SPEECH PERCEPTON IN NOISE IN MUSICIANS: A SYSTEMATIC REVIEW

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CERTIFICATE

This is to certify that this dissertation entitles "**Speech perception in noise in musicians: A systematic review**" is a bonafide work submitted as a part for the fulfilment for the degree pf Master of Science (Audiology) of the student with registration number: 20AUD016. This has been carried out under the guidance of the faculty of this institute and has not submitted earlier to any other University for the award of any other Diploma or Degree.

Mysuru

August, 2022

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DECLARATION

This is to certify that this dissertation entitled "**Speech perception in noise in musicians: A systematic review**" is the result of my own study under the guidance of Dr Ajith Kumar U, Professor in Audiology, Department of Audiology, all India Institute of Speech and Hearing, Mysuru and has not been submitted to any other University for the award of any other Diploma or Degree.

Mysuru **Registration No.: 20AUD016**

August, 2022

Dedicated to my mother *Mrs. Jayshree Mali*

The hardest thing for a mother is to make it possible for her daughter to be independent and at the same time let the daughter know how much she is loved, yet how truly essential it is for the daughter to fly on her own.

She is the only reason I’m able to do what I do.

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Abstract

Aim and objective: *The objectives of this systematic review was to document and classify the current, peer reviewed research evidence about speech perception in noise performance in musicians and non-musicians across all age ranges using behavioural and electrophysiological tests.* ***Method:*** *The search of the evidences began by finalizing keywords and putting them through various databases. The articles were screened across various stages and 46 articles were taken for the review.* ***Results:*** *The review provided with the factors that were documented to enhance speech perception in noise in musicians across both short-term and long-term musical training across all the age ranges.* ***Conclusion:*** *Musical training has a positive influence on individuals and is directly proportional to the number of years of musical experience.*

CHAPTER I

INTRODUCTION

In today's world, we are often surrounded by background noise. Speech-in-noise (SIN) perception would be the only combating strategy for smooth communication. It is the way through which the brain functions to perceive speech in the presence of competing noise. The integrity of the peripheral and central auditory system is the base for successful Speech in noise processing (Parbery-Clark et al., 2011). Any pathology in the auditory system results in deterioration of speech in noise perception.

It is proposed that musical training provides long-lasting benefits to the auditory system that contain perceptual enhancements, and other functions that are important for higher-order cognition, i.e., auditory working memory and intelligence (reviewed from Coffey et al., 2017). Structural changes in the brain were demonstrated in the motor and auditory areas after just 1.3 years of musical training in early childhood. Hyde et al., (2009) It is evident through research that musical training improves cognitive functioning. It is known that musical expertise enhances a range of auditory perceptual skills, including discriminating frequency change, which suggests that musical training can enhance the neural encoding of spectral features (Lee et al., 2020).

Studies suggest that perceptual abilities like pitch discrimination are enhanced in musicians (Bianchi et al., 2016). Auditory stream segregation was found to be better in musicians compared to non-musicians (Johnson et al., 2021). The ability to segregate concurrent sounds is enhanced in listeners as an effect of their musical experience.(Zendel & Alain, 2009). Pitch matching accuracy was found to be more accurate in trained musicians (Estis et al., 2011). Another study by Micheyl et al., (2006) revealed that musicians trained for ten years or more possessed more finer ability

to discriminate pitch compared to non-musicians. Musicians performed significantly better on spectral-pattern discriminations (Sheft et al., 2013). Mishra & Panda, (2014) reported enhanced temporal encoding abilities in musicians. This was supported by another study by Donai & Jennings, (2016) that found shorter gap detection thresholds in musicians compared to the performance of their age-matched non-musicians. Besides non-speech stimuli, fine-tuning for speech syllables has been found in musicians (Parbery-Clark, Tierney, et al., 2012).

1.1 Need of the study

Recent research by Amemane et al., (2020) reported lesser SNR loss performance on QUICK SIN. Older musicians show benefits in speech-in-noise perception as compared to young musicians. Older musicians have also shown a lower age-related decline in auditory processing (Zendel & Alain, 2012a). These findings are fascinating and may be clinically applied in intervention programs. A large number of factors seem to influence improvement of speech perception in noise and the literature reveals mixed findings. Hence a systematic review will help in studying these factors.

1.2 Aim of the study

The present study aims to initiate a systematic review of available scientific evidence on the speech in noise perception ability in musicians and to list out factors influencing the ability of musicians to perceive speech better than other groups.

1.3 Objectives of the study.

Therefore, the objective of this systematic review is to

- document and classify the current, peer reviewed research evidence about speech perception in noise performance in musicians and non-musicians across all age ranges using behavioural and electrophysiological tests.

