Prosody Perception in Older Adults: Exploring Links with Speech-in-Noise Perception, Musical Rhythm, and Musical Training

by
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Abstract

Prosody perception involves sensitivity to the temporal patterns in speech signals. These patterns, distinct from pitch modulations, include stress, rate, and meter. A sensitivity to the stressed syllables in words has been shown to be positively correlated with musical rhythm abilities and may be particularly important for understanding speech in noisy environments. This could be especially relevant for older adults, who commonly experience age-related hearing loss (ARHL) and impaired speech-in-noise (SIN) perception. Yet, little is known about how musicality traits interact with speech perception during age-related cognitive changes in older adulthood. The current study addresses the following questions in adults 65 years and older: (1) Do prosody (lexical stress) sensitivity and musical rhythm skills influence SIN perception? If so, (2) is prosody sensitivity a mediator between rhythm skills and SIN perception? Further, (3) does musical training have an influence on prosody sensitivity, mediated through musical rhythm abilities? Combined, results emphasize the importance of prosody and rhythm in SIN perception outcomes for older adults with normal hearing. Additionally, self-reported musical training was linked to prosody sensitivity, mediated through rhythm skills. Finally, theoretical considerations are posed for future investigations in larger, more diverse samples.

Keywords: prosody, lexical stress, speech-in-noise, age-related hearing loss, music, rhythm, speech, training, older adults

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List of Abbreviations

ARHL	Age-related hearing loss
EF	Executive Function
EM	Echoic Memory
Gold-MSI	Goldsmiths Musical Sophistication Index (Müllensiefen et al., 2014)
GWAS	Genome-Wide Association Study
PRESTO	Perceptually Robust English Sentence Test Open-set (Gilbert et al., 2013)
PTA	Pure Tone Average
PTA4	Pure Tone Average of 4 frequencies (500, 1000, 2000, 4000 Hz)
REDCap	Research Electronic Data Capture
RNDL	Research Notification Distribution List
SIN	Speech-in-Noise
SM	Sensory Memory
SMDT	Swedish Musical Discrimination Test (Ullén et al., 2014)
TOPsy	Test of Prosody via Syllable Emphasis (Nayak et al., 2022)
VUMC	Vanderbilt University Medical Center
WM	Working Memory

Introduction

Communication skills are an essential aspect of survival and social behavior across a wide variety of living species. In humans, communication abilities involving body language, eye contact, gesture, symbol, and verbal sounds are vital for conveying meaning, emotion, and intention in messages. Sound perception in humans, an ability which fosters the acquisition and comprehension of spoken language, begins prenatally and involves two separate sound schemas: language and music (Litovsky, 2015; Patel, 2010). Throughout human development, the perception, comprehension, and production of both language and music profoundly shape cognition, behavior, and environment (Boroditsky & Ramscar, 2002; Patel, 2010). An enduring ability to perceive and comprehend speech is instrumental in supporting social behaviors and facilitating positive psychological, emotional, and physical well-being across the lifespan, from infancy to old age.

The temporal organization of meaningful sounds and pitch modulations in speech exhibit a striking parallel with the structural elements of music. These characteristics of speech, involving rhythm and intonation patterns, are known as prosody. Scientific investigations of prosody, music, and language have shed light on shared and distinct neural networks involved with both music and language, pinpointing mechanisms that hold promise in the development of preventative and rehabilitative strategies for populations facing difficulties related to dyslexia, literacy, speech language disorders, and developmental disorders (Hausen et al., 2013; Gordon et al., 2015; Magne et al., 2016; Fiveash et al., 2021, 2022; Nayak, Coleman, et al., 2022; Nayak, Ladányi, et al., 2025). Prosodic discrimination (i.e., recognizing differences of pitch and inflection in speech) has been shown to be an intermediary factor between musical aptitude and vocal emotional recognition abilities (Vigl et al., 2024), further highlighting the underlying associations between traits of human musicality, speech perception, and communication. Recent work has demonstrated that musical rhythm skills share common genetic architecture and genomic underpinnings with language and speech abilities, suggesting a deep evolutionary significance within the temporal processing of communicative sound structures (Alagöz et al., 2024; Nayak, Coleman, et al., 2022; Scartozzi et al., 2026). By focusing on the temporal features of prosody distinct from pitch (e.g., spacing, rate, stress, and meter), spanning nested time-scales and perceptual windows, an emergent communicative structure of rich informative value is revealed (Heffner & Slevc, 2015).

As has been recently argued (Nayak, Moberly, et al., 2025), older adults may greatly benefit from investigations into the myriad of ways in which musical rhythm skills are linked with speech-language and communication outcomes, specifically in the realm of age-related hearing loss (ARHL). ARHL, one of the most common health conditions affecting older adults, is estimated to impact nearly two-thirds of individuals aged 70 and older in the U.S. (Lin et al., 2011; Uchida et al., 2019). ARHL is known to be correlated with elevated levels of suicidal ideation, decreased motor ability, decreases in quality of life, and is broadly associated with increased odds of psychological distress (Tuwaig et al., 2017; Loughrey et al., 2018; Bigelow et al., 2020; Choi et al., 2023). Further, ARHL is identified as one of the main modifiable risk factors for dementia and cognitive decline, encouraging remediation strategies such as the use of hearing-assistive devices and decreasing exposure to harmful environmental noise (Livingston et al., 2024). These significant risks underscore the need for research supporting early identification, screening, and functional support for those experiencing ARHL, since there is currently no cure for this hearing disorder. A crucial ability that can be negatively impacted by ARHL is a hallmark of central auditory functioning: speech-in-noise (SIN) perception. SIN perception is a vital skill facilitating the ability to participate in everyday communications, which is essential for maintaining strong relationships, functional independence, and emotional well-being.

Interestingly, studies have shown that when it comes to perceiving SIN, musicians may have an advantage. In a large-scale study within the Canadian Longitudinal Study of Aging, positive correlations were found between music engagement frequency and hearing sensitivity in older adults (Johnson et al., 2024). Musicians also consistently demonstrate less age-related decline in central auditory processing than non-musicians, exhibiting improved abilities in SIN perception when compared to non-musicians (Parbery-Clark et al., 2009; Zendel & Alain, 2012; Benítez-Barrera et al., 2022). Further, a recent study employing a continuous measure of musical sophistication has identified working memory and rhythm skills (on-beat accuracy) as having positive associations with SIN perception in a sample of older adults with hearing impairments (Lo et al., 2024). Genetic evidence from large, genome-wide association studies (GWAS), which identify polygenic markers of complex behaviors and traits, support these connections. Significant genetic correlations have been reported between musical rhythm abilities and SIN perception, as well as musical engagement and hearing acuity (Nayak, Henechowicz, et al., 2025). Further, recent work has reported shared genetic influences between speech rhythm, musical rhythm abilities, and reading (Scartozzi et al., 2026).

In studying the impacts of musical engagement on health outcomes, researchers have departed from using a binary categorization of 'musician' and 'non-musician' in experimental design, instead adopting the concept of 'musicality.' Musicality is defined as "a natural, spontaneously developing trait based on and constrained by biology and cognition" (Honing et al., 2015). This shift allows for the measurement of a wide spectrum of self-reported musical experiences, yielding data with greater ecological validity which, in turn, may be applied on a continuous scale (Müllensiefen et al., 2014). Such approaches provide more fine-grained detail of musical engagement behaviors such as training, emotion, and overall sophistication, providing nuanced information to health-relevant research. Through this paradigm, Perron et al. (2026) has identified working memory (WM) and rhythm skills (beat perception) as significant mediators linking musical sophistication with SIN outcomes in a sample of young adults with normal hearing.

Speech rhythm, the perceptual organization of temporal patterns in stressed and unstressed syllables, is considered an overlooked feature of language processing that supports word segmentation, parsing, and broader language comprehension (Peelle & Davis, 2012; Redford & Oh, 2016; Beier & Ferreira, 2018). A foundational component of speech rhythm is lexical stress sensitivity, which refers to the ability to identify stressed and unstressed syllables at the word level (Cutler et al., 2005; Field, 2005). The specific role of speech rhythm perception, particularly in relation to SIN perception, remains a largely unexplored domain of research in ARHL, with potential implications for improving speech comprehension in challenging listening environments and characterizing promotive factors for better hearing outcomes. Despite growing evidence supporting connections between musical rhythm and speech-language-hearing outcomes, the specific role of prosodic features (e.g., lexical stress) in SIN perception is underexplored. In investigating the perceptual dimensions that contribute to speech intelligibility, lexical stress sensitivity and musical rhythm abilities stand as valuable parallels and points of reference. Targeted investigations incorporating elements of speech features (e.g., speech rhythm) will have the potential to contribute to new understandings in this area, further disentangling the complex relationships between prosody, rhythm, and SIN perception, which exhibit distinct and shared underlying neural mechanisms and genetic architecture (see Figure 1 for a visual summary):

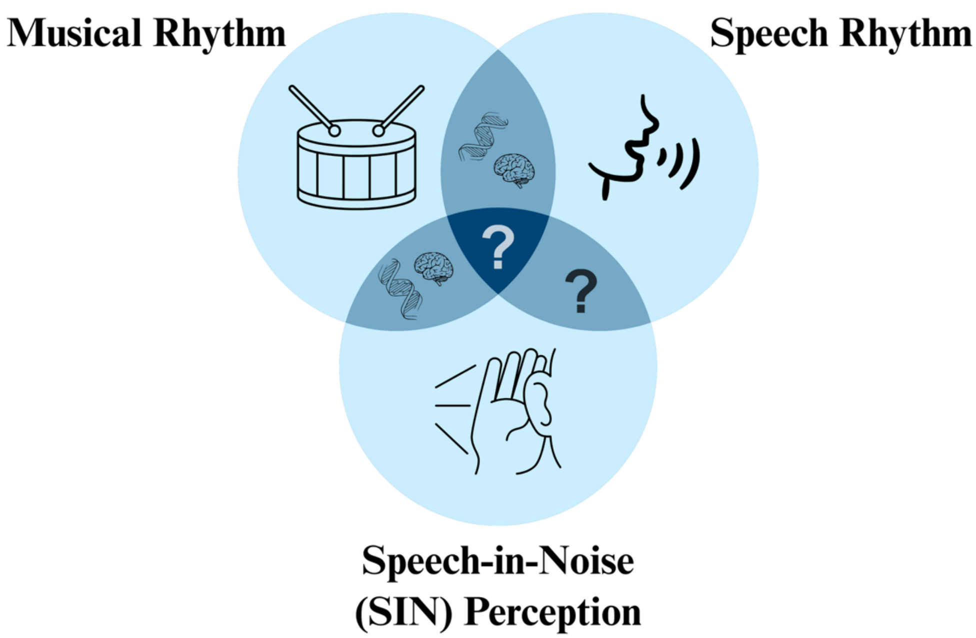

Figure 1. Neurobiological underpinnings across music and language domains of interest

Furthermore, individual differences in musical training are of interest when investigating relationships between older adults' rhythm, prosody, and SIN perception. Because musical training cultivates enhanced rhythm abilities, it has also long been considered to be a potential driver of transfer effects across areas of speech-language perception (e.g., Strait & Kraus, 2011; Fiveash et al., 2021). Acknowledging the gene-environment interplay that shapes musical engagement across the lifespan (Nayak, Coleman, et al., 2022), older adults represent a particularly relevant population in which lifelong predictors are most fully expressed. These highly complex and layered interactions associated with music training can help to guide future research working to disentangle health-relevant markers in aging, ARHL, and SIN perception (see Figure 2).

