, where linguistic scaffolding (semantic-lexical networks) enhances sequence encoding in adverse listening conditions.

Logistic regression analyses refined these observations, identifying TWAS as the sole significant predictor of SNR50 group classification ($\beta = 0.099$, $p = 0.011$; Odds ratio = 1.10). The model's modest explanatory power (McFadden $R^2 = 0.088$) suggests additional cognitive-linguistic mechanisms are involved. This finding resonates with Sharma et al.'s findings that central auditory deficits impair temporal sequencing (mediated by the thalamocortical loop) more severely than item recall (8). The dissociation between TW/NW sequencing effects may reflect the differential recruitment of cortical language networks. In contrast, TW sequencing engages left superior temporal gyrus lexical access (26), and NW tasks rely more heavily on right hemisphere spectrotemporal analysis, making them less sensitive to SNR50 variations (27).

The critical role of working memory in noise-resistant speech perception is further underscored by Sandra et al., who found that auditory working memory training improved SNR50 thresholds in older adults (28). Similarly, Sharma et al. reported that adolescents with listening difficulties exhibited deficits in forward/backward digit spans and frequency resolution, highlighting the interplay between memory, sequencing, and spectral-temporal processing (8). Jain et al. extended these observations, demonstrating significant negative correlations between central auditory skills (e.g., auditory closure) and working memory in adolescents (29). Although their focus was on closure tasks, the shared demand for real-time auditory reconstruction suggests analogous mechanisms may underlie sequencing deficits. The negative AS-SNR50 correlation in our study implies that impaired temporal organisation of auditory input under noise increases cognitive load, reducing working memory efficiency.

The current findings position sequencing as a noise-sensitive process mediated by dorsal stream networks, as demonstrated through large effect sizes ($d > 2$) and high statistical power ($>0.99$) in the within-subjects comparisons, while memory retention (ventral stream) appears more resilient. However, the modest predictive power of regression models underscores key limitations, suggesting the need to integrate broader cognitive measures like attention and executive function to fully account for individual differences in speech perception in noise. Furthermore, the study's focus on young adults and artificial nonsense words may limit generalizability. Future research should combine neurobiological approaches with more ecologically valid stimuli and diverse populations to better characterize these complex interactions.

**Conclusion:**

The present study demonstrates that linguistic meaningfulness significantly enhances auditory memory and sequencing performance in young adults, with true words eliciting substantially better outcomes than nonsense words, particularly for sequencing tasks. These findings highlight the critical role of lexical-semantic scaffolding in auditory processing, where top-down linguistic knowledge compensates for degraded acoustic signals in challenging listening conditions. The stronger association between sequencing ability (versus memory) and speech perception in noise suggests that temporal ordering mechanisms supported by the dorsal auditory stream and attentional control networks are more vulnerable to noise interference than item retention processes. Notably, true word sequencing emerged as the only significant predictor of SNR50 thresholds, reinforcing the importance of cognitive-linguistic integration for robust speech perception. These results align with contemporary working memory and auditory processing models, emphasising the interplay between sensory precision and predictive coding in noise.  This work advances our understanding of how cognitive-linguistic resources are strategically deployed to overcome acoustic challenges in real-world communication.

**Acknowledgement:**
The authors gratefully acknowledge the support and facilities provided by the Nitte Institute of Speech and Hearing. Sincere appreciation is extended to all participants for their valuable contribution to this study.

**Ethical Consideration:**
Informed consent was obtained from all participants before participating, guaranteeing they would follow ethical research standards and participant rights. Ethical permission for the study was obtained from the K. S. Hegde Medical Academy, Deralakatte, Mangalore (Ethical Clearance Number:  EC/EC/175/2024 dated 10.05.2024).

**Funding Statement:** This study obtained no financial support from internal or external agencies

**Conflict of interest:** The authors declare no conflict of interest

**Author Contributions:** SO: Methodology, Investigation, Formal Analysis, Data Collection, Writing – Original Draft. JSW: Conceptualization, Supervision, Analysis, Validation, Resources, Writing – Review & Editing.