To segregate studies based on short-term and long-term musical training and see the effect on speech perception in noise

CHAPTER II

METHOD

The systematic review was done using Preferring Reporting Items for Systematic Reviews and Meta-analyses statement's standards (PRISMA) (Liberati et al., 2009). PRISMA is takes into account how researchers can assure that systematic reviews and meta-analyses are appropriately and thoroughly reported. The PRISMA chart is used to identify relevant studies to come to the outcome of the research question.

Following stages were followed according to PRISMA (Page et al., 2021)

2.1 Stage 1: Identification of the articles

2.2 Stage 2: Screening of the articles

2.3 Stage 3: Finalization of studies

2.1: Stage 1: Identification of the articles

In this stage articles are identified based on the research question they are dealing with and their respective relevance to the topic of interest. An eligibility criterion was set for the selection of articles. Relevance was determined on the base of these criteria.

2.1.1 Eligibility Criteria:

The PECO given by Liberati et al., (2009) format was also used as inclusion criterion for selecting studies. PECO stands for patient population. Disease being addressed (P),

interventions or evaluation (I)/(E), control group (C), and outcome or endpoint (O) (Liberati et al., 2009). The criteria designed based on the PECO format helped in screening and analysing the relevant articles. It also helps formulate the search strategy by identifying the key concepts that need to be in the article to answer the research question. The following are the details of the PECO format followed in the current study:

Population: Studies that encompass normal hearing individuals with musical training, i.e., musicians cross all the age ranges. Studies reporting effect of long-term musical training (at least 10 years) and short-term musical training were included in this systematic review. The musicians' group may be trained under domains of instruments and vocals as part of Western or Indian Classical Music.

Evaluation: Studies that comprise assessment of speech perception in noise using behavioral tests such as Quick SIN and HINT; and objective tests such as speech evoked ABR and CAEP were included.

Control group: Studies with normal-hearing individuals as a control group or within-subjects comparisons were selected.

Outcomes: The outcome of the review will provide insight into the enhanced speech in noise perception in musicians that will help the researcher list out contributing factors to it and conclude on the importance of musical training in an individual’s ability to perceive speech in the presence of background noise.

2.1.2 Search strategy:

In this step, two different sets of keywords were decided by two investigators to get relevant articles. Keywords used were as follows:

"SPEECH IN NOISE" [MeSH] AND ¨MUSICIANS " [MeSH]

“SPEECH IN NOISE” [MeSH] AND “MUSICAL TRAINING” [MeSH]

“MUSICIANS” [MeSH] AND “COCKTAIL PARTY” [MeSH]

“SPIN” [MeSH] AND “MUSICIANS” [MeSH]

“SPIN” [MeSH] AND “MUSICAL TRAINING” [MeSH]

“MUSICIANS” [MeSH] AND “BACKGROUND NOISE” [MeSH]

The keywords were fed in the following search engines: PubMed, Sci- Direct, J- gate, Shodhganga, and Google scholar. The strategy of the advance search was used with the following keywords extracted from the Medical Subject Headings. The articles were obtained from PubMed, and Google scholar, and no articles were found in Shodhganga, Sci-Direct and J-gate.

2.2: Stage 2: Selection of the studies

Separately, two investigators glanced through all electronic databases. Duplicates were deleted from the collected studies using a reference management system. After eliminating the duplicates, the authors individually screened the titles. After the titles had been examined, both investigators evaluated the abstracts. At all levels, any

disagreements in judgments were handled through verbal discussion. The full text of the shortlisted abstracts was acquired for the data extraction technique. Following the screening of the studies, only those that satisfied the inclusion criteria in PECO format were subjected to the data extraction process.

2.3 Data Extraction:

The full-length articles of selected studies were read. All relevant information pertaining to the objective of the study was extracted. Further, a quality analysis of the selected articles was carried out.

2.4 Quality assessment:

All of the studies included in the review were subjected to a quality evaluation to determine whether they were appropriate for inclusion in the review. Each article was critically appraised using Ruth Brice's Critical Appraisal Skill Programme (CASP) checklist (Critical Appraisal Skills Programme, 2018). CASP consists of twelve questions broken into three sections. Three categories were used to score the questions: yes, can't tell, and no. The study's purpose, cohort recruitment, measurement bias, and the identification and analysis of confounding factors were all covered in the questions. The checklist was also used to grade the consistency of follow-up, the generalizability of the findings, and the implications of the findings.

