SPEECH RECOGNITION IN NOISE ABILITIES BETWEEEN MUSICIANS AND NON-MUSICIANS

by

Rebecca Davis

A Senior Honors Project Presented to the

Honors College

East Carolina University

In Partial Fulfillment of the

Requirements for

Graduation with Honors

by

Rebecca Davis

Greenville, NC

May, 2021

Approved by:

Andrew Vermiglio

Department of Communication Sciences and Disorders, College of Allied Health Sciences

Virginia Driscoll

Department of Music Education and Therapy, College of Fine Arts and Communications

Introduction

History of Speech Recognition in Noise (SRN) Testing

Pure-tone audiometry has long been considered the gold standard for hearing measurement since its creation in 1922 (Gatlin & Dhar, 2021). Today, the World Health Organization (WHO) determines speech recognition in noise (SRN) abilities based solely on pure-tone threshold averages (PTA; WHO, 2021). Even so, discrepancies between pure-tone thresholds and SRN results have been found. For example, Dickson et al. (1946) reported that pure-tone thresholds alone cannot be used to predict SRN abilities. During WWII, Royal Air Force candidates were required to pass a speech in simulated aircraft noise test called the Efficiency Test (Dickson et al., 1946). Candidates who passed this test subsequently took a pure-tone threshold test.

Over the years, different terms have been used to describe difficulties understanding speech in background noise in the presence of normal pure-tone thresholds. King (1954) coined the term “psychogenic deafness” referring to this challenge. He believed that when the patient had normal pure-tone sensitivity, the inability to understand speech in the presence of noise was purely psychological or fabricated by the patient. According to King, those with “low mentality, poor education, and ebbing morale” were most likely to develop psychogenic deafness. King also believed that treatment would best be provided by a psychiatrist. Similarly, Byrne and Kerr (1987) labeled the inability to understand speech in noise despite normal pure-tone thresholds the “auditory inferiority complex.” According to the authors, clinicians should simply reassure patients that their hearing was normal.

Unlike King (1954) and Byrne and Kerr (1987), Middelweerd et al. (1990) associated speech recognition in noise deficits with normal pure-tone thresholds to non-psychological issues. Middelweerd et al. (1990) recruited participants with normal pure-tone thresholds. The control group included participants who did not complain of SRN difficulties. The patient group included participants who complained of SRN difficulties in daily life. The results showed that the control group exhibited better SRN abilities than the patient group (Middelweerd, et al., 1990). Middelweerd et al. (1990) associated this difficulty understanding speech in noise with reduced temporal resolution in the auditory system.

Types of SRN Tests

A number of SRN tests are available, such as the Hearing in Noise Test (HINT; Nilsson et al., 1994; Vermiglio, 2008) and the AzBio Test (Spahr, et al., 2012). Because typical means of hearing measurement (e.g., pure-tone thresholds and speech recognition in quiet scores) may not adequately predict SRN abilities, the HINT was developed to detect speech recognition thresholds (SRTs). The HINT uses an up-down adaptive strategy to determine the sentence presentation levels. HINT results are reported in dB signal-to-noise ratio (SNR). The AzBio was created to evaluate speech recognition abilities for those with hearing loss and cochlear implant users. It includes over 1000 sentences that were recorded by 2 male and 2 female talkers. The AzBio target sentences are presented at a fixed SNR and is scored according to percentage of correctly repeated words.

Types of Maskers

Since different types of background noise can be encountered in everyday life, several types of maskers have been used in studies (Parbery-Clark et al., 2009; Eskridge et al., 2011; Gfeller et al., 2012; Vermiglio et al., 2019). Steady-state speech-shaped noise and multi-talker babble are two of the most common maskers used in SRN studies (Vermiglio et al., 2019). Parbery-Clark et al. (2009) and Vermiglio et al. (2019) incorporated speech-shaped noise and four-talker babble. Parbery-Clark et al. (2009) reported that an SRN test with speech-shaped noise and one test with four-talker babble were both sensitive to the effects of musical experience on SRN ability. Vermiglio et al. (2019) reported that, "One cannot assume that a patient who performs within normal limits on a speech in four-talker babble test will also perform within normal limits on a speech in steady-state speech-shaped noise test and vice versa."