**References**

1. Pillai R, Yathiraj A. Auditory, visual and auditory-visual memory and sequencing performance in typically developing children. Int J Pediatr Otorhinolaryngol. 2017;100:23-34. [DOI:10.1016/j.ijporl.2017.06.010]
2. Bellis TJ, Bellis JD. Central auditory processing disorders in children and adults. Handb Clin Neurol. 2015;129:537-56. [DOI:10.1016/B978-0-444-62630-1.00030-5]
3. Gathercole SE, Baddeley AD. Phonological working memory: A critical building block for reading development and vocabulary acquisition? Eur J Psychol Educ. 1993;8(3):259–72. [DOI:10.1007/BF03174081]
4. de Wit E, van Dijk P, Hanekamp S, Visser-Bochane MI, Steenbergen B, van der Schans CP, et al. Same or Different: The Overlap Between Children With Auditory Processing Disorders and Children With Other Developmental Disorders: A Systematic Review. Ear Hear. 2018;39(1):1-19. [DOI:10.1097/AUD.0000000000000479]
5. Akeroyd MA. Are individual differences in speech reception related to individual differences in cognitive ability? A survey of twenty experimental studies with normal and hearing-impaired adults. Int J Audiol. 2008;47 Suppl 2:S53-71. [DOI:10.1080/14992020802301142]
6. Baddeley AD, Hitch G. Working memory. In: Bower GH, editor. The psychology of learning and motivation (Vol. 8). New York: Academic Press;1974. p. 47-90.
7. Devi N, Nair S, Yathiraj A. Auditory memory and sequencing in children aged 6 to 12 years. Journal of All India Institute of Speech and Hearing. 2008;27(1):95-100.
8. Sharma M, Dhamani I, Leung J, Carlile S. Attention, memory, and auditory processing in 10- to 15-year-old children with listening difficulties. J Speech Lang Hear Res. 2014;57(6):2308-21. [DOI:10.1044/2014_JSLHR-H-13-0226]
9. Pichora-Fuller MK, Schneider BA, Daneman M. How young and old adults listen to and remember speech in noise. J Acoust Soc Am. 1995;97(1):593-608. [DOI:10.1121/1.412282]
10. Baddeley A. Working memory and language: an overview. J Commun Disord. 2003;36(3):189-208. [DOI:10.1016/s0021-9924(03)00019-4]
11. Gathercole SE, Willis C, Emslie H, Baddeley AD. The influences of number of syllables and wordlikeness on children's repetition of nonwords. Appl Psycholinguist. 1991;12(3):349–67. [DOI: 10.1017/S0142716400009267]
12. Goodman A. Reference zero levels for pure-tone audiometer. ASHA. 1965;7:262-3.
13. Folstein MF, Folstein SE, McHugh PR. "Mini-mental state". A practical method for grading the cognitive state of patients for the clinician. J Psychiatr Res. 1975;12(3):189–98. [DOI:10.1016/0022-3956(75)90026-6]
14. Vaidyanath R, Yathiraj A. Screening checklist for auditory processing in adults (SCAP-A): Development and preliminary findings. J Hear Sci. 2014;4(1):27-37. [DOI:10.17430/890788]
15. Eranna PK, Bhat JS, Aradith S. A language neutral nonsense speech-in-noise test for Dravidian language speakers: development and psychometric evaluation. Aud Vestib Res. In press.
16. Sone P. Development of Auditory Memory and Sequencing Test for Marathi Speaking Children. Online J. Health Allied Sci. 2018;17(1).

17. Kumar UA, Sandeep M. Development and test trial of computer based auditory-cognitive training module for individuals with cochlear hearing loss. Departmental Project [unpublished]. Mysore: All India Institute of Speech and Hearing. 2013.
18. American National Standards Institute. Maximum permissible ambient noise levels for audiometric test rooms (ANSI S3.1-2008). Washington, DC: ANSI; 2008.
19. Love J, Selker R, Marsman M, Jamil T, Dropmann D, Verhagen J, et al. JASP: Graphical statistical software for common statistical designs. J Stat Soft w. 2019;88(2):1-17. [DOI:10.18637/jss.v088.i02]
20. Baddeley A. Essentials of Human Memory (Classic Edition). 1st ed. London: Taylor & Francis; 2014.
21. Baezzat F, Moradi M, Motaghedifard M. The effect of phonological awareness on the auditory memory in students with spelling problems. Iran Rehabil J. 2018;16(1):83–90. [DOI:10.29252/nrip.irj.16.1.83]
22. Cowan N. An embedded-processes model of working memory. In: Miyake A, Shah P, editors. Models of working memory: mechanisms of active maintenance and executive control. Cambridge: Cambridge University Press; 1999. p. 506-20.
23. Das Gupta A, Karmarkar US, Roels G. The design of experiential services with acclimation and memory decay: Optimal sequence and duration. Manage Sci. 2016;62(5):1278–96. [DOI:10.1287/mnsc.2015.2172]
24. Roodenrys S, Hulme C, Lethbridge A, Hinton M, Nimmo LM. Word-frequency and phonological-neighborhood effects on verbal short-term memory. J Exp Psychol Learn Mem Cogn. 2002;28(6):1019-34. [DOI:10.1037//0278-7393.28.6.1019]
25. Majerus S, Poncelet M, Greffe C, Van der Linden M. Relations between vocabulary development and verbal short-term memory: The relative importance of short-term memory for serial order and item information. J Exp Child Psychol. 2006;93(2):95-119. [DOI:10.1016/j.jecp.2005.07.005]
26. Hickok G, Poeppel D. The cortical organization of speech processing. Nat Rev Neurosci. 2007;8(5):393-402. [DOI:10.1038/nrn2113]
27. Zatorre RJ, Belin P, Penhune VB. Structure and function of auditory cortex: music and speech. Trends Cogn Sci. 2002;6(1):37-46. [DOI:10.1016/s1364-6613(00)01816-7]
28. Sandra A, Shivananjappa SH, Pitchaimuthu AN. Effect of auditory verbal working memory training on speech perception in noise in older adults. Indian J Public Health Res Dev. 2018;9(11):268-73. [DOI:10.5958/0976-5506.2018.01465.1]
29. Jain C, Ghosh PGV, Chetak KB, Lakshmi A. Relationship Between Central Auditory Processing Abilities and Working Memory During Adolescence. Indian J Otolaryngol Head Neck Surg. 2023;75(1):1-7. [DOI:10.1007/s12070-022-03126-w]