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CHAPTER III

RESULTS

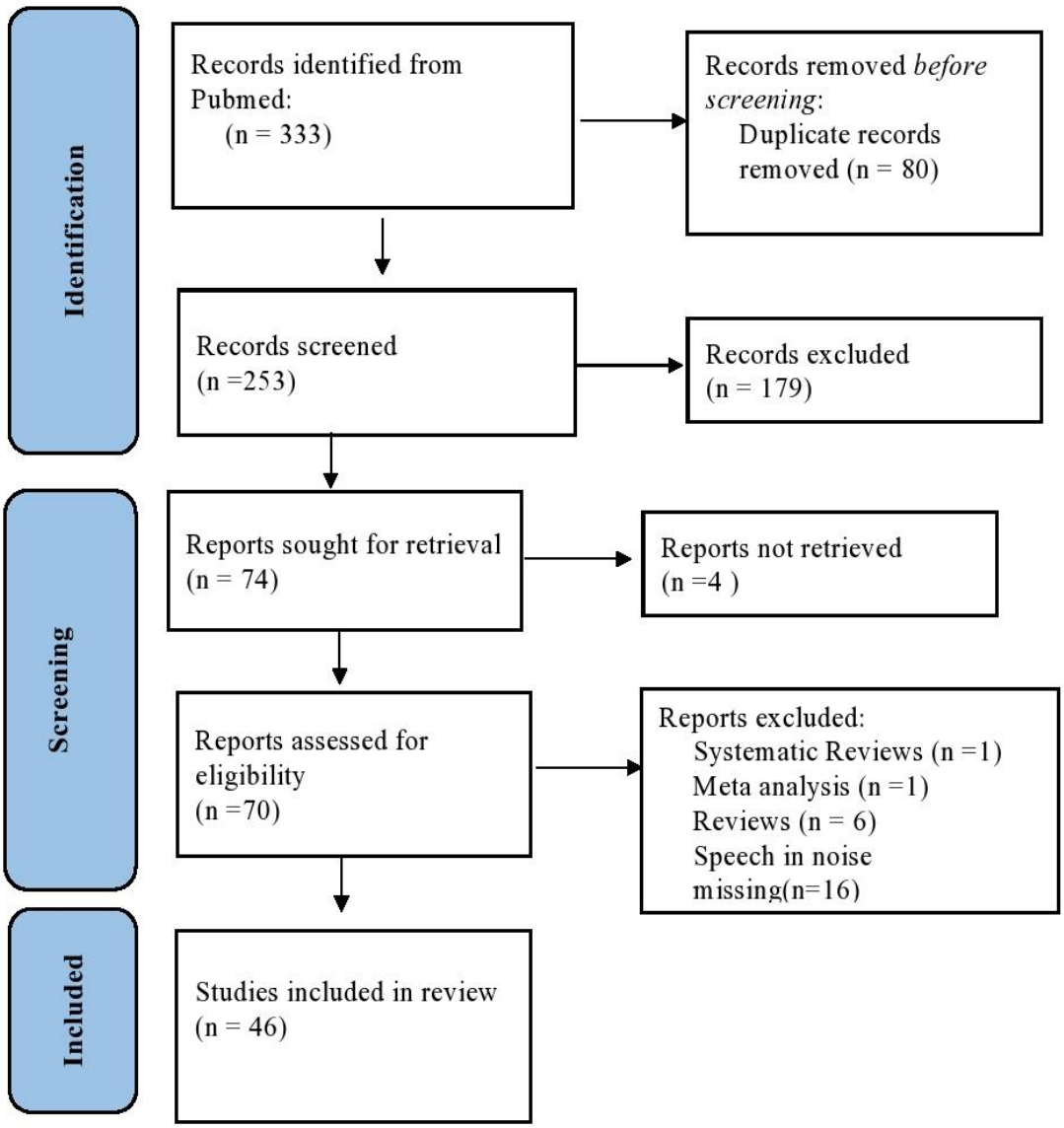
The aim of the study was to systematically review studies that incorporate speech in noise assessment in musicians.

3.1 Results of systematic approach process:

After compiling articles from all the databases, 333 articles were retrieved and were uploaded to Rayyan software. 80 duplicated were removed from these. The titles of other 253 articles were screened and 179 articles from these were found to be irrelevant to the aim of this study. 4 articles couldn't be retrieved. From the remaining 70 abstracts 16 did not meet the PECO criteria. The studies did not incorporate one speech in noise assessment were excluded. One was a systematic review; one was a meta-analysis and six review articles were also excluded. 46 articles were included for this study.

The Above details are given as a PRISMA flow chart.

Figure 3.1
Schematic representation of the systematic search process using PRISMA



3.2 Results of qualitative analysis:

Qualitative analysis was done for the finalized articles using the CASP questionnaire. It remains an important task to first separate the studies based on their quality. A score of 5 or more was listed in the inclusion criteria for close ended questions. The result is added in the Appendix-I

3.3 Characteristics of the study included in the systematic review:

The participant and study characteristics are tabulated for each of the 46 studies in the Table No. 3.1 and 3.2. A summary of each article that passed the inclusion and the quality assessment criteria has been represented in the table. The behavioral and objective tests used to assess Speech perception in noise in each of the articles have also been mentioned in the table.