Wilson, Carnell et al. (2007) argued that it was better to use babble noise since background speech in social situations are commonly encountered. In this study, participants with normal hearing and participants with hearing loss performed better in the babble noise than in the speech-shaped noise. Killion et al. (2004) argued that "the use of continuous noise has the advantage of reducing the variability in noise level and the disadvantage that it is less representative of everyday speech-in-noise situations than babble noise" (page 2395). Killion and colleagues (2004) developed the Quick-Speech-in-Noise (SIN) test with four-talker babble.

Music backgrounds can also provide insight to SRN abilities as music is heard in a variety of social settings. While less common, competing musical backgrounds have also been used in studies on SRN abilities (Gfeller et al., 2012; Eskridge et al., 2011). Gfeller et al. (2012) studied SRN abilities among cochlear implant recipients and normal hearing listeners, using three musical backgrounds including a piano solo, large symphony orchestra, and a vocal solo with a drum and guitar accompaniment. They found structural characteristics of the background impacted perceptual accuracy with piano have the lowest SNR, followed by voice and orchestra. In addition to using speech-shaped noise, Eskridge et al. (2011) used a variety of different musical excerpts, including "Lounge Lizard," "MC Scarlatti Mass for Four Voices," "Power Theme," "Violin Fight," and "TV Star Tonite" to study SRN abilities among cochlear implant recipients and normal hearing listeners. They also incorporated music-shaped noise and music-shaped noise modulated by the music temporal envelope. Eskridge and colleagues reported that performance among cochlear implant recipients in speech-shaped noise was higher than performance in the music maskers. The researchers found that performance among cochlear implant recipients decreased when more spectro-temporal complexity was added to the maskers and reported that performance in music-shaped noise, modulated by the music temporal envelope, was significantly higher than performance in the music maskers. Similarly, performance in the music-shaped noise modulated by the temporal envelope was higher than performance in the music-shaped noise condition.

For these reasons, it is useful to incorporate multiple listening conditions, as SRN results may not be correlated across all listening conditions (Vermiglio et al. 2020). Convergent validity is the degree in which two tests measure the same ability. For SNR testing, it is useful to determine the convergent validity across listening conditions.

The Benefits of Musical Training

Musical training has offered benefits in many areas. Gilliland (1951) reported that music therapy was considered helpful for those with physical disabilities, such as cerebral palsy, muscular dystrophy, and paraplegia. She believed that music therapy would "enable them to become more independent" and "enrich their lives in happiness, fellowship, experience, and learning." Not only that, but Gilliland also suggested that thought, emotion, sight, movement, and hearing could be influenced by music.

Other investigators have shown musical training is associated with improved academic performance, such as mathematics, reading, and language skills (Schmithorst and Holland, 2003; Kraus et al., 2014). Schmithorst and Holland et al. (2003) found those with musical training had increased activation in in the left fusiform gyrus and prefrontal cortex while performing mathematical tasks. Kraus et al. (2014) studied the effect of musical training on speech processing. Using the Intelligent Hearing System's SmartEP Platform, Kraus et al. (2014) conducted neurophysiological test that consisted of click- and speech-evoked auditory brainstem responses. The authors showed that while one year of musical training was unable to produce changes in neural functioning associated with language, children engaged in musical training for two or more years had enhanced neural processing of speech. Specifically, the children with musical training showed improvements in the neural differentiation between similar speech sounds. As a result, Kraus et al. (2014) advocated for community and co-curricular music programs as an intervention to improve language skills for high-risk children.

Music Experience and SRN Abilities

Various studies have shown musical experience positively affects SRN abilities in those with normal pure-tone thresholds (Parbery-Clark et al., 2009; Brown et al., 2017; Soncini & Costa, 2006). Table 1 shows a review of the literature on musical training on SRN performance. Results from various studies regarding the effect of musical experience on SRN abilities have been mixed. While some show a statistically significant difference between musicians and non-musicians in which musicians outperformed non-musicians in SRN tasks (Parbery-Clark et al., 2009; Brown et al., 2017; Soncini & Costa, 2006), others show no statistically significant differences between the two groups (Boebinger et al., 2017; Escobar et al., 2019; MacCutcheon et al., 2020).