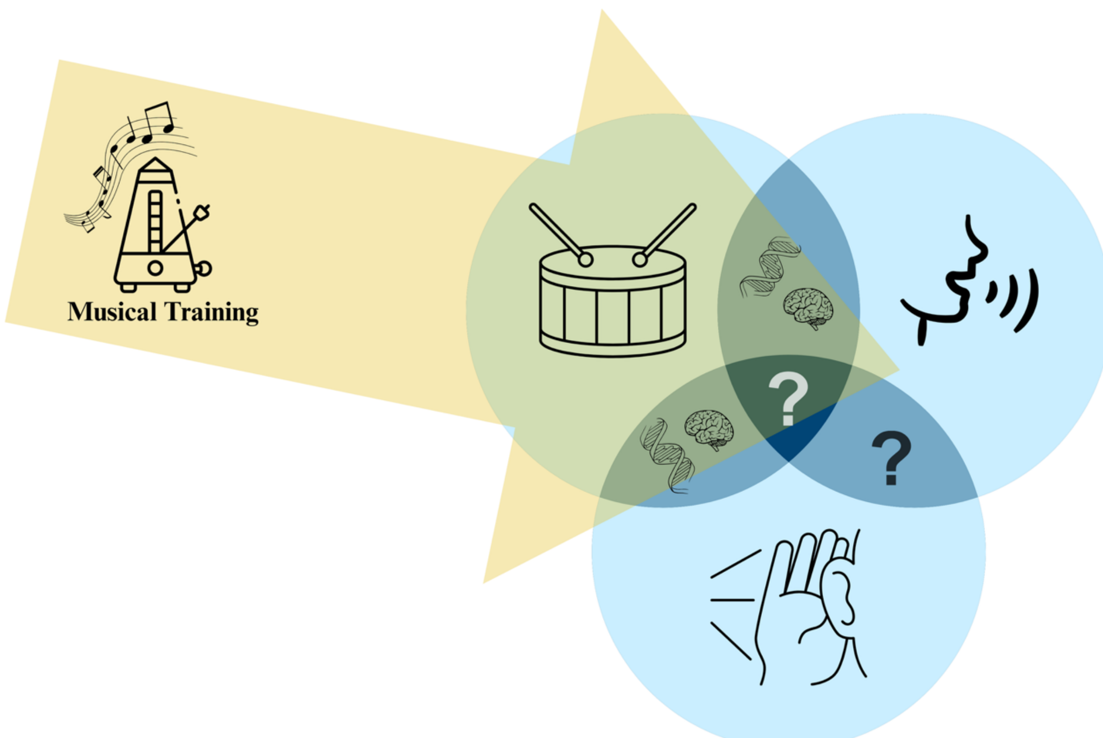

Figure 2. Considering interactions between musical training and variables of interest

Longitudinal studies have explored musical training interventions in older adults, reporting significant improvements in musical skill in inexperienced participants after one year of regular training (Losch et al., 2024), as well transfers to speech perception domains, such as improved SIN recognition after six months of piano lessons (Zendel et al., 2019), 10 weeks of choral singing (Dubinsky et al., 2019), and 14 weeks of choral singing (Lo et al., 2024). These studies contribute to a larger picture of how musical training may drive some changes across shared neurobiological features within SIN processing and aging, while the specific impact of musical training on prosody perception in older adults is unknown. Exploring the ways that musical training impacts prosody (lexical stress) sensitivity, considering musical rhythm skills as an intermediary correlate, can help to illuminate if and how these variables interact. Notably, if musical training shows positive associations with prosody perception, and if prosody perception is positively associated with SIN perception, a new line of evidence may emerge supporting musical training as an effective intervention supporting SIN perception. This could give rise to investigations examining the roles of individual differences in musicality and prosody perception in supporting SIN outcomes in older adults. Additionally, genetic studies can further reveal for whom such activities and interventions may be most beneficial.

By contributing to a greater understanding of the relationships between prosody (lexical stress) sensitivity, musical rhythm skills, musical training, and SIN perception, this study can support the development of early risk identification and effective, accessible interventions for older adults with ARHL and/or SIN perception difficulties.

Research Aims of the Current Study

This study fills a gap in the literature by exploring prosody (lexical stress) perception as a meaningful factor that may contribute to better SIN perception outcomes in older adults with normal hearing. Specifically, I hypothesize that (1) prosody (lexical stress) perception scores in older adults will be positively correlated with SIN perception and (2) prosody (lexical stress) perception will mediate the relationship between rhythm discrimination skills and SIN perception (see Figure 3):

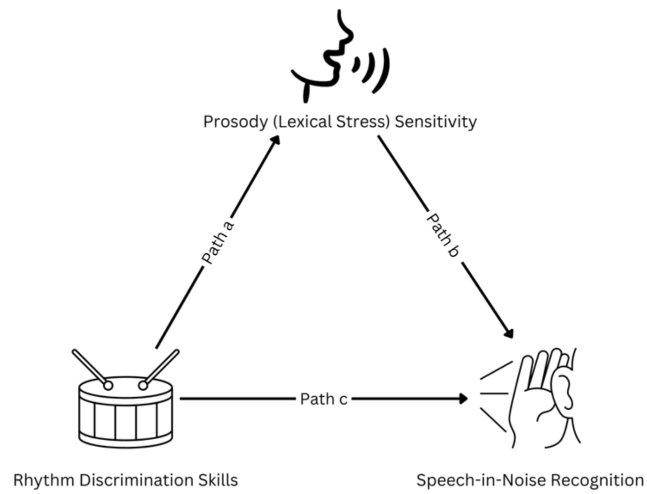

Figure 3. Mediation model

Furthermore, observed correlations among musical training, rhythm discrimination, and prosody (lexical stress) sensitivity suggested a potential mediating role of rhythm discrimination. A mediation analysis was therefore conducted to explore this possibility (see Figure 4):

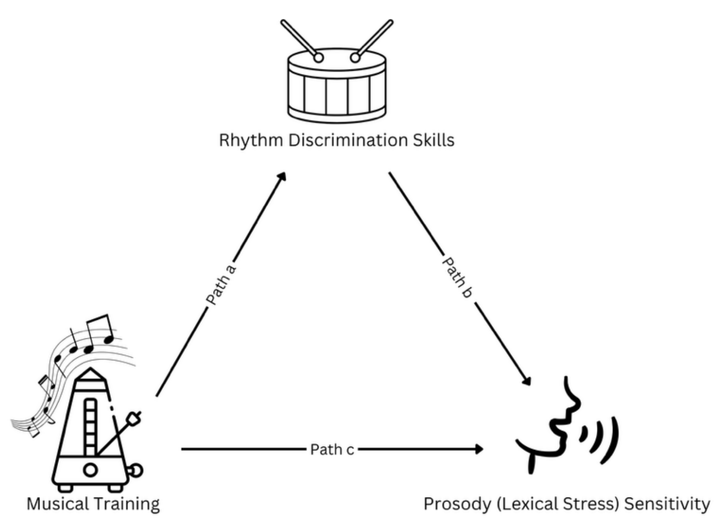

Figure 4. Post-hoc mediation model

Methodology

Participants

In this study, $N = 46$ were included in the final analyses models related to prosody (lexical stress) sensitivity, musical rhythm discrimination, and musical training (M = 68.98 yrs; SD = 4.19). 14 of these participants (30.4%) were male, and 32 (69.6%) were female. A subset of this group ($N = 39$) completed the blind, double scoring process for the Perceptually Robust English Sentence Test Open-set (PRESTO), a task measuring SIN perception. Therefore, a subset of $N = 39$ was used for all analyses models related to SIN (M = 69.21 yrs; SD = 4.48), in which 13 of the participants (33.3%) were male, and 26 participants (66.7%) were female. An additional 37 individuals had enrolled and participated but were excluded from final analyses due to technical difficulties or meeting exclusionary criteria (e.g., failing to pass an attention check or measuring with clinically significant hearing impairments).

All participants were native speakers of American English and had self-reported normal hearing, meaning that they considered their hearing abilities to be fine for daily functioning, and they did not require the use of hearing assistive devices (e.g., hearing aids, cochlear implants). Recruitment efforts were carried out through the VUMC Research Notification Distribution List (RNDL), MyVUMC Newsletter listserv announcements, ResearchMatch.org email invitations, Nashville-based community events supporting wellbeing in older adults, social media posts, and study flyers. Data for the current study are a subset of a larger, ongoing study ($N = 77$) at VUMC, results for which have been reported elsewhere (Eum et al., 2026).

Experimental Procedure

Enrolled participants completed an e-consent form, online questionnaires, and a prosody (lexical stress) perception task using an online Research Electronic Data Capture (REDCap) survey queue, followed by an in-person study visit at VUMC's Bill Wilkerson Center. During the in-person study visit, participants completed several tasks measuring hearing health, communication, and musical behaviors. Experimental measures used for the purposes of this study were the Pure Tone Audiometry Test, Swedish Musical Discrimination Test (SMDT) Rhythm subtest, and the Perceptually Robust English Sentence Test Open-set (PRESTO).

Because the existing study had been actively enrolling participants prior to the addition of a prosody (lexical stress) perception task, 41 previously enrolled participants from whom data had already been collected were retroactively invited to complete the prosody (lexical stress) perception task online. 36 individuals successfully enrolled, completed the follow-up prosody task, and were compensated with a $15 e-gift card from Amazon (or another leading retailer) for their participation.

Data Collection Instruments and Measures

Pure Tone Audiometry Test

Pure tone audiometry is a standard measure used to quantify an individual's hearing sensitivity at different frequencies (Humes, 2019; *World Report on Hearing*, 2021). During this task, participants listened to pure tones (250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz) in both ears via headphones, indicating to the experimenter whether they could hear each tone. Following established practice outlined by the *World*

Report on Hearing (2021), four-frequency pure tone averages (PTA4) of 500, 1000, 2000, and 4000 Hz were computed to assess hearing acuity, with the better hearing ear threshold used for analyses. To isolate perception of SIN independent of peripheral hearing loss, these thresholds were used to stratify analyses across levels of impairment. Due to insufficient representation in the mild impairment category, analyses focus on normal hearing, excluding participants with clinically significant hearing loss.

Swedish Musical Discrimination Test (SMDT) Rhythm subtest

The Swedish Musical Discrimination Test (SMDT) assessed participants' perceptual acuity of rhythm discrimination, administered through a computerized paradigm using PsychoPy software. While wearing headphones, participants listened to two short rhythms and were prompted to select whether the pair of rhythms were the same or different (see Figure 5 for an example of the SMDT rhythm subtest stimuli). Throughout this task, 18 different rhythm pairs were played, with each pair separated by one second of silence within trials. The rhythm stimuli featured 500 Hz sine tone sequences and progressed from using 5 to 7 different sounds in each stimulus. Showing high internal consistency, the Cronbach's alpha value for this test was measured across two samples, resulting in values of 0.81 and 0.82. This test's split-half coefficient was 0.83 and 0.84 across the two samples (Ullén et al., 2014).

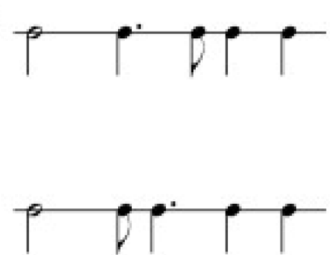

Figure 5. SMDT Rhythm subtest stimuli (Ullén et al., 2014)

Perceptually Robust English Sentence Test Open-set (PRESTO)

In administering the Perceptually Robust English Sentence Test Open-set (PRESTO), participants used headphones to listen to spoken sentences embedded in a variety of talker babble conditions. Participants' verbal responses (repeating the exact sentences that were heard) were audio recorded in a soundproof booth during the task. Responses were later assessed using scoring lists accounting for variables within the specific stimuli (e.g., signal to noise ratio, speaker gender, and speaker dialect) and accuracy in identifying primary keywords in the spoken sentence. In this study, primary keyword accuracy was the only score of interest. The recorded responses were scored by two independent scorers, blind. When scores differed by over 1%, both scorers met to discuss and reach a consensus. Final scores were calculated as the mean of the two final ratings.