Table 3.1

The study characteristics and participant characteristics- Long-term musical training

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
1	Mestre et al (2004)	To study the effect of long-term musical practice on SIN.	55 non-musicians (31-69years) 45 Musicians (30-93 years) At least 5 years of musical experience.	SNR was obtained based on SRT. Noise and speech were fixed at 65dB HL	No significant difference in quiet condition. Musicians outperformed Non musicians in noise condition.
2	Parbery-Clark et al (2009)	To study the effect of long-term musical practice on SIN and speech ABR.	16 musicians and 15 non musicians. (Mean age 23+- 3 years) minimum 10 years of musical experience.	Behavioral: HINT and QUICK SIN Objective: Speech evoked ABR (BIOMARK)	Musicians Had robust ABR amplitude onsets and greater phase locking. This was related to their better performance on HINT
3	Parbery-Clark(2009)	To study the effect of long-term musical practice on SIN and auditory working memory.	16 musicians (18-35 years) age of musical training < 7 years and had consistently practiced for ≥11years and 15 non musicians (18-35 years)	HINT- front left right. QUICK SIN, auditory working memory and frequency discrimination.	Musicians performed better in QUICK SIN and HINT F. Better memory and frequency discrimination
4	Strait and Kraus (2011)	To study the effect of long-term musical practice on SIN on selective auditory attention.	11 musicians. At least 11 years of experience and age of training at >= 7 years of age. 12 non-musicians (18-35 years).	HINT and Auditory Attention subtest.	Musicians performed better in SIN supported with selective attention. Response variability decreased with increased attention.

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
5	Parbery-Clark et. al (2011)	To study the effect of long-term musical practice on SIN and working memory	18 musicians. At least 11 years of experience and age of training at >= 9 years of age (45-65 years of age)	HINT, Quick SIN, Words in Noise test (WIN), Auditory working memory.	Musicians performed better in all the domains. Auditory working memory correlated with SIN.
6	Parbery-Clark et al (2011)	To study the effect of long-term musical practice on SIN and its sensitivity to acoustic regularities.	16 musicians. At least 11 years of experience and age of training at >= 7 years of age (18-30 years)	HINT, Speech evoked ABR-predictable condition /da/ presented 100% of the time and variable condition /da/ presented 12.5 % of the time. 87.5 % sounds differed in formant structure, duration, VOT and F0.	Musicians performed better than non-musicians. Musicians showed greater enhancement of the F0 in the predictable condition at the subcortical level.
7	Parbery-Clark(2012)	To study the effect of long-term musical practice on SIN and subcortical responses.	23 musicians. Age of training >= 9 years 25 non musicians. (45-65 years of age)	Speech evoked ABR, HINT, SSQ	Musicians performed better in HINT. Less difficulty rated on SSQ. Robust Speech ABR-less degradation due to noise.
8	Zendel and Alain (2012)	To study the effect of long-term musical practice on age-related offset in auditory perception	74 musicians (age 18-91 years) Age of training at >= 9 years of age. At least 6 years of musical training. 89 non musicians.	PTA, GDT, QUICK SIN	Musicians performed better and have lower thresholds. The rate (slope of the regression line) at which thresholds increase with age is slower in musicians

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
9	Anderson et al (2013)	To study the effect of long-term musical practice on cognitive factors involved in SIN in older adults	7 musicians with 1 to 71 years of musical training, 113 non-musicians. (55-79 years)	QUICK SIN, HINT, WIN, auditory attention, auditory working memory. Speech evoked ABR	Musicians perform better. Among non- musicians those with better life experiences such as high socioeconomic status, greater physical activity, and high intellectual engagement variables performed better than the others.
10	Parbery-Clark et al (2013)	To study the effect of long-term musical practice on SIN and encoding of speech in noise with hearing loss.	17 musicians and 17 non musicians (45-65 years of age) Mild to moderate hearing loss	speech ABR, HINT	Musicians performed better.
11 Exp 1	Ruggles DR; Freyman RL; Oxenham AJ(2014)	To study the effect of long-term musical practice on SIN with various types of stimuli, maskers and various SNR's	16 musicians and 13 non musicians (18- 31 years)	Three types of speech (voiced, whispered, and adjusted whispered), two types of noise (continuous and gated), and three different SNRs (26 dB, 23 dB, and 0 dB)	No significant effects of musical training were found
11 Exp 2	Ruggles DR; Freyman RL; Oxenham AJ (2014)	To study the effect of long-term musical practice on standard	10 musicians, 12 non musicians	Quick SIN, HINT	No significant difference in the groups

		clinical speech-in-noise tests.			
12	Boebinger at al (2015)	To study the effect of long-term musical practice on processing of masked speech	50 British Native speakers. 25 musicians with at least 10 years' experience and reported practicing consistently. 25 non musicians (MEAN age 27.2 years SD 6.9)	Musicianship questionnaire. BKB test, Pitch and duration Discrimination threshold, Forward and Backward digit span subtest if WAIS	No effect of musicianship
13	Zendel at al. (2015)	To study the effect of long-term musical practice on attention dependent cortically evoked potentials.	13 musicians and 13 non musicians (18-35 years) age of 15 years, 10 years of minimum musical experience, and practiced 10 hour per week in the year the testing took place	Words in presence of multiple talker babble. SNR 15 SNR 0, N400	Musicians performed better IN SNR 0, No musician effect on N400 latency
14	Swaminathan et al (2015)	To study the effect of long-term musical practice on SIN	12 musicians 12 non musicians (18-24 years)	Short sentences were presented in the presence of maskers collocated with the target or separated from it. Both intelligible and unintelligible maskers were used.	Musicians performed better.