Study	SRN Test	Noise Condition	Group with Better Performance	Reported Differences	*p*-value
Soncini & Costa (2006)	Portuguese Sentence Lists test	Speech Spectrum Noise	Musicians	1.52dB for right ear, 1.15dB for left ear	$p<0.05$
Parbery-Clark et al. (2009)	HINT	Speech-Shaped Noise	Musicians	Approximately 0.4dB	$p=0.008$
Parbery-Clark et al. (2009)	QuickSIN	Four-Talker Babble	Musicians	Approximately 0.4dB	$p=0.004$
Brown et al. (2017)	AzBio	Ten-Talker Babble	Musicians	Not reported	$p=0.046$
Boebinger et al. (2017)	BKB	Clear Speech, Spectrally Rotated Speech, Speech-Amplitude Modulated Noise, Speech-Spectrum Steady-State Noise	No significant difference	0.5dB	$p=0.240$
Escobar et al. (2019)	HINT	Four-Talker Babble, Speech-Shaped Noise, Multi-Talker Babble	No significant difference	Not reported	$p=0.459$
MacCutcheon et al. (2020)	Pre-recorded stimuli	Simulated Virtual Classroom	No significant difference	0.7dB	$p=0.448$
Libermann et al. (2016)	Northwestern University Auditory Test Number 6	White Noise	Non-Musicians	Not reported	$p<0.05$
Present Study	AzBio	Speech-Shaped Noise			
Present Study	AzBio	Ten-Talker Babble			
Present Study	AzBio	Three Musical Backgrounds			

Table 1. Review of the literature on musical training and SRN performance.

Parbery-Clark et al. (2009) measured SRN ability for musicians and non-musicians using the HINT and QuickSIN (Killion et al 2004). They reported that the musicians outperformed the non-musicians in both SRN tasks with a 0.6 dB difference between the groups with the HINT (p=0.008) and 0.7 dB difference between in the groups with the QuickSIN (p=0.004). Brown et al. (2017) reported that musicians outperformed non-musicians on the AzBio (p=0.046).

Conversely, two studies have reported no statistically significant relationship between musical training and SRN abilities (Boebinger et al 2014; Escobar et al. 2019). Boebinger et al. (2014) found no significant differences in SRN abilities between musicians and non-musicians using the Bamford-Kowal-Bench (BKB) sentence lists (p=0.240) Similarly, Escobar et al. (2019) found no differences in SRN abilities between musicians and non-musicians for both the HINT (p=0.459) and QuickSIN (p=0.743). In contrast, Liberman et al. (2016) reported that a group comprised mostly of musicians performed significantly poorer than non-musicians on SRN tasks (p<0.05). While the studies mentioned all included highly trained musicians, other studies have included participants with less musical experience (Fleming et al. 2017; MacCutcheon et al. 2020).

Fleming et al. (2017) investigated SRN abilities in older adults for three study groups. The first group was given piano training, the second group was given videogame training, and the third group was offered no piano or video game training. SRN abilities were measured in all three groups before training commenced using the French-Canadian version of the HINT. MRI-compatible Sensimetrics S14 insert earphones were used to present the stimuli. After six months of piano and videogame training, SRN abilities were retested among all three groups. Although no significant differences in SRN abilities between the groups were found, fMRI data indicated that training in piano enhanced response to speech in the bilateral frontal, left parietal, and right temporal regions of the brain (Fleming et al., 2017). On the other hand, MacCutcheon et al. (2020) found that limited musical training offered no benefit in SRN abilities (p=0.448). Young children aged five to seven years either received musical training or participated in sports in the school setting for thirty-eight weeks. No statistically significant differences in SRN abilities between the groups were found. While numerous studies have been conducted with single speech-related background maskers or musical maskers for word or spondee recognition, few studies exist where musicians and non-musicians are evaluated on their ability to recognize speech in numerous background conditions including music.

Research Questions and Hypothesis

This leads us to our research questions: 1) Do musicians have better SRN abilities than non-musicians across five different masker conditions? 2) What is the relationship between SRN results across noise conditions? It was hypothesized that musicians would outperform non-musicians in SRN tasks. It was also hypothesized that results would significantly correlate across the different listening conditions based on the complexity of the listening condition.

Methods

Participants

A total of 29 adults (16 musicians and 13 non-musicians) age 19-22 participated in the study. The mean age was 20.31 years (SD=0.930). Subjects were recruited through flyers and announcements made in music courses in the School of Music and in Communication Sciences. Students in a Communication Sciences and Disorders course were offered extra credit for participation in the study.

Materials

Due to the COVID-19 pandemic, all testing was conducted with an online platform using Qualtrics (Qualtrics, Provo, UT). Approval was obtained from the Institutional Review Board at East Carolina University.