An example of primary keywords used in the PRESTO task can be seen below in Figure 6, where bold and underlined formatting is used to emphasize target keywords. Validity of PRESTO has been assessed through correlational analysis of participant performance on the HINT (Hearing in Noise Test) and demonstrates great test-retest reliability, providing a valid assessment of speech recognition-in-noise skills (Gilbert et al., 2013).

That is only **partly** **non-nonsense**, he **began**.

Figure 6. A PRESTO sentence, emphasizing target keyword (Gilbert et al., 2013)

Test of Prosody via Syllable Emphasis (TOPsy)

The Test of Prosody via Syllable Emphasis (TOPsy) was administered online through REDCap. Participants were instructed to use a computer and headphones to complete the task from home and were asked to report if any errors or technical difficulties occurred throughout the task. Participants were given an option to complete this test at their study visit, if preferred. This test started with a headphone check and syllable identification task, which oriented participants to the stimuli, and were not used in analyses. Then, participants completed the final 28-item syllable stress identification task. During this final task, participants listened to an audio recording of a spoken word and identified the syllable carrying the primary emphasis based on how it was pronounced in the recording. Below, Figure 7 shows an example of an item within the TOPsy REDCap instrument. During task administration, item 19 served as an attention check to ensure participants were attending to the audio stimuli. Six participants did not pass the attention check and were excluded from analyses. TOPsy has demonstrated high reliability and validity in previous research. Internal consistency of this task has been evaluated, with a reported Cronbach's alpha ≈ 0.92 (Nayak et al., 2022). The entire task is available to view in supplemental information, Appendix D.

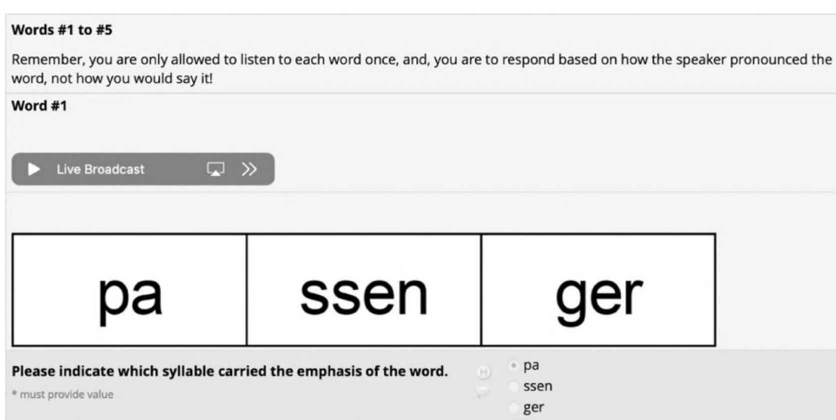

Figure 7. An item within the TOPsy REDCap instrument (Nayak et al., 2022)

Goldsmith's Musical Sophistication Index (Gold-MSI): Music Training Subscale

The Goldsmith's Musical Sophistication Index (Gold-MSI) is a validated self-report questionnaire developed to broadly measure musical sophistication in the general population through five distinctly indexed factors: active engagement, perceptual abilities, musical training, singing abilities, and emotions (Müllensiefen et al., 2014). Enrolled participants completed the Gold-MSI during the questionnaire portion of their study participation. Of significant interest in this study is the musical training subscale within the Gold-MSI, comprised of seven items which combine to create a composite musical training score. These items address: (1) regular daily practice, (2) number of instruments played, (3) being complimented on performances, (4) number of hours practiced at peak, (5) years of music theory training, (6) years of instrument training, and (7) self-identification as a musician. These items are then combined into a composite score, enabling use as a continuous predictor in statistical analyses. This scale captures several aspects of musical training otherwise missed in investigations employing a binary measure of musician/non-musician status. This musical training sub-scale has been translated and validated across several different languages (Li et al., 2024; Santangelo et al., 2024), has been supported for use in older adults (Petrovsky et al., 2017), and has been validated using construct validity and internal consistency with Cronbach's alpha ≈ 0.90 (Müllensiefen et al., 2014).

Analysis

Data Cleaning

Initially, the sample for this study consisted of 83 records, a portion of which were removed due to failure of the TOPsy attention check (6), technical malfunction during the TOPsy task (1), missing data (2), incomplete study participation (3), and measurement of a clinically significant hearing impairment (25). This resulted in a final $N = 46$. All data analyses were conducted using RStudio, version 2026.01.1+403 (R Core Team, 2025) and *jamovi*, version 2.7.6.0 (The jamovi project, 2024).

To filter for peripheral hearing loss, pure tone averages in the better ear across four frequencies: 500, 1000, 2000, and 4000 Hz, also known as better ear PTA4, were used to measure for hearing acuity in the participant records. Participants measuring with clinical hearing impairments in the better ear were excluded from analyses to ensure that SIN performance reflected central auditory processing rather than peripheral hearing abilities. This approach is intended to establish a normal-hearing baseline in older adults that can be compared to future investigations with more variability, including hearing-impaired or mixed-hearing samples. Hearing impairment thresholds established by the World Report on Hearing (2021) were used to quantify peripheral hearing loss using better ear PTA4 measurements of mild impairment (20 to < 35 dB), moderate impairment (35 to < 50 dB), moderately severe impairment (50 to < 65 dB), severe impairment (65 to < 80 dB), profound impairment (80 to < 95 dB), complete or total hearing loss / deafness (≥ 95 dB) and unilateral impairment (< 20 dB in the better ear and ≥ 35 dB in the worse ear). A total of 25 participants measured with a better ear PTA4 of ≥ 20 dB and were subsequently excluded from analysis. No participants measured with unilateral hearing impairments.

Bivariate Correlations and Multiple Regression Models

Percentages and z-scored values were calculated from raw scores for all variables of interest. Descriptive statistics were then assessed to check for outliers, defined using a threshold of ±3 *SD* beyond the mean, and to verify normality of the data. A correlation table featuring all variables of interest was evaluated to assess bivariate relationships and determine if correlations supported the hypothesized mediation model (Figure 3).

To better understand interactions in the three-way relationships between variables in the mediation model, three multiple regression models were also conducted using RStudio. These regression models allowed for multivariate analyses between a predictor and outcome variable, controlling for covariates of sex and musical training. The covariates included in these three models were chosen based on significant p-values in the correlation table. To account for additional variance in the sample, age was also included as a covariate.

Model 1. Do rhythm discrimination skills predict prosody (lexical stress) sensitivity? (*Path a* of the mediation model, shown in Figure 3).

Model 2. Does prosody (lexical stress) sensitivity predict SIN perception? (*Path b* of the mediation model, shown in Figure 3).

Model 3. Do rhythm discrimination skills predict SIN perception? (*Path c* of the mediation model, shown in Figure 3).

Post-Hoc Mediation Analysis

Observed correlations among musical training, rhythm discrimination skills, and prosody (lexical stress) sensitivity suggested a potential mediating role of rhythm discrimination in the relationship between musical training and prosody (lexical stress) sensitivity. A post-hoc mediation analysis was conducted using standardized variables in *jamovi* (version 2.7.6.0) to investigate this possibility. The direct effect of musical training on prosody (lexical stress) perception (*Path c'*), the effect of musical training on rhythm discrimination *(Path a),* the effect of rhythm discrimination on prosody (lexical stress) perception while controlling for musical training (*Path b*), and the total effect of the entire model (*Path c*) were estimated. The significance of the indirect effect (*a*b*) was assessed via bias-corrected (BC) bootstrapping with a 95% confidence interval (5000 bootstrapped samples). No covariates were included in the model. Assumptions of the mediation analysis, including linearity, normality of residuals, multicollinearity (assessed via VIFs), and absence of unmeasured confounders, were checked.

Results

Descriptive Statistics

Descriptive statistics were computed for all variables of interest using *jamovi* statistical software. As shown below in Table 1, a sample of *N* = 46 participants successfully completed their study measures. *N* = 39 records had made it through the blind, double scoring process for the PRESTO SIN perception task. Outliers were defined using a threshold of ±3 *SD* beyond the mean, none of which were detected in the sample. Skewness and kurtosis values were within acceptable ranges (±3), indicating no substantial need to transform variables for analyses.

Table 1: Descriptive statistics for variables of interest in the final analysis sample

Descriptives

							Skewness		Kurtosis	
	N	Mean	Median	SD	Minimum	Maximum	Skewness	SE	Kurtosis	SE
TOPsy Score (%)	46	72.83	80.36	27.173	10.7	100.0	−0.527	0.350	−1.05308	0.688
PRESTO Score (%)	39	54.76	56.45	6.373	38.4	65.6	−0.876	0.378	0.37532	0.741
SMDT Rhythm Score (%)	46	86.11	88.89	9.278	61.1	100.0	−0.434	0.350	0.00129	0.688
Age	46	68.98	68.00	4.193	65	82	1.522	0.350	2.14530	0.688
Sex	46	1.70	2.00	0.465	1	2	−0.879	0.350	−1.28457	0.688
Music Training Score	46	23.52	22.00	11.127	7	44	0.233	0.350	−1.20376	0.688

Note: Sex was coded as 1 = Male and 2 = Female.

Bivariate Correlational Analyses

Pearson's r correlation coefficients were calculated in R to assess the strength and direction of correlations between variables. This analysis included central measures of interest: rhythm skills, prosody sensitivity, and SIN perception, as well as key demographic variables and aspects of musical backgrounds (i.e., age, sex, musical training). This step allowed for an initial assessment of whether the variables were correlated in the expected directions, providing preliminary support for the hypothesized relationships to be investigated in the mediation analysis.

Significant correlations were found between prosody sensitivity and musical rhythm discrimination ($r = 0.5$, $p < .001$), music training and musical rhythm discrimination ($r = 0.42$, $p < .01$), musical training and prosody sensitivity ($r = 0.46$, $p < .01$), and sex and prosody sensitivity ($r = -0.34$, $p < .05$), as seen below in Figure 8.