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
15	Slater and Kraus (2016)	To study the effect of long-term musical practice on SIN	17 non musicians, 21 vocalists, 16 percussionists at least 7 years of training AGE 18-35 YEARS	MET, QUICK SIN, WIN, Auditory Working Memory	Musicians performed better. Percussionist group performed than the vocalists.
17	Başkent D; Gaudrain E (2016)	To study the effect of long-term musical experience on SIN	18 musicians and 20 non-musicians 19-27 years	target sentences presented on masker sentences target to masker ratio of -6db	Musicians performed better.
18	Morse-Fortier et al (2017)	To study the effect of long-term musical practice on informational and energetic masking	20 musicians and 20 non musicians (22 mean age)	SNR 50 in Natural spatial, vocoded spatial, natural non-spatial, vocoded non-spatial conditions for CVC syllables	Musicians performed better.
19	Coffey et al (2017)	To study the effect of long-term musical practice on SIN.	20 young adults (mean age 25.7 years) out of which 12 have some level of musical training.	HINT, pitch discrimination, FFR ERP	Musicians performed better than non-musicians
20	Rostami and Moossavi (2017)	To study the effect of long-term musical practice on representation of comodulation masking release.	19 musicians and 17 non musicians (18-35 years)	c ABR in presence of speech shaped noise with and without modulation.	Musicians showed greater comodulated release from masking

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
24	Slater et al (2018)	To study the effect of long-term musical practice on SIN and the role of rhythm perception in it.	8 percussionists and 9 non musicians	QUICK SIN. For rhythm perception: Drumming tests such as drumming to beats, drumming to metronome and drumming with jittered or metrical sequences	Percussionists performed better.
25	Yates et al (2019)	To study the effect of long-term musical practice on SIN and the role of rhythm, melody and beat sensitivity in it.	24 adults (19-40 years)	Goldsmiths' Musical Sophistication Index, DST, TFS, UK matrix sentence test, MET, BAT,	Musical training has an effect on speech perception in the presence of noise.
26	Jessica and Beidelmen (2019)	To study the effect of long-term musical practice on SIN and role of cognition.	16 musicians and 15 non musicians (18-35 years)	Quick SIN WIN HINT, backward and simultaneous masking, digit span and raven matrices	Musicians performed better. Benefit of musicianship on SIN processing is limited to complex SIN tasks that require recognition at sentence level in the presence of linguistic maskers.
27	Madsen et al (2019)	To study the effect of long-term musical practice on SIN	32 musicians and 32 non musicians	F0 discrimination limens (F0DLs) and ITDL's, speech-on-speech closed set identification task.	Musicians performed better at F0DLs, ITDLs, and attentive tracking. SINscores were not significantly different between the two groups. No significant musician advantage was found.

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
28	Puschmann et al (2019)	To study the effect of long-term musical practice on SIN during selective listenning	20 musicians 18-24 years of age	MEG, FFR(series of analysis) , HINT,	Musicians performed better.
29	Zhang et al (2019)	To study the effect of long-term musical practice on SIN	17 musicians and 17 non musicians (20-30 years)	HFA, QUICKSIN, BMLD,	Musicians scored better score in the right ears for QUICKSIN and lower threshold in the SoNo condition,
30	Bidelman and Yoo et al (2020)	To study the effect of long-term musical practice on SIN	14 musicians and 14 Non musicians 19-33 years of age.	speech on speech task, QUICK SIN, fluid intelligence and other general cognitive skills like attention, working Memory and IQ	Musicians performed better with quicker and better target speech recognition.
31	Escobar et al (2020)	To study the effect of long-term musical practice on SIN and to assess whether benefit of musical experience can be differentiated from that of WM capacity.	27 musicians and 22 musicians (22-24 years)	QUICK SIN, HINT SPIN R , LE	Musicians and Non musicians with higher working memory capacity performed better than musicians and non-musicians with lower WM.