**Figures**

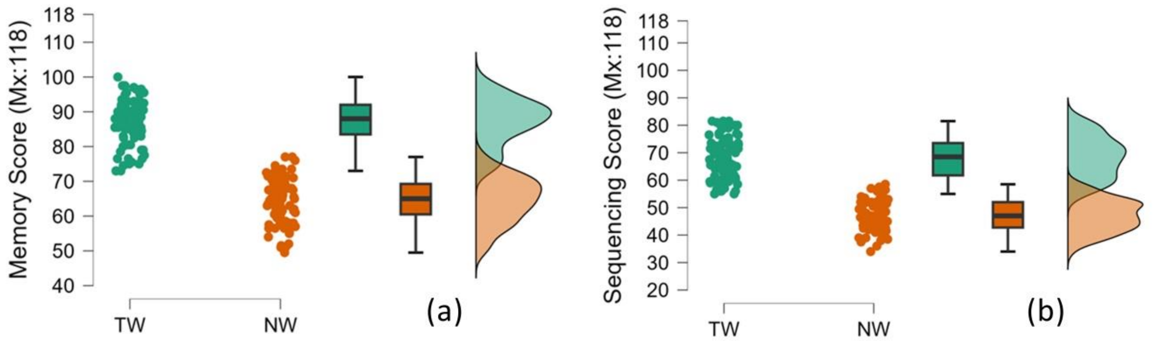


Figure 1: Raincloud plots comparing true words (TW) and nonsense words (NW) auditory memory (a) and sequencing (b) scores.