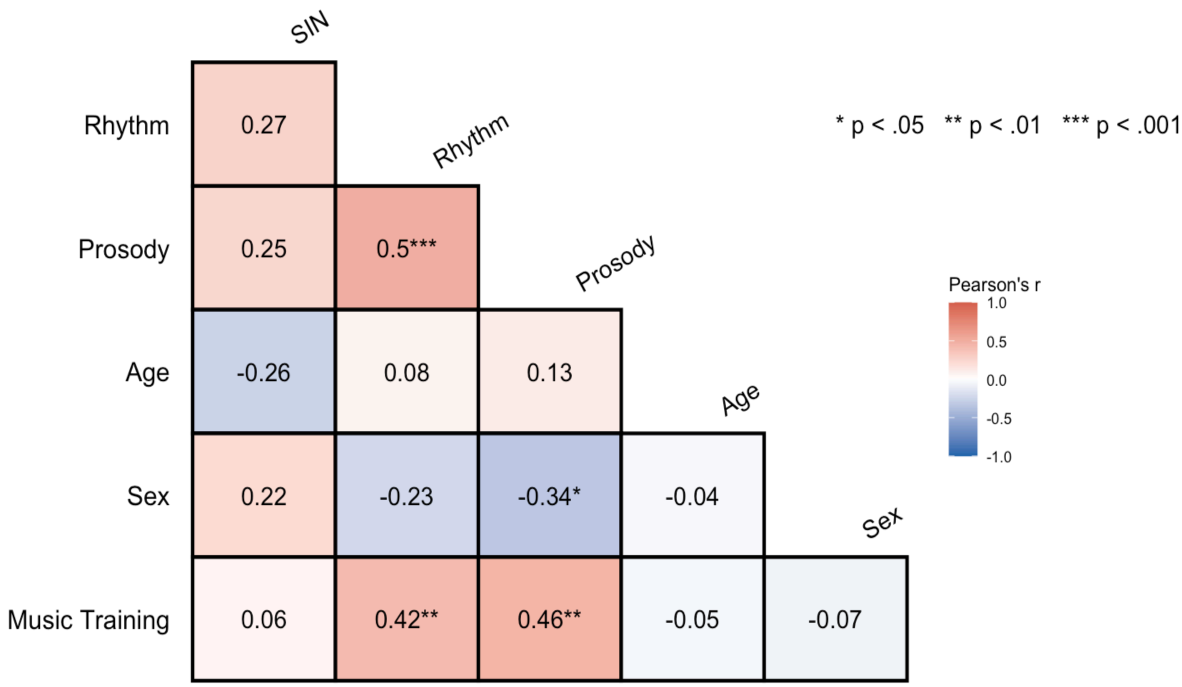

Figure 8: Correlation plot displaying variables of interest[1]

To test whether prosody (lexical stress) sensitivity mediates the relationship between rhythm skills and SIN perception, all three variables were required to be correlated. Below, Figure 9 depicts the three paths of the mediation model along with correlations between all variables. As the correlation results show, two of these paths

[1] Visualized in RStudio using *ggplot2* (Wickham, 2016) and *tidyr* (Wickham et al., 2024)

were not significantly correlated with $N = 39$: lexical stress sensitivity and SIN (*Path b:* $r = 0.25$, $p = .1$) and rhythm discrimination and SIN (*Path c':* $r = 0.27$, $p = .1$). Therefore, the hypothesized mediation analysis was not conducted.

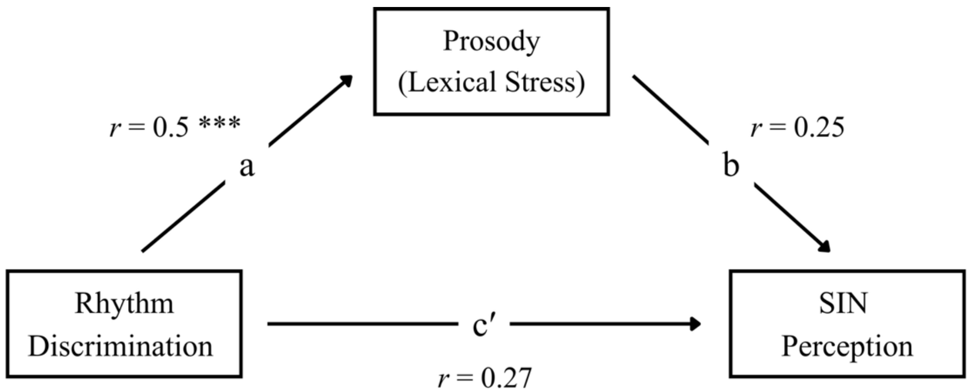

Figure 9: Path model displaying bivariate correlation results, $^{***}p < 0.001$

Multiple Regression Models

To better understand the three-way relationships between musical rhythm skills, prosody, and SIN perception, three multiple linear regression models were conducted in the sample of older adults with normal hearing, controlling for age, sex, and musical training.

Model 1: Musical Rhythm as a Predictor of Prosody (Lexical Stress) Sensitivity

To examine if musical rhythm discrimination abilities predict prosody (lexical stress) sensitivity in a sample of older adults with normal hearing, a multiple regression model was conducted, regressing TOPsy accuracy scores (outcome) onto SMDT accuracy scores as the predictor, and sex, age, and music training as covariates ($N = 46$). The overall model was statistically significant (F (4, 41) = 6.674, $p < .001$, $R^2 = 0.39$, *adjusted* $R^2 = 0.34$), explaining 34% of the variability in prosody (lexical stress) sensitivity scores. Controlling for age, sex, and musical training, rhythm discrimination scores were a positive predictor of prosody (lexical stress) sensitivity ($\beta = 0.3$, $p < .05$; see Figure 10), with a 1 *SD* increase in rhythm discrimination associated with a 0.3 *SD* increase in prosody (lexical stress) sensitivity scores. Additionally, musical training was a significant predictor of TOPsy scores in this sample ($\beta = 0.3$, $p < .05$).

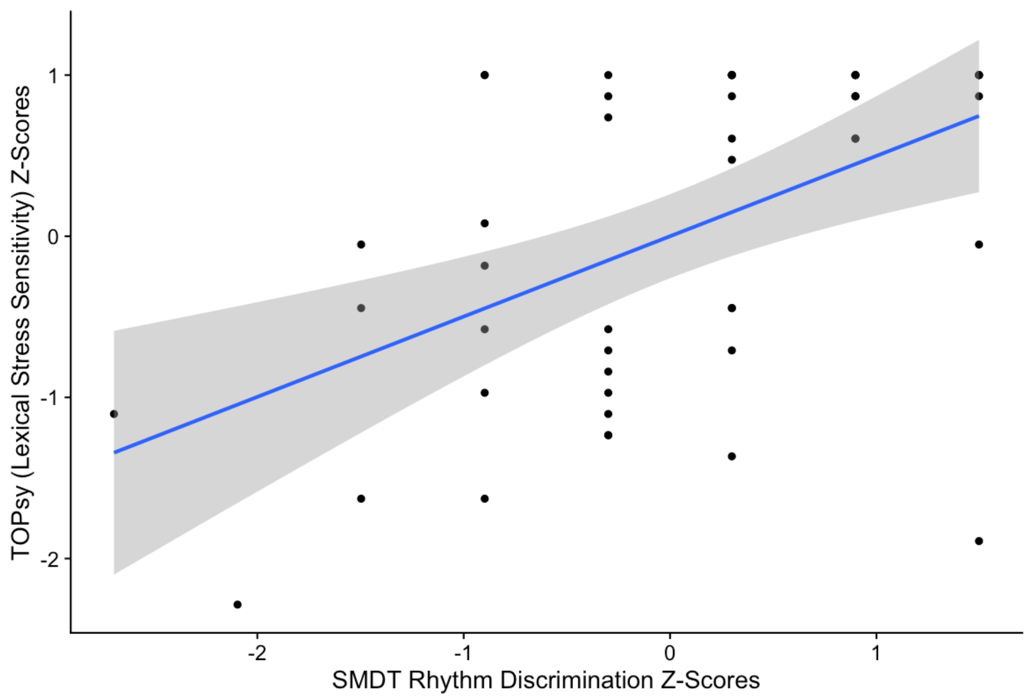

Figure 10: Scatterplot depicting the relationship between rhythm discrimination scores and TOPsy (prosody) scores

Model 2: Prosody (Lexical Stress) Sensitivity as a Predictor of SIN Accuracy

To examine if prosody (lexical stress) sensitivity predicts SIN perception in a sample of older adults with normal hearing, a multiple regression model was conducted, regressing PRESTO sentence accuracy scores (outcome) onto TOPsy accuracy scores as the predictor, and sex, age, and music training as covariates ($N = 39$). The overall model was statistically significant (F (4, 34) = 3.219, $p < .05$, $R^2 = 0.27$, *adjusted* $R^2 = 0.19$), explaining 19% of the variability in SIN perception scores. Controlling for sex, age, and musical training, prosody (lexical stress) sensitivity was a positive predictor of SIN scores ($\beta = 0.47$, $p < .05$; see Figure 11), with a 1 *SD* increase in TOPsy scores associated with a 0.47 *SD* increase in PRESTO scores. Further, both age ($\beta = -0.07$, $p < .05$) and sex ($\beta = 0.78$, $p < .05$) were significant predictors of PRESTO scores in this sample.

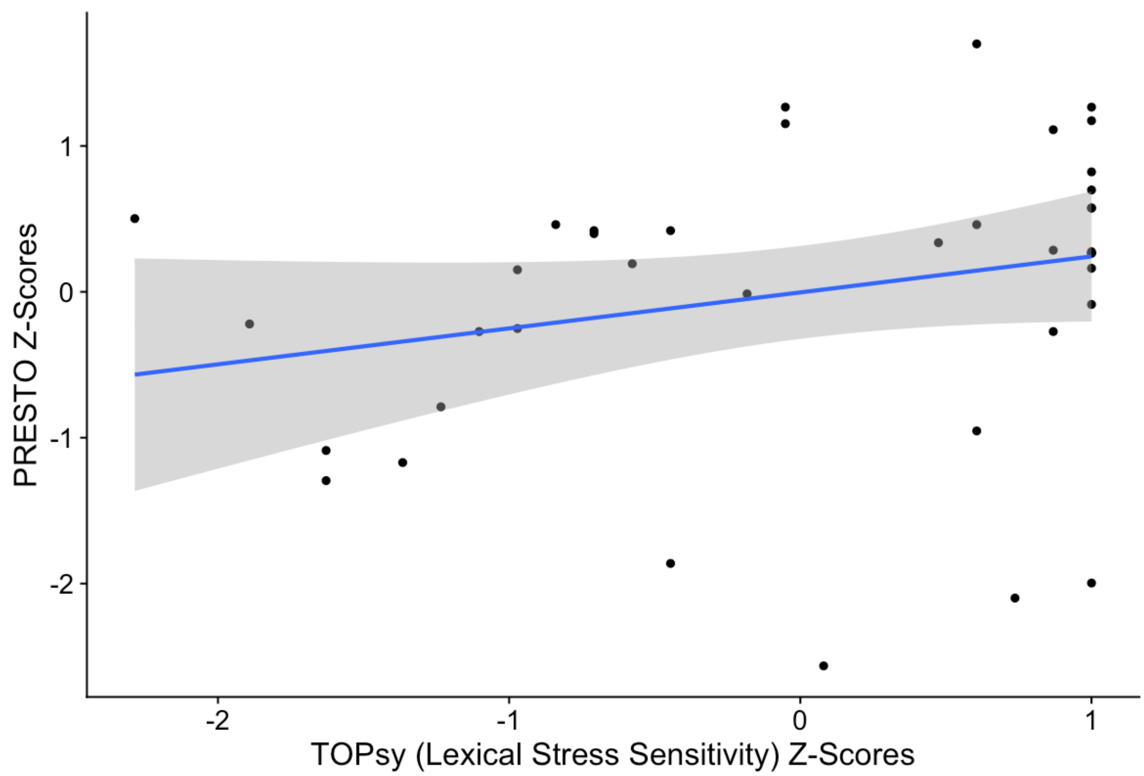

Figure 11: Scatterplot depicting the relationship between TOPsy (prosody) scores and PRESTO (SIN) scores

Model 3: Musical Rhythm Discrimination as a Predictor of SIN Perception

To examine if musical rhythm discrimination predicts SIN perception in a sample of older adults with normal hearing, a multiple regression model was conducted regressing PRESTO accuracy scores (outcome) onto SMDT rhythm accuracy scores as the predictor, and sex, age, and music training as covariates ($N = 39$). The overall model was statistically significant (F (4, 34) = 2.942, $p < .05$, $R^2 = 0.26$, *adjusted* $R^2 = 0.17$), explaining 17% of the variability in SIN perception scores. Controlling for sex, age, and musical training, musical rhythm discrimination was a positive predictor of SIN scores ($\beta = 0.4$, $p < .05$; see Figure 12), with a 1 *SD* in rhythm discrimination scores associated with a 0.4 *SD* increase in SIN perception scores. Additionally, sex ($\beta = 0.68$, $p < .05$) was a significant predictor of PRESTO scores.