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
32	Zhang et al (2021)	To study the effect of long-term musical experience and aging on SIN perception ability	48 older musicians 29 older non musicians 48 young musicians and 24 young non musicians	Speech recognition of sentences lacking context, perceptually collocated or separated with a noise masker (energetic masking) or a two-talker speech masker (informational masking). Auditory working memory.	Older musicians performed better. Musician advantage was not observed in young musicians. Musical training offsets age-related deficit at adverse listening conditions by the virtue of auditory working memory.
33	Kaplan et al 2021	To study the effect of long-term musical practice on speech-on-speech processing	16 musicians and 17 non musicians 21-45 years of age	Sentence recall task	Musicians performed better.
34	Li et al (2021)	To study the effect of long-term musical practice on white matter diffusivity of Arcuate Fasciculus bilaterally and its involvement in SIN perception ability.	15 musicians and 15 non musicians (20-2 years)	Four 500-ms consonant-vowel syllables were randomly presented 500-ms white noise segment at 5 signal-to-noise ratios (SNRs: −12, −8, −4, 0, and 8 dB). Fiber tractography.	Musicians showed significantly higher Functional anisotropy and higher axial diffusivity in the right direct Arcuate Fasciculus.

Table 3.2

The study characteristics and participant characteristics- Short-term musical training

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
1	Strait et al (2012)	To study the effect of short-term musical practice in early childhood on speech-in-noise perception.	31 normal hearing children (7-13 years) 15 Musicians age of training 5 years and consistent for at least 4 years (≥ 20 minutes at least 5 days per week). 16 non-musicians.	WIN and HINT. speech evoked ABR	Musically trained children performed better. Less degradation was observed in responses of musicians.
2	Strait et al (2013)	To study the effects of short-term musical practice during early childhood on SIN.	18 musicians and 14 non musicians (3-5 years of age)	speech ABR quiet and noise conditions	Musically trained children demonstrated performed better
3	Jain et al (2015)	To study the effect of short-term musical practice on the auditory system.	10 individuals given musical training 8 individuals who received no training. (18-25 years) The participants were divided into two groups - group 1 received musical training of 2 Carnatic ragas. Group 2 did not receive any training.	Quick SIN was administered pre and post training.	Musical training improved the scores. Also, the ability to identify the Raga improved

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
4	Slater et al (2015)	To study the effect of short-term musical practice on SIN	19 children trained for music right away(b) and 19 children trained in music after one year(a) 8-9 years of age	HINT done pre-training, 1 year no training and 1 year post training(a) and 2 years post training(b)	Children who were given training right away performed better than the group which received training a year later. More the hours of training better the HINT performance.
5	Baskent D et al (2018)	To study the effect of short-term musical practice on SIN in young adolescents.	10 musicians 11 non musicians (11-14 years)	Vocal emotion identification, Words in noise, sentences in competing speech, vocoder degradation.	Musicians performed better although improvements were sometimes small
6	Mc Cutcheon et al (2019)	To study effect of short-term musical practice on SIN.	41 normal hearing male children (5-7 years)	Exp. group - given training of 1hour per week for 38 weeks control group- No musical training. SIN.	Baseline- No differences between the groups in SIN.

Sr. no,	Study	Characteristics/ Research question	Population type(n)	Testing parameters used	Outcomes
7	Dubinsky et al (2019)	To study the effect of short-term choir practice on SIN perception in older adults with hearing loss.	34 adults received training. 29 age matched adults received no training. (54-79 years age)	QUICK SIN, FDL, FFR	The group receiving musical training performed better in SPIN and pitch discrimination task. The strength of neural representation of 0 was more in choir group on FFR.
8	Fleming et al (2019)	To investigate the effects of short-term musical practice on the neural processing of SIN in older adults	38 participants. 15 received musical training, 8 received video gaming training and 15 served as the control group (passive)	f MRI , HINT	There was an increase in the response to speech in bilateral frontal, left parietal and right temporal cortical regions.
9	Raksha et al (2021)	To study the effect of short-term music listening practice on SIN in adults	28 participants 40-71 years of age	QUICK SIN	The group receiving musical training performed better
10	Worschech et al (2021)	To investigate effect of short-term musical practice on SIN perception in the elderly	159 normal hearing individuals (62-78 years)	Binaural and monoaural SIN	The group receiving musical training performed better. Women showed more improvement. No improvement was seen on right ear scores.
11.	Hennessey et al (2021)	To examine the effects of short-term musical practice on SIN perception in older adults	41 participants (50-65 years) with mild hearing loss	BKB SIN, P300	The group receiving musical training performed better N1 response. However behavioral differences were not observed.

CHAPTER IV

DISCUSSION

The present study aimed to review articles on speech in noise perception in musicians as an effect of long-term musical training as well as short term musical training across all the age groups in a systematic manner. The results of the systematic review will be discussed under the following sections.

Majority of the studies report that musicians perform better than non-musicians. The factors facilitating speech in noise performance are discussed in this section.