Questionnaire

Participants completed a questionnaire comprising items related to their musical experience in ensembles, taking lessons, or playing a musical instrument, ability to perceive speech in quiet, history of hearing health, and other relevant questions. Participants indicated no difficulty hearing speech in quiet environments. A modified version of the Iowa Musical Background Questionnaire was used to categorize musicians and non-musicians (Brown et al., 2017; Driscoll et al., 2009). Musicians were classified as having formal musical training (lessons). Non-musicians were classified as those having no formal musical training.

AzBio

SRN abilities were measured using the AzBio speech perception test (Spahr, et al 2012) paired with five maskers presented at fixed signal-to-noise ratios: speech-shaped noise, ten-talker babble and three music maskers. The three music maskers that were also used in a study by Eskridge et al. (2011) were taken from freeplaymusic.com. Prior to testing, SNR levels were set by evaluating pilot data of a small sample of participants (lab members) listening to sentence lists with progressively easier SNR. An average score of approximately 50% was selected as the criterion for the fixed SNR used during the test. This was chosen to limit ceiling and floor effects. Those maskers and SNRs were as follows: speech-shaped noise, -3 dB; ten-talker babble, -1 dB; “Lounge Lizard,” -27 dB; “Four Voices,” -10 dB; and “Power Theme,” -7 dB.

Prior to beginning the SRN task, a sample audio with practice stimuli and maskers was played. Participants were asked to set their volume control so that stimuli were presented at comfortable listening levels, and the target speech was clearly audible. After setting the volume, they were instructed not to change the volume for the rest of the SRN tasks. The target speech and noise maskers were played binaurally through earbuds, and participants typed the words they heard in a textbox provided after each sentence played. Sentences were scored according to percent of words correct by two independent reviewers. Discrepancies between raters were decided based on consensus. Data were analyzed using the JMP Pro 14 Statistical Software (JMP, 2019).

Results

The descriptive statistics are presented on Table 2. Musicians scored higher than non-musicians in the speech-shaped noise condition, ten-talker babble condition, and “Four Voices” but the differences were not statistically significant (p=0.279, p=0.236, and p=0.311, respectively) Non-musicians scored higher than musicians in the “Lounge Lizard” and “Power Theme” but these differences were also not statistically significant (p=0.844, p=0.829). Across all participants, the “Lounge Lizard” listening condition was the easiest with an average score of 55.10%. The most difficult listening condition was “Power Theme” with an average score of 29.01%.

A repeated measures ANOVA revealed no significant main effect for group (F = 0.0359, p = 0.8512). Group differences are also shown in Table 2. and Figure 1 a-e. There were no statistically significant differences in SRN abilities between musicians and non-musicians for any of the listening conditions. For the “Lounge Lizard” listening condition musicians performed 7.73% worse than non-musicians, however, this difference was not statistically significant (p =

0.8442). In the ten-talker babble listening condition, musicians performed 4.12% better than non-musicians. This difference was also not statistically significant (*p*=0.2363). The correlation matrix for all listening conditions and across all participants is shown in Table 3. The strongest relationship was found for speech-shaped noise vs the "Four Voices" listening conditions (r = 0.736, $p < 0.01$) as shown in Figure 2. The weakest relationship was found for speech-shaped noise vs the "Lounge Lizard" listening condition (r = 0.168, $p = 0.384$).

Variable	**Group**	**n**	**Mean**	**SD**	**Min**	**Max**	**Range**	**Group Difference**	***p*-value**
Speech-Shaped Noise	Musicians	16	54.83%	10.8	39.31%	73.10%	33.79%	1.89%	0.279
	Non-Musicians	13	52.94%	5.99	44.14%	61.38%	17.24%		
Ten-Talker Babble	Musicians	16	46.40%	16.33	2.92%	69.34%	66.42%	4.12%	0.236
	Non-Musicians	13	42.28%	14.08	17.52%	58.39	40.88%		
Lounge Lizard	Musicians	16	51.63%	21.46	1.45%	78.99%	77.53%	-7.73%	0.844
	Non-Musicians	13	59.36%	18.89	10.87%	81.16%	70.29%		
Four Voices	Musicians	16	49.61%	13	23.97%	69.18%	45.21%	2.30%	0.311
	Non-Musicians	13	47.31%	11.86	12.33%	61.64%	49.32%		
Power Theme	Musicians	16	27.35%	10.63	7.52%	41.35%	33.83%	-3.71%	0.829
	Non-Musicians	13	31.06%	9.99	6.77%	45.86%	39.10%		

Table 2. Descriptive statistics for AzBio results (n=29). Group difference refers to musician minus non-musician group means.