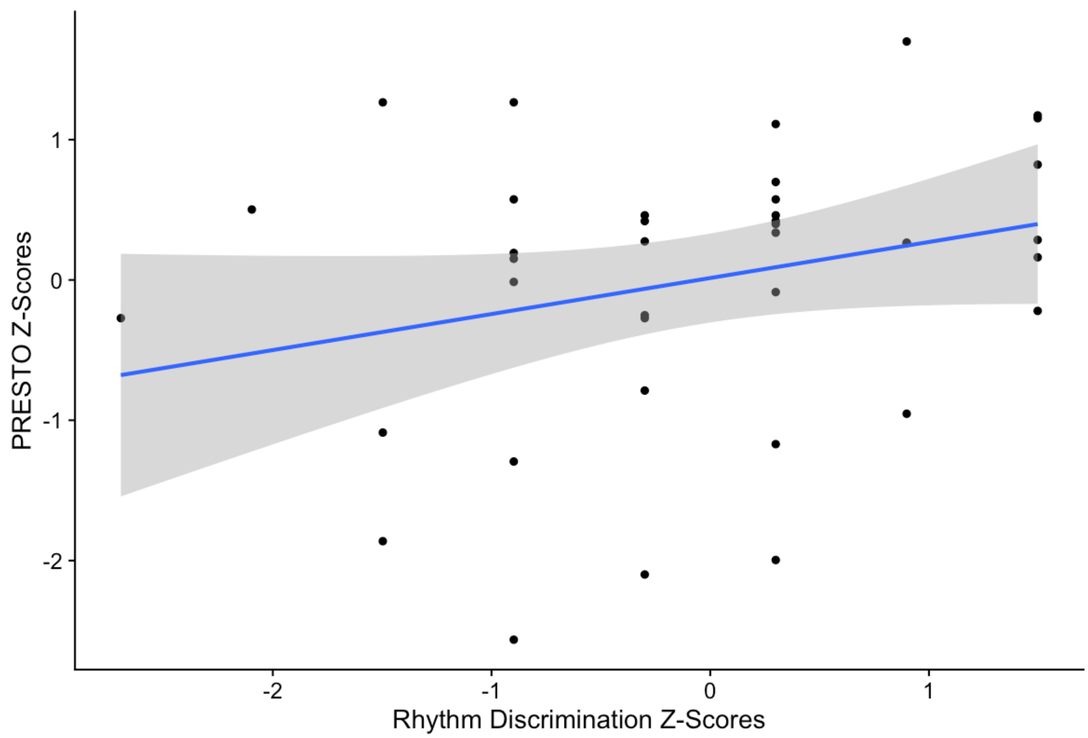

Figure 12: Scatterplot depicting the relationship between rhythm discrimination scores and PRESTO (SIN) scores

Post-Hoc Mediation Analysis

Significant, positive associations observed among musical training scores, rhythm discrimination, and prosody (lexical stress) sensitivity suggested a potential mediating role of rhythm discrimination skills in the relationship between musical training and prosody sensitivity. Therefore, an exploratory mediation analysis using standardized variables ($N = 46$) was conducted to investigate this possibility (See Figure 13) using *jamovi* software.

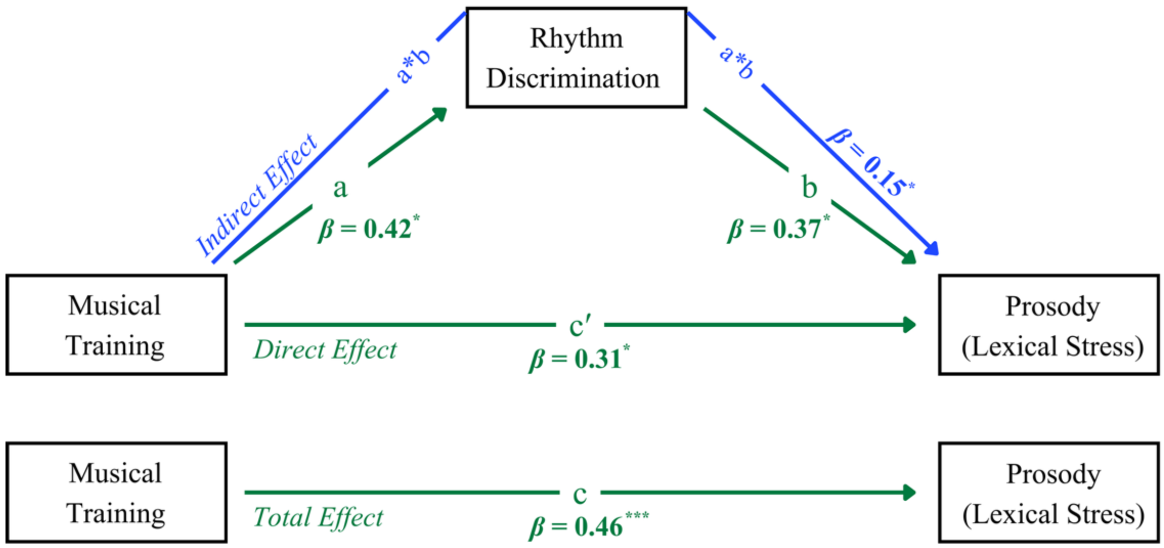

Figure 13: Post-hoc mediation result, $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

Above, Figure 13 shows that rhythm discrimination is a partial mediator of the relationship between musical training scores and prosody (lexical stress) sensitivity in this sample of older adults with normal hearing. The indirect effect of musical training on prosody through rhythm discrimination was statistically significant (*Path a*b*: $\beta = 0.15$, $SE = 0.074$, $p < .05$, 95% CI [0.025, 0.356]).

Additionally, the total effect (*Path c*) of the model showed that every 1 *SD* increase in musical training scores is associated with a 0.46 *SD* increase in prosody (lexical stress) sensitivity. This result indicates that musical training has a moderate to large, positive association with prosody perception ($\beta = 0.46$, $SE = 0.132$, $p < .001$, 95% CI [0.207, 0.713]).

Individual paths within the model showed a positive association of musical training with rhythm discrimination (*Path a:* $\beta = 0.42$, $SE = 0.134$, $p < .005$, 95% CI [0.161, 0.686]) and rhythm discrimination with prosody (*Path b:* $\beta = 0.37$, $SE = 0.133$, $p = .005$, 95% CI [0.03, 0.649]). The direct effect of musical training on prosody, controlling for rhythm discrimination, was also found to be positively associated and statistically significant. (*Path c':* $\beta = 0.31$, $SE = 0.133$, $p < .05$, 95% CI [0.039, 0.602]), highlighting a partial mediation effect of rhythm discrimination.

Discussion

This thesis aimed to examine the three-way relationship between prosody (lexical stress) sensitivity, SIN perception, and musical rhythm skills in older adults with normal hearing. Further, relationships of musical training to prosody perception and rhythm skills were explored. To do this, data was collected on key demographics and musical backgrounds in addition to measures of music and language perception in older adults, examined using correlational, multiple regression, and mediation analyses. Overall, findings show that the measure of prosody (lexical stress) sensitivity predicts a significant proportion of variability in SIN perception in older adults, illuminating the importance of prosodic features in SIN perception. Further, musical rhythm skills were found to partially mediate the relationship between musical training and prosody (lexical stress) sensitivity, emphasizing links between these domains. Musical rhythm skills were also found to be significantly associated with prosody (lexical stress) sensitivity, as has been demonstrated in wider age ranges, and has now been extended to older adults. Overall, these results underscore positive and significant associations between prosody, music, and hearing abilities in older adults.

Prosody (Lexical Stress) Sensitivity Predicts Variability in SIN Accuracy

The finding that lexical stress sensitivity significantly predicts SIN accuracy, even when accounting for age, sex, and musical training, suggests that prosody perception is a distinct cognitive-perceptual contributor to speech processing in noise, independent of demographic or experiential factors. To date, there is little known work concerned with the relationships between perceptual features of prosody and SIN perception. Two prior studies were found that operationally defined “prosody” broadly and qualitatively in order to assess the relevance of prosody discrimination in SIN perception in samples of young adults with and without cochlear implants (van Zyl & Hanekom, 2011; Van Zyl & Hanekom, 2013). Results of this prior work underscore the importance of layered contrasts in pitch, emphasis, duration, timbre, and articulation rate for the perception of meaning in challenging listening conditions, though the work did not extend to identify the specific prosodic features contributing to SIN perception. In contrast, this thesis uniquely focuses on a single element of prosody and speech rhythm: lexical stress sensitivity in native English speakers, carried out using an established measure of word-level syllable stress sensitivity (Nayak, Daniel E. Gustavson, et al., 2022). This is the first study to find prosody (lexical stress) sensitivity as a meaningful perceptual ability supporting successful speech perception in noisy environments. This relationship likely stems from the use of rhythmic cues to ‘segment’ the speech stream; individuals more sensitive to the predictable patterns of lexical stress may be better equipped to reconstruct missing phonological information when the acoustic signal is degraded by noise.

The Impact of Musical Training on Prosody with Rhythm as a Mediator

In a post-hoc mediation analysis, musical training was found to be positively associated with prosody (lexical stress) sensitivity, with rhythm discrimination as a partial mediator. Based on this evidence, musical training appears to be a potential driver of prosody perception in our sample of older adults, partially applied through the improvement of musical rhythm skills. This finding aligns with prior literature supporting transfer effects of musical training to domains of speech and language abilities across a wide variety of populations, including older adults (e.g., Strait & Kraus, 2011; Dubinsky et al., 2019; Fiveash et al., 2021). However, there has not yet been work published examining the specific role of musical training in prosody (lexical stress) sensitivity, nor has the role of rhythm skills been modeled as a significant mediator in the relationship. This finding illuminates a potential impact of musical training on rhythm skills and auditory processing mechanisms in older adults, therefore enhancing accurate perception and identification of the nuanced syllabic stress patterns in speech signals. As previously mentioned, this musical rhythm – lexical stress pathway is what appears to provide the scaffolding for SIN perception.

Musical Rhythm Discrimination Predicts Prosody (Lexical Stress) Sensitivity

The result of a multiple regression analysis placing musical rhythm discrimination as a predictor of variability in prosody (lexical stress) sensitivity, controlling for age, sex, and musical training, demonstrated a positive and significant relationship in our sample. This finding is consistent with previously reported associations between musical rhythm and speech rhythm shown in younger and wider age range samples (Hausen et al., 2013; Morrill et al., 2015; Magne et al., 2016; Nayak, Daniel E. Gustavson, et al., 2022). Until now, a specific relationship of lexical stress sensitivity and musical rhythm skills had not yet been examined in older adults. By establishing this baseline in normal-hearing older adults, we can better understand how perception of rhythmic structures might protect speech perception in challenging listening environments, even as peripheral hearing abilities decline. Future research involving samples with more hearing variability will contribute to a greater understanding of the shared mechanisms between musical rhythm skills and lexical stress sensitivity (e.g., temporal processing, beat perception, sensory memory, working memory) during age-related cognitive changes.

Musical Rhythm Skills Significantly Predict SIN Accuracy

The results of this study demonstrate musical rhythm discrimination as a significant predictor of SIN perception in older adults with normal hearing, controlling for covariates of sex, age, and musical training. A similar result has previously been reported in a sample of participants (*N* = 77) within the larger study that this data is a subset of (Eum et al., 2026). Eum et al.'s (2026) study differs from the analyses conducted in this thesis through the inclusion of all participant hearing profiles and utilization of better ear PTA as a covariate, rather than musical training. Further, reports of musical rhythm skills significantly predicting SIN perception has been demonstrated in prior literature revealing that on-beat tapping (Lo et al., 2024) and beat perception (Perron et al., 2026) are associated with improved SIN perception abilities. The findings of this study support this previously established association between rhythm skills and SIN abilities, uniquely in a sample of older adults with normal hearing. Overall, this work suggests that rhythm is not just a function of musical expression or musical context, but an overarching mechanism of perceptual processing and organization.