4.1. Effect of long-term musical training studied using behavioral measures

4.1.1 Young adults

The included studies have administered a spectrum of behavioral tests to assess speech perception in noise wiz, Hearing in noise test (HINT) and Quick SIN -tests that requires identification of sentences in the presence of a speech shaped noise and a multitalker babble respectively. Quick SIN includes longer and advanced vocabulary as compared to HINT(Aarts et al., 2006).

The resilience towards auditory distractions increases with the increase in years of musical training. SIN benefits increase with experience. The listeners' degree of music training predicted their QuickSIN performance even after controlling for working memory. This suggests that musicianship might provide an additional boost to basic figure-ground speech perception beyond cognitive factors alone.

Auditory working memory was the first factor reported in the literature along with the amount of musical expertise (Zhang et al., 2019). The speech in noise performance on Quick SIN was found to be better and it correlated with better auditory working memory (Parbery-Clark et al., 2009). Here, the reverse hierarchical theory was used to explain this fact in which it hypothesizes that, as the task gets difficult, the low-level cues play a major role which in turn are used by musicians to process sounds and hence performance in SIN is better. Auditory working memory equally contributes to driving SIN performance (Puschmann et al., 2019). Working memory was associated with better speech streaming and reduced target localization error at the cocktail party (Zhang et al., 2019). Escobar et al., (2019) Working memory plays a role in SIN performance. The role of spatial hearing in musicians was reported through a study by Swaminathan et al., (2015) where the SIN was assessed in which the signal and the masker were spatially separated and collocated the task was easier when the maskers were spatially separated which reduced the amount of informational masking as compared to the condition where the maskers were collocated. This was attributed to their enhanced ability to suppress irrelevant background sounds, which suggests that musicians are less affected by informational masking than non-musicians. Another condition in the same study used maskers which were reversed making them unintelligible. In this condition the thresholds were lower due to lack of meaningfulness in the speech maskers that would produce informational masking.

Rhythm perception also plays a role in facilitating SIN by helps to compensate impoverished sensory information in the presence of noise (Slater & Kraus, 2016). Evidence states the presence of an overlap in the neural circuitry involved in perception of speech and music, specifically with respect to rhythm and pattern processing (Patel et

al., 2014). Yates, (2019) in her study stated that the overlap between speech and musical rhythm lies in temporal sequences and small timing deviations. correlations between drumming to sequences and speech-in-noise perception remain significant within the non-musician group considered alone, suggesting that natural variations in timing skills may influence speech perception, in the absence of musical training. Musicians are able in discerning the rhythm of what is said even when the speech was inaudible. Temporal structure of the masker is also a factor affecting speech perception in noise

Finer f0 discrimination was found to be one of the factors enhancing speech perception in noise (Başkent & Gaudrain, 2016). Coffey et al., (2017) reported that better f0 discrimination correlated with better SIN performance. Yoo & Bidelman, (2019) in their study reported that musicians' SIN advantage is limited to conditions with linguistic maskers that arguably involve heavier use of cognitive function. duration of musical training predicted not only SIN perception but also cognitive measures which implies that these perceptual-cognitive skills may be driven by experience-dependent plasticity. Zhang et al., (2019) found that binaural masking level differences scores were better in musicians specifically the right ear scores. The musician advantage was reported in the in the SoNo condition but not the SπNo. The SoNo condition is more perceptually challenging than the SπNo condition, in which extra spatial cues are provided. According to Bidelman & Yoo, (2020) musician benefits in cocktail party speech seem to manifest only under the most challenging and ecological listening scenarios in tasks that tap linguistic and cognitive processing. However, enhanced cognitive faculties in musicians i.e., IQ and working memory were reported. IQ, WM, and attention presumably play a large role in SIN processing. Thus, musicians' cocktail party benefits could reflect enhancements in domain- general cognitive abilities.

Although these studies report a significant effect of musicianship, some findings from the literature claim no effect of musicianship on speech perception in noise. Ruggles et al., (2014) found no significant differences in the SIN scores for musicians and non-musicians in both whispered and voiced speech conditions. Another experiment of the same study carried out clinical SIN tests and reported no observed musician advantage in any of the measures. There was an absence of main effect of musicianship pertaining to individual differences and age of the listeners. The authors claim that older musicians may show a musician advantage in congruence to a study by Zendel & Alain, (2012). Similar findings were reported by Madsen et al., (2019) despite of a large sample size. Although there was a marked advantage in auditory tasks like frequency discrimination, interaural time differences and attention tracking, Boebinger et al., (2015) reported no advantage for musicians' masked speech perception over that of non-musicians, across all the masker types.- steady-state and modulated noises, as well as maskers with and without a clear pitch to identify whether differences between the groups were associated with enhanced temporal processing and/or pitch processing abilities in musicians. However, no interaction was noted, the number of years of musical experience correlated with Quick SIN but not HINT test.