	Ten-Talker Babble	Lounge Lizard	Four Voices	Power Theme
Speech-Shaped Noise	0.258 (0.176)	0.168 (0.384)	**0.736 (<0.0001)**	**0.428 (0.021)**
Ten-Talker Babble		**0.422 (0.023)**	0.210 (0.274)	**0.437 (0.018)**
Lounge Lizard			0.210 (0.274)	0.342 (0.069)
Four Voices				**0.615 (0.0004)**

Table 3. Correlation Matrix across all participants using Spearman rho. The statistically significant correlations are in bold font. The *p*-values are listed in parenthesis.

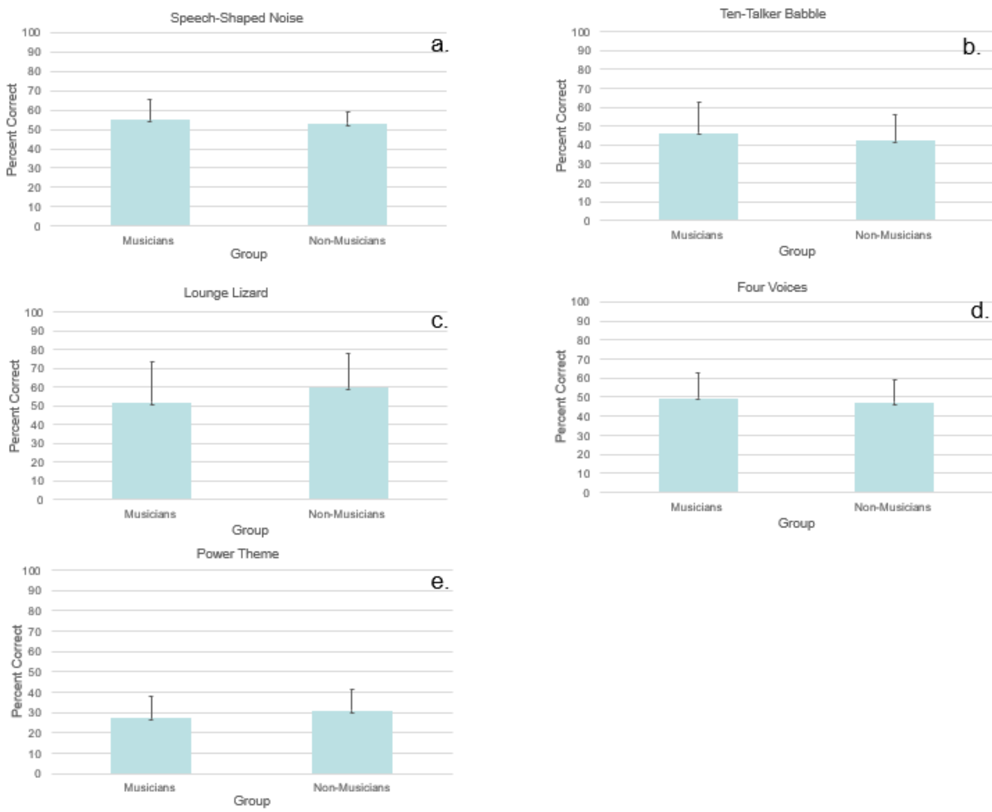

Figure 1. Bar graphs comparing average AzBio scores between musician and non-musician groups.