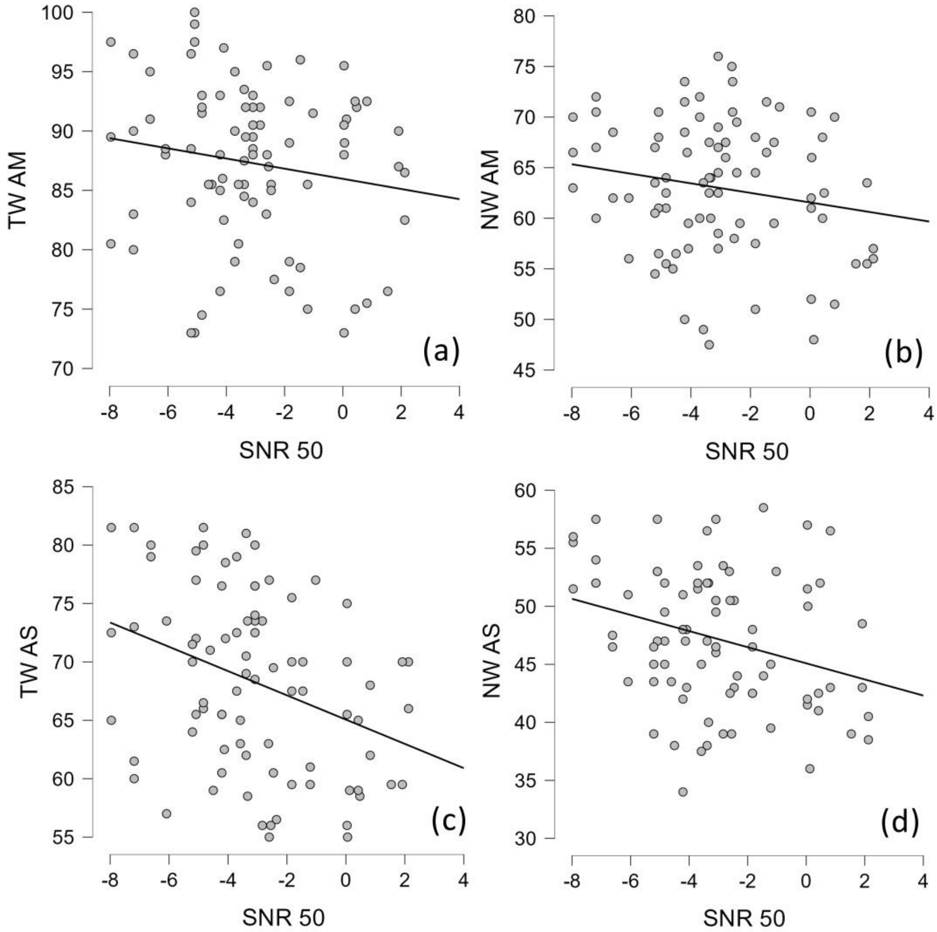


Figure 2: Scatter plots showing the relationship between SNR50 and auditory memory (AM) and sequencing (AS) scores for true words (TW) and nonsense words (NW).

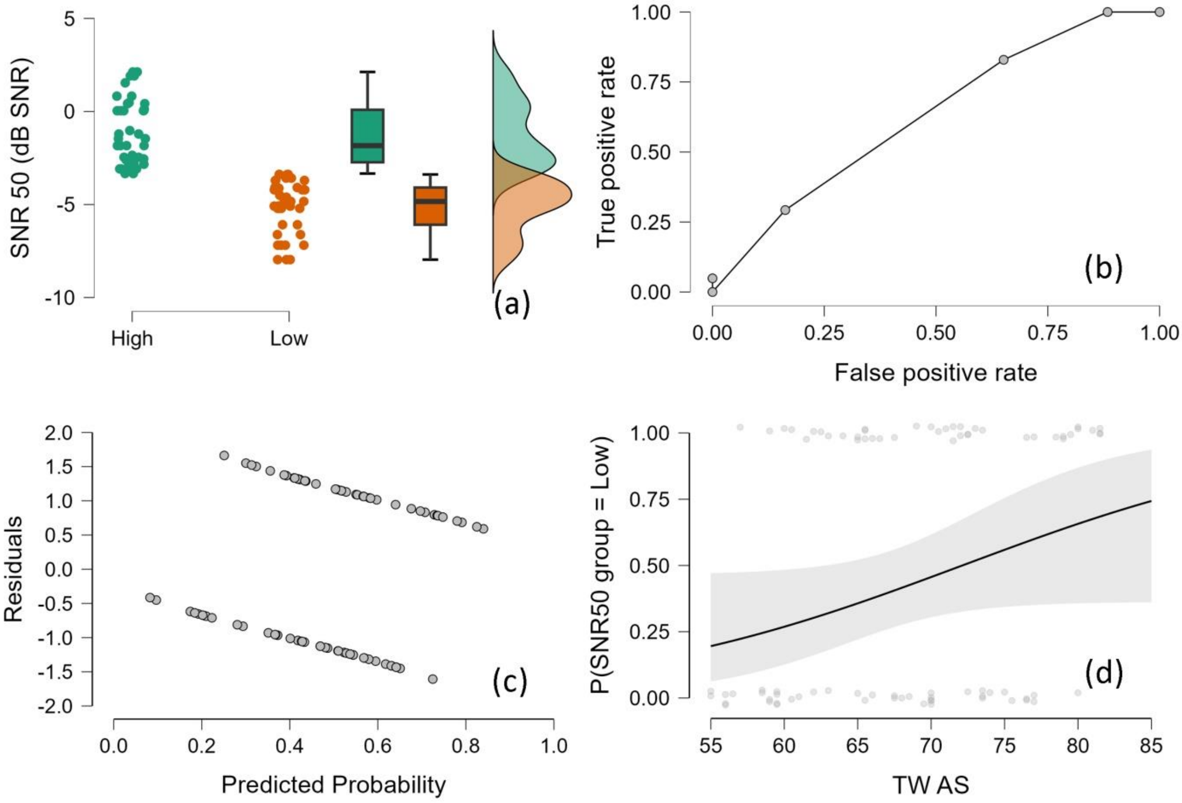


Figure 3: Analysis of SNR50 group differences and logistic regression outcomes. (a) Raincloud plot showing distribution of SNR50 scores between high and low performance groups. (b) Receiver Operating Characteristic curve demonstrating the predictive accuracy of the logistic regression model (area under the curve = 65.5). (c) Predicted probability-residual plot assessing model fit, with ideal fit shown as horizontal line at zero. (d) Conditional estimates plot displaying the marginal effect of true word auditory sequencing (TW AS) on SNR50 group classification, with shaded 95% CIs.