Study Limitations

Given that this study is based on a cross-sectional design, it is difficult to infer causality of musical training on speech perception skills in older adults. Self-selection and genetic influences are an important consideration when interpreting the impact of musical training across larger samples and populations. Recent longitudinal studies with multiple timepoints of data collection are supportive of effects of music training on language perception in older adults (Dubinsky et al., 2019; Lo et al., 2024) and genetic studies may be able to further reveal for whom such activities and interventions are most beneficial. While longitudinal studies are optimal designs to contribute to an understanding of causal relationships, it is worth noting that older adults represent the population in whom lifelong predictors and their associated outcomes are most fully expressed.

Biological sex differences are also of important consideration. While current understandings of cognitive decline and ARHL in older adults remain incomplete, evidence of sex differences in the expression and trajectory in biological aging processes warrants consideration. Given that this sample of older adults has a significantly higher proportion of females, findings may not generalize equally across sexes. Future research should focus on balanced representation, incorporate gender identity, and examine sex- and gender-related differences.

Care should be taken to avoid generalizing these results to populations with clinical hearing impairments. While ARHL is a core motivation of this thesis, this study ultimately examined individuals without clinical hearing impairments, providing evidence of these links in older adults with normal hearing which can now guide future work. Future inclusion of participants with clinically significant hearing loss through cross-sectional and longitudinal studies will be an important next step in further explorations emphasizing individual differences and natural variability in hearing acuity during aging processes.

The measures employed in this study have been positioned to represent broader, overarching constructs (i.e., musical rhythm discrimination ≈ musical rhythm skills; lexical stress sensitivity ≈ speech rhythm and prosody perception; PRESTO sentence in noise speech recognition ≈ SIN perception) and are acknowledged as partial operationalizations. Findings should be carefully interpreted with this in mind. Future study designs incorporating multiple measures of each construct would greatly contribute to understandings of the mechanisms involved in these complex processes.

By implementing multiple measures of each construct of interest, comparative and multivariate approaches can identify meaningful sources of variance in speech-language-hearing outcomes in older adults. Of note, capturing syllable or word stress sensitivity at the level of sentence may more appropriately map onto a sentence-level SIN task like PRESTO and common phrase durations in musical rhythm. The use of TOPsy in this study captures word-level stress sensitivity, representing nested rhythms within the greater context of sentence stress patterns. Considering our findings, these nested rhythmic structures appear to combine with other levels to contribute to SIN perception, analogous to subdivision classification systems in musical rhythm. Incorporating a similarly scaled stress measure (i.e. metrical stress sensitivity) at the level of sentence and word stress would contribute to understanding how different levels of speech rhythm perception interact and support SIN perception.

Additionally, complementary measures of SIN perception could feature stimuli that incorporate inter-aural timing differences, inter-aural volume differences, and sound localization as meaningful variables for auditory scene analysis and targeted speech tracking. This would help to narrow and disentangle contributing auditory processes supporting SIN perception in older adults.

Future Directions

Several paths for future consideration are clear. The significant predictive relationships observed between musical rhythm, prosody, and SIN perception confirm that these constructs are deeply interconnected, although the precise underlying mechanisms remain to be fully elucidated. As this is a currently ongoing study, revisiting the original correlation analysis at a higher *N* could also reveal preliminary correlations required to revisit the original mediation hypothesis.

Moving forward, the analyses of this thesis should be revisited (1) after additional data collection, considering the potential to revisit the original mediation hypothesis if preliminary correlations emerge; (2) in samples of older adults with greater hearing variability; (3) in experimental study designs incorporating multiple measurements of each construct (i.e., rhythm skills, prosody sensitivity, and SIN perception); and (4) in experimental designs collecting data on neurocognitive variables such as WM, sensory memory (SM), executive function (EF), and functional connectivity, the latter of which can be assessed through different neuroimaging techniques. These neurocognitive variables are of interest due to their well-established relationships to attention, perception, memory span, and inhibitory control, all of which are known to influence speech and language processing. This is especially relevant in older adult populations, who may experience age-related differences in cognition and employ sophisticated adaptive strategies that impact how results should be interpreted. Each of these directions has the potential to provide helpful insights, contributing to a greater understanding of how these related mechanisms are operate through age-related cognitive changes and ARHL in older adults.

In addition to this list, a post-hoc mediation examining the role of musical training on SIN perception considering prosody (lexical stress) perception as a mediator of the relationship may provide more information about the potential transfer effects of musical training in the current sample, given that the preliminary correlations exist. Longitudinal studies implementing musical interventions and employing a diverse set of measurements for each construct of interest (rhythm skills, prosody sensitivity, SIN perception) would contribute greatly to the understanding of how musical training interventions impact speech-language-hearing outcomes in older adults.

Further work investigating the temporal components of prosody (e.g., speech rhythm) is of significant interest, as well. Subdividing elements of speech prosody into measurable features, such as spacing, rate, stress, and meter—spanning multiple timescales, perceptual windows, and levels—enables targeted investigation pitch-independent and pitch-complementary characteristics, as well as the neural mechanisms implicated in successful speech processing. This can inform the design of future studies as well as therapeutic interventions aimed to promote speech perception outcomes for vulnerable populations, such as older adults experiencing challenges with SIN perception. Since all streams of auditory information rely on temporal attention and temporal processing, distinctly investigating and conceptualizing these varied patterns and characteristics of speech signals will be supportive for future work in this area.

Auditory Attenuation Thresholds as a Mechanism in the Musician-SIN Advantage

This thesis synthesizes the work of several studies demonstrating evidence for what has been referred to as the "musician's advantage" in the processing of SIN (Parbery-Clark et al., 2009; Zendel & Alain, 2012; Benítez-Barrera et al., 2022; Perron et al., 2026). Recent work by Perron et al. (2026) comprehensively investigates this advantage, reporting beat perception and WM as significant mediators in the relationship between musical sophistication and SIN. Framing current understandings through a lens of musical temporal processing and examining bottom-up and top-down processing through these frameworks brings new theoretical considerations of echoic memory (EM) and auditory attenuation for future investigation.

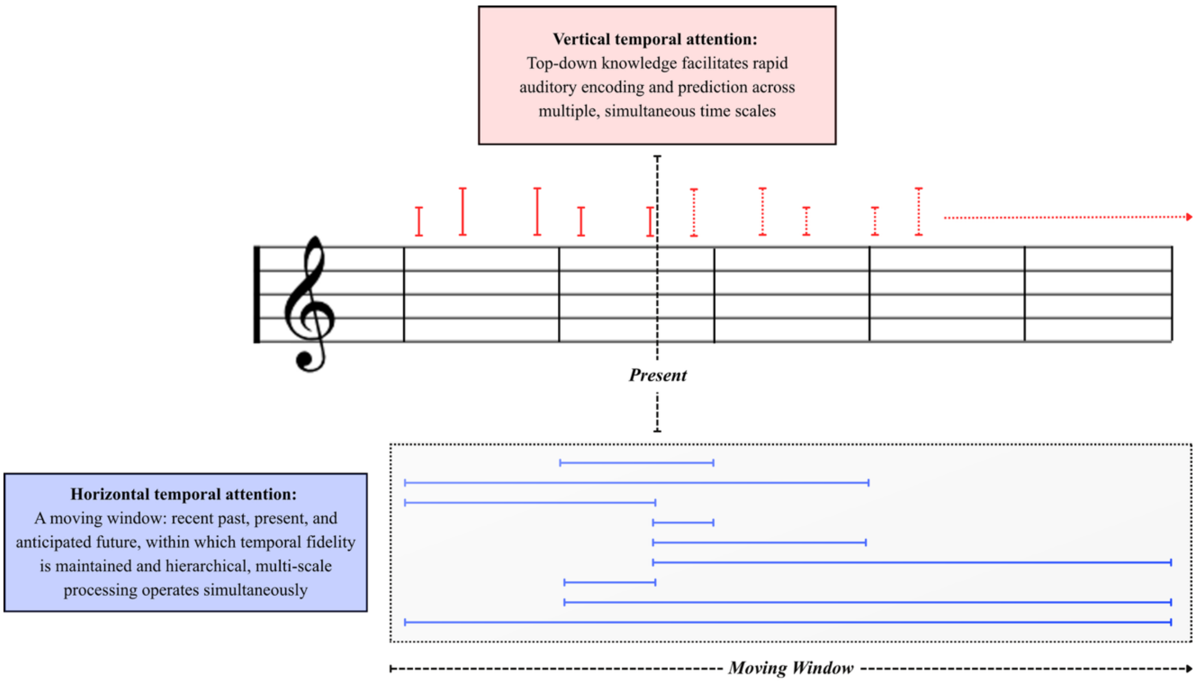

Figure 14: Proposed dimensions of temporal attention through musical training[2]

Musical training involves the development of highly refined predictive and recollective auditory abilities, demanding simultaneous hierarchical processing of complex information streams (i.e., “vertical temporal attention”; Jones, 1976) across events in the recent past, present, and anticipated future (i.e., “horizontal temporal attention”; Large & Jones, 1999), illustrated in Figure 14. These demands may underlie the greater echoic memory (EM) span and enhanced pre-attentive auditory processing reported in musicians (Bonetti et al., 2018), consequently reducing demand on WM and allowing for the preservation of auditory information before its relevance is known.

[2] Vertical and horizontal temporal attention are used as terms here, developed through the work of Jones (1976) and Large & Jones (1999).

This is consistent with attenuation theory (Treisman, 1964) which states that unattended auditory streams are still attenuated rather than completely filtered out, preserving them for potential late selection. Similarly, late-selection accounts propose that all auditory information is perceptually processed before attentional selection (Deutsch & Deutsch, 1963). Notably, a recent study of human selective listening behavior has endorsed late-selection as an optimization solution in computational models of the human auditory system (Griffith et al., 2026). Taken together, these accounts suggest attenuation and late selection as a unified theoretical basis from which the musician's advantage in SIN perception may be understood.

Building on this, I propose that musical training is associated with raised auditory attenuation thresholds in which individuals experience longer temporal windows where retroactive access to the auditory environment is available and temporal fidelity is maintained—while simultaneously engaging in attentional processing demands of the present auditory environment and encoding new EM traces. It should be noted that the direction of this relationship is unclear: elevated auditory attenuation thresholds may partly reflect a genetic predisposition toward heightened auditory sensitivity, which itself could increase the likelihood of musical engagement and training, rather than arising as a sole product of training (Nayak, Coleman, et al., 2022). Musical training and auditory attenuation capacity may be mutually reinforcing, with training refining pre-existing sensitivities while motivating further musical engagement.

Notably, musical training fosters a top-down framework of hierarchical, temporal relationships, allowing auditory information to be more rapidly and meaningfully interpreted. This is consistent with recent findings linking beat perception and on-beat rhythm to SIN perception (Lo et al., 2024; Perron et al., 2026), and suggests that quickly accessing and interpreting auditory feedback helps to update predictive models, promoting the ability to quickly adjust temporal attention and action. Efficient allocation of attentional resources (top-down) and stronger traces of EM (bottom-up) may therefore meaningfully contribute to speech perception in challenging environments, driving the well-documented perceptual processing advantage shown in musicians in SIN via attenuation of EM, rather than solely through differences in WM. Figure 15 illustrates proposed mechanisms of action in this effect, reflecting a raised auditory attenuation threshold in which more of the auditory environment is preserved for late selection and meaningful processing.