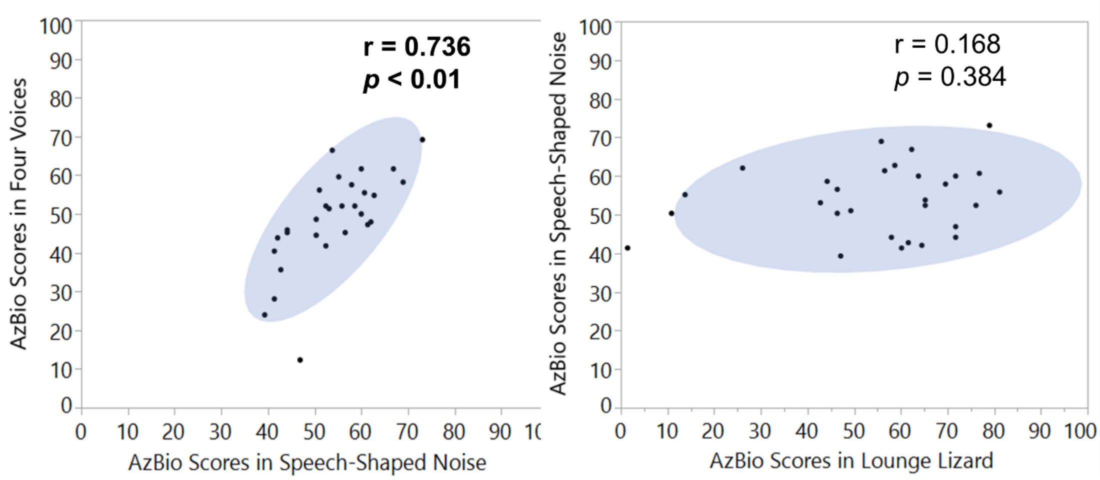

Figure 2. Scatterplot comparison showing weakest and strongest correlations between listening condition (n=29). The correlation coefficients and *p*-values are also shown. The statistically significant relationships are presented in bold font.

Discussion and Conclusion

Data for this study do not support the hypothesis that musicians would outperform non-musicians on the SRN tasks. The study results are consistent with studies by Boebinger et al. (2014), Escobar et al. (2019), and MacCutcheon et al. (2020) who found no significant differences in SRN results between musicians and non-musicians. Boebinger et al. (2014) reported that nonverbal IQ predicted SRN abilities while Escobar et al. (2019) reported that working memory predicted SRN abilities. Both studies suggested that cognitive abilities of the individual may be the key factor in SRN abilities, not musicianship.

This is contrary to previous investigations that found musicians out-performed non-musicians on SRN tasks (Parbery-Clark et al., 2009; Brown et al., 2017; Baskent & Gaudrain, 2016). Differences in the test results may be due to other variables, such as frequency and timbre recognition (Brown et al., 2017). In addition to higher performances in SRN tasks, musicians also performed higher on frequency and timbre recognition tasks, which can be used in processing speech (Brown et al., 2017). Brown et al. (2017) categorized musicians as those who ranked themselves a 9 or 10 in two 10-point Likert scales looking at musical training. A 10 on the first Likert scale referred to “extensive music classes and musical training”, and a 10 in the second scale referred to “regular involvement in music for many years” (page 4). Those who ranked themselves between 1 and 3 on both Likert Scales were categorized as non-musicians. A 1 on the first Likert scale referred to no music class beyond elementary school, and a 1 on the second Likert scale referred to “no involvement in music – past or present” (page 4). The Brown et al. (2017) study contrasts with the present study where musicians were categorized as having any form of musical training, which could explain the difference in results.

Parbery-Clark et al. (2009) found that musicians had better working memory than non-musicians, which was related to better SRN abilities. Parbery-Clark et al (2009) categorized musicians as having begun "playing a musical instrument before the age of 7, had 10 or more years of musical experience, and had continued to practice consistently three times a week" within 3 years of the study (p 654). The present study categorized musicians as having any sort of musical training, in which musicians may not necessarily have played their instrument for a long period of time. It is possible that more extensive musical training or continued consistent practice is needed to for improved working memory that in turn affects SRN abilities.

Fleming et al., 2017 found no significant differences in SRN results between musicians and non-musicians but reported that those with music experience were shown to have enhanced response to speech in the bilateral frontal, left parietal, and right temporal regions of the brain. Kraus et al. (2014) showed that while one year of musical training was unable to evoke changes in neural functioning associated with language, children engaged in musical training for two or more years had strengthened neural processing of speech as well as reading and language skills.

Factors that could potentially affect these mixed results in SRN abilities include years of musical experience, intensity of musical training, practice frequency. A small age range of participants might also have contributed to lack of significance. The present study included college-aged individuals between the ages of 19 and 22. Other studies have included children, young adults, middle-aged adults, older adults, or a wider age range of participants (Kraus et al., 2014; Parbery-Clark et al., 2009; Soncini & Costa, 2006; Fleming et al., 2017).

Future research could incorporate a larger number of participants with a wider range of musical experience to determine if more highly skilled musicians show a more significant improvement in SRN abilities as compared to those with little to no experience or how much experience is necessary to demonstrate an improvement in performance.