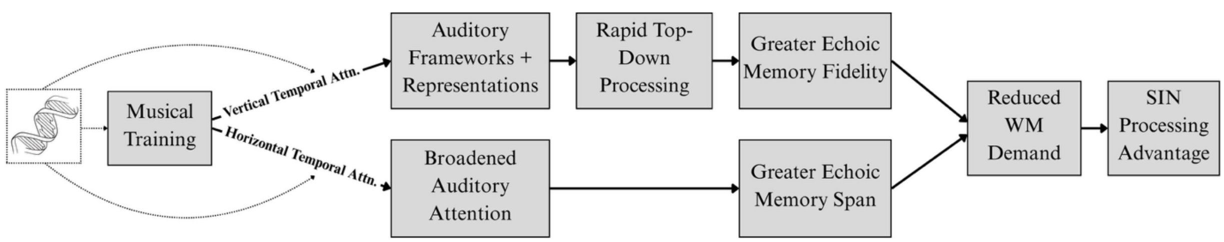

Figure 15: Proposed model of contributing mechanisms in the musician-SIN processing advantage

Conclusion

This study aimed to highlight the temporal features of prosody distinct from pitch (e.g., spacing, rate, stress, and meter) as noteworthy signals that may foster speech perception and comprehension in challenging listening environments for older adults, who experience age-related cognitive changes and are at risk for ARHL. Combined, findings establish a proof of concept that can be applied to future work, revealing the significance of prosody (lexical stress) sensitivity in several multivariate relationships across SIN perception and musical rhythm discrimination.

Crucially, a rhythmic pathway for the "musician's advantage" was identified, showing that musical training enhances prosody perception partially through the refinement of rhythm discrimination skills. This establishes that the ability to perceive word-level stress is not just a linguistic skill, but a perceptual anchor that helps older adults navigate degraded acoustic environments.

While a robust link was established, the mediation through rhythm was only partial, suggesting that other unexamined mechanisms—likely cognitive or spectral—as contributors to the prosodic advantage. Additionally, because this study focused on a normal hearing "baseline" sample, the results do not yet account for the complex interactions introduced by clinical hearing impairment, differences in fidelity and span of echoic memory (EM), or the high-level cognitive load managed by working memory (WM) and executive function (EF).

Combined, these findings provide a foundation for integrating specified, temporally relevant prosodic measures into a study of age-related hearing changes. By isolating lexical stress, this thesis moves the field toward a more granular, layered understanding of how the brain uses rhythmic scaffolding to protect speech communication. Ultimately, this work suggests that rhythmic training—whether musical or linguistic—could serve as an effective tool for maintaining functional hearing health across the lifespan.

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Appendix A

VUMC IRB Formal Authorization Letter, pp. 1–4

Submission Details

Study Title	Investigating the role of musicality in older adults' hearing health outcomes
Type	AMENDMENT
Status	SUBMITTED
Principal Investigator	Srishti Nayak (srishti.nayak@vumc.org)
Study Coordinator	Jonathan Liu (jonathan.z.liu@Vanderbilt.Edu)
IRB Number	240078
Description	Incorporating a measure of speech-rhythm identification into our study.

Amendment Information

Amendment Number	1
Amendment Date	1/20/2025

Signature History

Principal Investigator	Signed by **Nayak, Srishti** on 1/20/2025 at 9:11pm

Date of IRB Approval: 2/10/2025

Institutional Review Board

VANDERBILT

Electronic Signature: Jeremy Neal/VUMC/Vanderbilt : (080c9af536479902f461fc6e3f935a4f)
Signed On: 02/10/2025 6:04:40 PM CST

Page 1 of 6

Amendment

Please indicate what is being changed with this amendment:
[ ] Study Title/Grant Title
[ ] Increase in total subject numbers/accrual
[ ] Investigator's Brochure (IB) with NO change in safety data or the currently approved consent document(s)
[ ] Data and Safety Monitoring Report
[ ] Investigator's Brochure (IB) WITH changes in safety
[**x**] **Consent Form changes**
[**x**] **Protocol changes**
[ ] Changes to recruitment materials
[ ] Submission of new documents
[ ] Other

Please indicate the version date of the protocol:
2025-01-20

Please indicate the version date of the consent documents:
2025-01-20

Please provide the rationale for the amendment/changes:
The purpose of this amendment is to incoporate a ~10-minute online prosody (speech rhythm) identification task into the at-home questionnaires portion of this study.

Please itemize all changes to the consent documents:
Both the consent form and the e-consent form have been amended to reflect the addition of a REDCap-based prosody (speech rhythm) perception task, incorporated into the at-home questionnaires portion of this study.

For newly enrolled participants from whom data has not yet been collected: The time duration of the home-based portion of the study has been increased by 10 minutes to reflect the addition of the REDCap-based prosody perception task, resulting in a ~50 minute duration for the at-home questionnaires and task.

For follow-up study participants from whom data has already been collected: The follow-up study is expected to take about 10 minutes, and involves completing the REDCap-based prosody task. An additional e-consent form has been created to collect informed consent related to the new prosody perception task: Test of Prosody via Syllable Emphasis (TOPsy). This new consent form is referred to throughout as the TOPsy e-consent form.

This submission includes the following consent-related documents:

Consent form for new participants-
1. Consent Form (v2): tracked changes, dated: 1/20/2025
2. Consent Form (v2): clean version, dated: 1/20/2025
3. E-consent Form (v2): clean version, dated: 1/28/2025

Consent form for enrolled participants who have already completed their study activities-
1. TOPsy E-consent Form (v1): clean version, dated: 1/28/2025

Date of IRB Approval: 2/10/2025

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Indicate how the new information will be communicated to currently enrolled participants, If applicable:
Currently enrolled participants from whom data has already been collected will be contacted through email or phone in accordance with their documented contact preferences using IRB approved scripts.

Does this amendment involve ionizing radiation?
[ ] Yes
[**x**] **No**
[ ] N/A

Does this amendment change the billing plan?
[ ] Yes
[**x**] **No**
[ ] N/A

Does this amendment involve any changes to the IBC Review for Live, Recombinant, and/or Attenuated Microorganisms for Vaccination, Therapy, or Gene Transfer?
[ ] Yes
[**x**] **No**

Date of IRB Approval: 2/10/2025

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Funding Questions

Does the study involve the use of Vanderbilt hospital facilities or assays related to human samples/tissue?	No
Does this study have an associated billing plan?	No
Billing Plan #	
FACTr #	
Center Number	

Funding Sources

Name	Type	VICTR #	Coeus #	Contract #	Award #	Investigational?	VUMC Direct Recipient?	Updated
National Institute on Deafness and Communication Disorders	Federal		M2301304		1R21DC021276-01			12/19/2024

Date of IRB Approval: 2/10/2025

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Appendix B

TOPsy task follow-up e-consent form

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TOPsy Econsent Form

Please complete the survey below.

Thank you!

1) Record ID ______________________

2) Full Name: ______________________

3) Age: ______________________

4) Today's Date: ______________________

Principal Investigator: Srishti Nayak, PhD
Study Title: Investigating the role of musicality in older adults' hearing health outcomes

Institution/Hospital: VUMC
Revision Date: (v1- TOPsy Task Only) 1/20/2025

Greetings, thank you for your interest. This form tells you about our research study. Please read carefully. We are happy to answer any questions. You will be given a copy of this consent form.

KEY INFORMATION:

The purpose of this study is to look at the relationship between musical behaviors, hearing, and communication behaviors. Using your home computer, you will answer questions related to counting the number of syllables in words and identifying what syllables are emphasized in words. This task will take you approximately 10 minutes to complete.

If you have any questions related to the completion of this task or require any technical assistance, our study staff is available to assist you.

DETAILED INFORMATION:

Why are we doing this research and why are you being asked to participate?

You are being asked to take part in this research study because you previously participated in our study on musicality and hearing health. The purpose of the study is to look at the relationship between musical behaviors, hearing, and communication behaviors; to better understand how musicality, cognition, and hearing/communication are related in humans.

Any data collected from you as part of this follow-up study on rhythms in speech will be linked to information previously collected as part of the musicality and hearing study.

You do not have to be in this research study. You may choose not to be in this study and get other treatments without changing your healthcare, services, or other rights. You can stop being in this study at any time. This is not a treatment study, so there are no alternative treatments. If we learn something new that may affect the risks or benefits of this study, you will be told so that you can decide whether or not you still want to be in this study.

Date of IRB Approval: 02/10/2025 Institutional Review Board VANDERBILT

What will you do and how long will it take?

At home, you will read and securely sign an informed consent form. You will then complete a ~10 minute activity about rhythms and speech on your home computer.

The option is available to complete this task in person if you prefer. Please let our study staff know if you would like to participate in-person so we can schedule you for an in-person study visit.

What good things might come from this study?

a.) The benefits to science and humankind that might result from this study: We hope to learn more about musicality and its relationship with various aspects of communication and hearing health.

b.) The benefits you might get from being in this study: You will not receive any benefit as a result of participation in this study; however, this study may help us learn more about hearing loss, hearing health, and communication across the lifespan.

Are there any risks or discomforts for this study? Can anything bad happen to you?

There are no known risks of participating in the experiment greater than those encountered in daily life or routine tests. The risks outlined here fit the definition of "minimal risk" established by the Vanderbilt University Human Research Protection Program.

How can you find out the results of the study?

Aggregated and anonymized results of the study will be shared with the scientific community in our publications, which will be free to access through federal publication databases. Occasionally certain highlights will be shared with you through lab newsletters. Individual results based on your participation will not be available to you.

What compensation will you receive for participating in the study?

You will be compensated in the form of a gift card from Amazon or another leading retailer, valued at a total of $15. You will receive this gift card in electronic form, via email, within a week of completing the study online.

You are not allowed to accept any money for taking part in this study if you are not eligible to receive money from a U.S. person or company or the U.S. government because of U.S. national security and/or foreign policy laws. You can still take part in the study; however, you will not be paid if you are a resident of a country restricted by the U.S. government's comprehensive territorial sanctions or if you are listed on the U.S. Treasury Department's Office of Foreign Assets Control's Specially Designated Nationals (SDN) list of prohibited individuals. You do not have to say why you choose not to be paid.

Are there any reasons the researchers may remove you from the study?

You will be included in the study as long as you meet all eligibility criteria for the study, and if you consent to participate. Your data may be excluded if you do not complete all study measures, and your participation may be discontinued, or data may be excluded if your circumstances change such that you no longer meet the eligibility criteria of the study.

What happens if you choose to stop being in the study?

Nothing bad will happen to you if you withdraw from the study. You can withdraw from the study at any time by stopping participation, or you can contact our team at vanderbiltmusicalityresearch@gmail.com, or the principal investigator Dr. Nayak at srishti.nayak@vumc.org to inform us you would no longer like to participate, or no longer want your data to be included in the study.

Who can you talk to about this study?

If you should have any questions about this research study or if you feel you have been hurt by being a part of it, please feel free to contact Dr. Nayak at srishti.nayak@vumc.org.

For additional information about giving consent or your rights as a participant in this study, to discuss problems, concerns, and questions, or to offer input, please feel free to contact the Institutional Review Board Office at (615) 322-2918 or toll free at (866) 224-8273.

How will your confidentiality and privacy be maintained?

All efforts, within reason, will be made to keep your personal information in your research record confidential, but total confidentiality cannot be guaranteed. We may share some information about you for others to use for research, but to protect your privacy we will not share information that could identify you, like your name. We adhere the Health Insurance Portability and Accountability Act of 1996 (HIPAA), a federal law setting national standards to protect sensitive patient health information from being disclosed without the patient's consent or knowledge.