Clinical Relevance

Results from this study are relevant for clinical practice in audiology and speech-language pathology. Audiologists and speech-language pathologists may come across individuals, who experience SRN difficulties despite normal pure-tone thresholds. Knowledge in this area may help speech-language pathologists better understand the issues associated with SRN difficulties and allow them to provide adequate therapy. The results of this study showed a range of convergent validity between masker conditions. Some comparisons revealed that the masker conditions are measuring different forms of SRN ability. This knowledge will be useful for clinicians to understand that poor performances for one condition do not relate to poor performances on another condition.

Study Limitations

Due to the COVID-19 pandemic, all testing was conducted online. For this reason, pure-tone threshold testing was not available. Instead, participants indicated they had no difficulty understanding speech in quiet environments. Since testing was not conducted in a controlled environment, some factors could not be controlled, such as background noise and device or earbud sound quality nor were we able to confirm normal pure-tone thresholds. Future research should be conducted in-person so that these factors can be better controlled.

References

Başkent, D., & Gaudrain, E. (2016). Musician advantage for speech-on-speech perception. *The Journal of the Acoustical Society of America, 139*(3), EL51-EL56. doi:10.1121/1.4942628

Boebinger, D., Evans, S., Rosen, S., Lima, C. F., Manly, T., & Scott, S. K. (2015). Musicians and non-musicians are equally adept at perceiving masked speech. *The Journal of the Acoustical Society of America, 137*(1), 378-387. doi:10.1121/1.4904537

Brown, C. J., Jeon, E., Driscoll, V., Mussoi, B., Deshpande, S. B., Gfeller, K., & Abbas, P. J. (2017). Effects of long-term musical training on cortical auditory evoked potentials. *Ear and Hearing, 38*(2), e74-e84. doi:10.1097/aud.0000000000000375

Byrne, J. E. T., & Kerr, A. G. (1987). Sensorineural hearing loss. *Scott-Brown's Otolaryngology. 5th ed. London: Butterworth-Heinemann Publishers*, 381-6.

Dickson, E. D. D., Simpson, J. F., Fry, D. B., Swindell, G. E., & Brown, R. E. C. (1946). A new method of testing the hearing efficiency of aviation candidates. *The Journal of Laryngology & Otology, 61*(3), 139-203. doi:10.1017/S0022215100007830

Driscoll, V. D., Oleson, J., Jiang, D., & Gfeller, K. (2009). Effects of training on recognition of musical instruments presented through cochlear implant simulations. *Journal of the American Academy of Audiology, 20*(1), 71-82. doi:10.3766/jaaa.20.1.7

Escobar, J., Mussoi, B., & Silberer, A. (2020). The effect of musical training and working memory in adverse listening situations. *Ear and Hearing, 41*(2), 278-288. doi:10.1097/AUD.0000000000000754

Eskridge, E.N., Galvin III, J.J., Aronoff, J.M., Li, T., Fu, Q. (2011). Speech perception with maskers by cochlear implant users and normal listeners. *Journal of Speech, Language, and Hearing Research, 56*(3), 800-810. doi:10.1044/1092-4388(2011/11-0124)

Fleming, D., Belleville, S., Peretz, I., West, G., & Zendel, B. R. (2019). The effects of short-term musical training on the neural processing of speech-in-noise in older adults. *Brain and Cognition, 136*, 103592. doi:10.1016/j.bandc.2019.103592

Fuller, C. D., Galvin, J. J., Maat, B., Başkent, D., & Free, R. H. (2018). Comparison of two music training approaches on music and speech perception in cochlear implant users. *Trends in Hearing, 22*, 233121651876537-2331216518765379. doi:10.1177/2331216518765379

Gatlin, A. E., & Dhar, S. (2021). *History and lingering impact of the arbitrary 25-dB cutoff for normal hearing* American Speech Language Hearing Association. doi:10.1044/2020_aja-20-00181

Gilliland, E. G. *Music therapy, 1951: book of proceedings of the National Association for Music Therapy, volume I* (Doctoral dissertation, Colorado State University. Libraries).

Gfeller, K., Turner, C., Oleson, J., Kliethermes, S., & Driscoll, V. (2012). *Accuracy of cochlear implant recipients on speech reception in background music* Retrieved from https://explore.openaire.eu/search/publication?articleId=od_______267::29f9fe45fc0b37bf0315ea68afd70ab6

Humes, L. E. (2019). The world health organization's hearing-impairment grading system: An evaluation for unaided communication in age-related hearing loss. *International Journal of Audiology, 58*(1), 12-20. doi:10.1080/14992027.2018.1518598

JMP®, Version 14. SAS Institute Inc., Cary, NC, 1989-2019.