All data files will be coded with multi-digit/study abbreviation letter codes assigned in a consecutive order (the digits will reflect your participant number). Codes will not contain any information as to the specific identity (or any HIPAA identifiers) of any participant involved in testing. Names, signed informed consent forms, and contact information will be kept in a file separate from those containing your data so as to ensure anonymity once the data are filed. Your confidentiality will be ensured by storing all data in secure locations and by keeping all data only generically identified for analysis. Only research personnel will have access to participants' files. Data will be used for research purposes only. Personal information will be stored securely for 3 years after study closure, as required by the institution.

REDCap will be used for all capture and storage of data. REDCap is a secure web application for building and managing online surveys and databases. While REDCap can be used to collect virtually any type of data in any environment (including compliance with HIPAA), it is specifically geared to support online and offline data capture for research studies and operations. REDCap servers are housed in a local data center at Vanderbilt, and all web-based information transmission is encrypted. REDCap was developed specifically around HIPAA-Security guidelines and is recommended to all Vanderbilt researchers by both our Privacy Office and Institutional Review Board. Finally, any publications of study findings will be of pooled results, so that no individual person can be identified. These procedures are an effective way to maintain confidentiality even in the event of a data security breach.

5) Statement by person agreeing to be in this study:

○ I have read this informed consent document and the material contained in it has been explained to me verbally. All my questions have been answered, and I freely and voluntarily choose to take part in this study.

6) Participant Signature:

____

(Click "Add signature" and use your mouse (or finger on a touchscreen device) to sign.)

7) Date:

____

Date of IRB Approval: 02/10/2025

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Appendix C

TOPsy follow-up study email script

Subject Line: Follow-up Study: Online Speech Rhythm Activity

Dear XXXX,

I hope this email finds you well! This is [name of lab member] at the Vanderbilt Music Cognition Lab. Thank you for your recent participation in our study exploring hearing health and musical behaviors.

I'm reaching out because we are introducing a supplementary task to our study related to hearing rhythms in speech, and would like to invite you to take part in this additional activity.

This task can be completed online at home and takes about 10 minutes total, during which you will listen to spoken words and answer some questions.

We will compensate you with a $15 electronic gift card from Amazon or another leading retailer for your time.

If this sounds like something you would be interested in, please let me know by responding to this email. From there, I can follow up with a link to the speech rhythm activity.

Thank you again for your time and consideration.

Best,

[name of lab member]
Vanderbilt Music Cognition Lab

Date of IRB Approval: 02/10/2025 Institutional Review Board
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Appendix D

TOPsy Task REDCap Instrument (Nayak et al., 2022)

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Page 1

Prosody Test Part 1

The Prosody Test has two parts.

Part 1 - How many syllables?

All words have syllables. For example, tomato has three syllables (to-ma-to) while paper has two syllables (pa-per). In the first part of this test, we are asking you to listen to some words and count how many syllables they have. After each word, click on the corresponding number of syllables. You will only be allowed to listen to each word once.

There are 10 words total in Part 1.

Record ID ______________________________

If you wish, you can listen to the instructions here:

[Attachment: "Part 1 - Instructions.mp3"]

Date of IRB Approval: 02/10/2025

Institutional Review Board

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01/20/2025 5:20pm

projectredcap.org

Word #1	
Word #1 [Attachment: "Organism.mp3"]	
How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Word #2

Word #2:

[Attachment: "Application.mp3"]

How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Word #3

Word #3:

[Attachment: "Memory.mp3"]

How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Word #4

Word #4:

[Attachment: "Coordinator.mp3"]

How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Word #5	
Word #5: [Attachment: "Interference.mp3"]	
How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Word #6

Word #6:

[Attachment: "Representative.mp3"]

How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Word #7

Word #7:

[Attachment: "Metabolism.mp3"]

How many syllables does this word have?

- ◯ 3
- ◯ 4
- ◯ 5

Word #8

Word #8:

[Attachment: "Opportunity.mp3"]

How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Word #9

Word #9:

[Attachment: "Enthusiasm.mp3"]

How many syllables does this word have?

- ◯ 3
- ◯ 4
- ◯ 5

Word #10

Word #10:

[Attachment: "Economy.mp3"]

How many syllables does this word have?	◯ 3 ◯ 4 ◯ 5

Prosody Part 2 Instructions

Part 2 - Where is the emphasis?

In English, we do not say each syllable of a word with the same strength. Some syllables have stronger emphasis than others. In the next part of the test, you will hear words and have to decide which syllable has the strongest emphasis. For example, listen to the words banana and melody below:

If you would like to listen to the instructions, you can do so here:

[Attachment: "Part 2 - Instructions.mp3"]

Banana has the main emphasis on the second syllable (ba-NA-na).

[Attachment: "Banana.mp3"]

However, melody has the main emphasis on the first syllable (ME-lo-dy)

[Attachment: "Melody.mp3"]

You will now listen to some more words. For each word, indicate the syllable on which you hear the strongest emphasis.

In some cases, you may say the word differently than the speaker in the recording. However, you should try to respond based on where you heard the strongest emphasis (not the way you might say it in your head).

Like in part 1, you will only be able to listen to each word once.

There are 29 words in Part 2. Click the SUBMIT button to begin.

Prosody Test Part 2

Words #1 to #5

Remember, you are only allowed to listen to each word once, and, you are to respond based on how the speaker pronounced the word, not how you would say it!

Word #1

[Attachment: "Passenger.mp3"]

pa	ssen	ger

Please indicate which syllable carried the emphasis of the word.

- ◯ pa
- ◯ ssen
- ◯ ger

Word #2:

[Attachment: "Civilization.mp3"]

ci	vi	li	za	tion

Please indicate which syllable carried the emphasis of the word.

- ◯ ci
- ◯ vi
- ◯ li
- ◯ za
- ◯ tion

Word #3:

[Attachment: "Example.mp3"]

ex	am	ple

Please indicate which syllable carried the emphasis of the word.	◯ ex ◯ am ◯ ple
Word #4: [Attachment: "Education.mp3"]	

e	du	ca	tion

Please indicate which syllable carried the emphasis of the word.	◯ e ◯ du ◯ ca ◯ tion
Word #5: [Attachment: "Laboratory.mp3"]	

la	bo	ra	to	ry

Please indicate which syllable carried the emphasis of the word.	◯ la ◯ bo ◯ ra ◯ to ◯ ry

Words #6 to #10

Remember to respond based on how the speaker pronounced the word, not how you would say it!

Word #6:

[Attachment: "Agriculture.mp3"]

a	gri	cul	ture

Please indicate which syllable carried the emphasis of the word.

- ◯ a
- ◯ gri
- ◯ cul
- ◯ ture

Word #7:

[Attachment: "Vitamin.mp3"]

vi	ta	min

Please indicate which syllable carried the emphasis of the word.

- ◯ vi
- ◯ ta
- ◯ min

Word #8:

[Attachment: "Organization.mp3"]

or	ga	ni	za	tion

Please indicate which syllable carried the emphasis of the word.

- ◯ or
- ◯ ga
- ◯ ni
- ◯ za
- ◯ tion

Word #9:

[Attachment: "University.mp3"]

u	ni	ver	si	ty

Please indicate which syllable carried the emphasis of the word.

- ◯ u
- ◯ ni
- ◯ ver
- ◯ si
- ◯ ty

Word #10:

[Attachment: "Development.mp3"]

de	ve	lop	ment

Please indicate which syllable carried the emphasis of the word.

- ◯ de
- ◯ ve
- ◯ lop
- ◯ ment

Words #11 to #15

Remember to respond based on how the speaker pronounced the word, not how you would say it!

Word #11:

[Attachment: "Motivation.mp3"]

mo	ti	va	tion

Please indicate which syllable carried the emphasis of the word.

- ◯ mo
- ◯ ti
- ◯ va
- ◯ tion

Word #12:

[Attachment: "Secretary.mp3"]

se	cre	ta	ry

Please indicate which syllable carried the emphasis of the word.

- ◯ se
- ◯ cre
- ◯ ta
- ◯ ry

Word #13:

[Attachment: "Environment.mp3"]

en	vi	ron	ment

Please indicate which syllable carried the emphasis of the word.

- ◯ en
- ◯ vi
- ◯ ron
- ◯ ment

Word #14:

[Attachment: "Inventor.mp3"]

in	ven	tor

Please indicate which syllable carried the emphasis of the word.	◯ in ◯ ven ◯ tor

Word #15:

[Attachment: "Veterinary.mp3"]

ve	te	ri	na	ry

Please indicate which syllable carried the emphasis of the word.	◯ ve ◯ te ◯ ri ◯ na ◯ ry

Words #16 to #20

Remember to respond based on how the speaker pronounced the word, not how you would say it!

Word #16:

[Attachment: "Literature.mp3"]

li	te	ra	ture

Please indicate which syllable carried the emphasis of the word.

- ◯ li
- ◯ te
- ◯ ra
- ◯ ture

Word #17:

[Attachment: "Technology.mp3"]

tech	no	lo	gy

Please indicate which syllable carried the emphasis of the word.

- ◯ tech
- ◯ no
- ◯ lo
- ◯ gy

Word #18:

[Attachment: "Flexibility.mp3"]

fle	xi	bi	li	ty

Please indicate which syllable carried the emphasis of the word.

- ◯ fle
- ◯ xi
- ◯ bi
- ◯ li
- ◯ ty

Word #19:

[Attachment: "PT - AttentionCheck.mp3"]

ho	spi	ta	li	ty

Please indicate which syllable carried the emphasis of the word.

- ◯ ho
- ◯ spi
- ◯ ta
- ◯ li
- ◯ ty

Word #20:

[Attachment: "Category.mp3"]

ca	te	go	ry

Please indicate which syllable carried the emphasis of the word.

- ◯ ca
- ◯ te
- ◯ go
- ◯ ry

Words #21 to #25

Remember to respond based on how the speaker pronounced the word, not how you would say it!

Word #21:

[Attachment: "Registration.mp3"]

re	gi	stra	tion

Please indicate which syllable carried the emphasis of the word.

- ◯ re
- ◯ gi
- ◯ stra
- ◯ tion

Word #22:

[Attachment: "Discussion.mp3"]

di	scu	ssion

Please indicate which syllable carried the emphasis of the word.

- ◯ di
- ◯ scu
- ◯ ssion

Word #23:

[Attachment: "Continent.mp3"]

con	ti	nent

Please indicate which syllable carried the emphasis of the word.

- ◯ con
- ◯ ti
- ◯ nent

Word #24:

[Attachment: "Communication.mp3"]

co	mmu	ni	ca	tion

Please indicate which syllable carried the emphasis of the word.

- ◯ co
- ◯ mmu
- ◯ ni
- ◯ ca
- ◯ tion

Word #25:

[Attachment: "Entertainment.mp3"]

en	ter	tain	ment

Please indicate which syllable carried the emphasis of the word.

- ◯ en
- ◯ ter
- ◯ tain
- ◯ ment

Words #26 to #29

Remember to respond based on how the speaker pronounced the word, not how you would say it!

Word #26:

[Attachment: "Television.mp3"]

te	le	vi	sion

Please indicate which syllable carried the emphasis of the word.

- ◯ te
- ◯ le
- ◯ vi
- ◯ sion

Word #27:

[Attachment: "Library.mp3"]

li	bra	ry

Please indicate which syllable carried the emphasis of the word.

- ◯ li
- ◯ bra
- ◯ ry

Word #28:

[Attachment: "Federalism.mp3"]

fe	de	ra	li	sm

Please indicate which syllable carried the emphasis of the word.

- ◯ fe
- ◯ de
- ◯ ra
- ◯ li
- ◯ sm

Word #29:

[Attachment: "Ability.mp3"]

a	bi	li	ty

Please indicate which syllable carried the emphasis of the word.

- ◯ a
- ◯ bi
- ◯ li
- ◯ ty