Killion, M. C., Niquette, P. A., Gudmundsen, G. I., Revit, L. J., & Banerjee, S. (2004). Development of a quick speech-in-noise test for measuring signal-to-noise ratio loss in normal-hearing and hearing-impaired listeners. *The Journal of the Acoustical Society of America, 116*(4), 2395-2405. doi:10.1121/1.1784440

King, P. F. (1954). Psychogenic deafness. *London: Royal Society of Medicine, 47*(11), 941-942. doi: 10.1177/003591575404701106

Kraus, N., Slater, J., Thompson, E. C., Hornickel, J., Strait, D. L., Nicol, T., & White-Schwoch, T. (2014). Music enrichment programs improve the neural encoding of speech in at-risk children. *The Journal of Neuroscience, 34*(36), 11913-11918. doi:10.1523/JNEUROSCI.1881-14.2014

MacCutcheon, D., Füllgrabe, C., Eccles, R., van der Linde, J., Panebianco, C., & Ljung, R. (2019). Investigating the effect of one year of learning to play a musical instrument on speech-in-noise perception and phonological short-term memory in 5-to-7-year-old children. *Frontiers in Psychology, 10*, 2865. https://doi.org/10.3389/fpsyg.2019.02865

Madsen, S. M. K., Marschall, M., Dau, T., & Oxenham, A. J. (2019). Speech perception is similar for musicians and non-musicians across a wide range of conditions. *Scientific Reports, 9*(1), 10404-10. doi:10.1038/s41598-019-46728-1

Middelweerd, M. J., Festen, J. M., & Plomp, R. (1990). Difficulties with speech intelligibility in noise in spite of a normal pure-tone audiogram. *Audiology*, *29*(1), 1-7. doi:10.3109/00206099009081640

Nilsson, M., Soli, S. D., & Sullivan, J. A. (1994). Development of the hearing in noise test for the measurement of speech reception thresholds in quiet and in noise. *The Journal of the Acoustical Society of America*, *95*(2), 1085-1099. doi:10.1121/1.408469

Parbery-Clark, A., Skoe, E., Lam, C., & Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing, 30*(6), 653-661. doi:10.1097/aud.0b013e3181b412e9

Qualtrics software, Version April 2021 of Qualtrics. Copyright © 2021 Qualtrics. Qualtrics and all other Qualtrics product or service names are registered trademarks or trademarks of Qualtrics, Provo, UT, USA. https://www.qualtrics.com.

Schmithorst, V. J., & Holland, S. K. (2004). The effect of musical training on the neural correlates of math processing: A functional magnetic resonance imaging study in humans. *Neuroscience Letters, 354*(3), 193-196. doi:10.1016/j.neulet.2003.10.037

Soncini F. & Costa, M. J. (2006). The effect of musical practice on speech recognition in quiet and noisy situations. *FapUNIFESP (SciELO), 18*(2), 161-170. doi:10.1590/s0104-56872006000200005

Spahr, A. J., Dorman, M. F., Litvak, L. M., Van Wie, S., Gifford, R. H., Loizou, P. C., . . . Cook, S. (2012). Development and validation of the AzBio sentence lists. *Ear and Hearing, 33*(1), 112-117. doi:10.1097/aud.0b013e31822c2549

Vermiglio, A. J., Bulla, E., Skinner, J., Heeke, P., Fang, X., Velappan, K., . . . Garner, E. (2021). A convergent validity study: Listening in spatialized noise-sentences (LiSN-S) test and the hearing in noise test (HINT). *International Journal of Audiology, 60*(1), 27-34. doi:10.1080/14992027.2020.1791367

Vermiglio, A. J., Herring, C. C., Heeke, P., Post, C. E., & Fang, X. (2019). Sentence recognition in steady-state speech-shaped noise versus four-talker babble. *Journal of American Academy of Audiology*, 30(54-65). doi:10.3766/jaaa.17083

Vermiglio, A.J., (2008). The American English hearing in noise test. *International Journal of Audiology, 47*, 386-387, doi:10.1080/14992020801908251

World report on hearing. Geneva: World Health Organization; 2021. License: CC BY-NC-SA 3.0 IGO.

Wilson, R.H., Carnell, C.S., (2007). The Words-in-Noise (WIN) test with multitalker babble and speech-spectrum noise maskers. Journal of American Academy of Audiology, *18*(6), 522-529, doi: 10.3766/jaaa.18.6.7