4.1.2 Older adults

Musicians were better able to perceive speech in unfavourable SNRs as compared to non-musicians when musical practice was the only differentiating factor between the two groups (Mestre et al., 2006). Enhanced SIN performance correlated with auditory cognitive (working memory) and perceptual (temporal acuity) abilities in musicians of age

45-65 years who had been practicing music throughout their lives (Parbery-Clark, Anderson, et al., 2012; Yeend et al., 2017). Cognition and central processing estimate a significant proportion of the variability in speech-in-noise performance, with life experiences additionally mediating the brainstem's effects through top-down modulation. Memory and attention, along with central (brainstem) processing of speech, help to determine ability of older individuals to recognize speech in the presence of background noise. Life experiences and cognition can also fine tune processing of sound at the brainstem level indirectly. Life experiences were found to be the factor in the group with no musical training.

Pitch discrimination task performance and the low-cue condition of the LiSN-S in musicians correlated to each other. The OPERA hypothesis states that ''experience-dependent plasticity'' takes place if five requirements are met- Overlap, Precision, Emotion, Repetition and Attention (Patel et al., 2014). The musicians showed significantly better performance on pitch discrimination and amplitude modulation (4 Hz). The ''overlap'' aspect of OPERA implies that there should be a commonality in the networks that process aspects of music and speech. ''Precise'' encoding in musicians may refer to their superior performance on auditory tasks. Low-cue condition of LiSN-S and pitch discrimination significantly correlates in musicians. Collectively the behavioral and electrophysiological outcomes explain the ''precise'' neural representation at various levels of auditory pathway which may assist during speech recognition in noise.

Older musicians demonstrated better auditory working memory by auditory digit span which correlated with years of training and SIN performance in older but not young participants. A positive correlation between years of musical training and auditory

working memory as well as correlations between auditory working memory and SIN thresholds in older adults was established. Musical training is associated with better auditory selective attention (Strait & Kraus, 2011), Another explanation for the differences between musicians and non-musicians may be pertaining to the enhanced selective and/or focussed attention in musicians (Meha-Bettison et al., 2018)

Musicians could take better advantage of spatial attention in facilitating SIN perception that led to a larger direct effect of musical training on SIN performance in addition to the indirect effect mediated by auditory working memory.

The first evidence by Zhang et al., (2021) reveals that long-term vocal training was equally effective as long-term instrumental training in offsetting the age-related SIN deficit, even when vocalists received fewer years of training than instrumentalists. (Zendel & Alain, 2012) suggests that continued practice throughout life may reduce some of the age-related decline in speech perception which is often experienced by older adults. Effect of continuous practice on the cognitive aspect and its facilitation to processing at various perceptual inputs can be one possible mechanism of the musically delayed offset of aging.

4.2 Objective measures

4.2.1 Young adults

Attempts were made to objectively measure the interference of noise on speech perception tasks in musicians. On speech evoked ABR, the temporal features in the responses were less affected by noise and a shorter change in onset timing was observed in musicians as a result of experience-based modulation (Parbery Clark, 2009). The

responses for spectral features depicted by the steady state portion of syllable /da/ were also robust pertaining to the fine-grained acoustic bottom-up processing in musicians as a result of musical experience.

Another study by Strait & Kraus, (2011) emphasizes the role of selective attention in better speech in noise perception. The response variability in the prefrontal area was decreased only in the musicians' group and this shapes the sustenance of auditory attention required for facilitating musicians' performance on auditory tasks. Musician sensitivity of sound patterns is also found for speech domain which is evident by better pitch representation in the predictable condition and this is enhanced with years of musical experience. Pitch being the readily available constant feature, speech in noise perception is facilitated in musicians and this ability is fine-tuned by the number of years of training.

Faster neural timing and greater response consistency were factors that facilitated perception in the diotic condition but not in the monoaural condition indicating an experience related processing of the binaural information (Parbery-Clark et al., 2013). Zendel & Alain, (2012) reported that N400 is less affected by the presence of background noise in the musicians' group but not in the non-musicians' group. A decrease in the amplitude and increase in the latency of the P1–N1–P2 was observed as the noise level increased. P1 enhancement and latency delay was observed in musicians suggesting a top-down influence on cortical processing of acoustic sounds and time requirement in this process.

Musicians use spectral cues to separate speech from the background noise whereas non musicians use lexical content and thus there is increased activity in the left temporal areas that involve lexical and semantic processing (Rostami & Moossavi, 2017).

Stream segregation results in improved comodulation-masking release. Because perceptual cues are significant for segregating the target signal from background noise, those with enhanced auditory perceptual skills can identify fine acoustical signals and show improved ability to auditory stream segregation. Musicians have the potential to listen-in the dips. Another study supports this phenomenon of dip listening that reports the speech stream is represented strongly in musicians in the on-going response as compared to the to be ignored stream. Robust cortical tracking of the to-be-attended speech stream was observed in auditory sensory regions, motor and somatosensory cortex, and inferior frontal brain regions. Individuals with superior auditory working memory performance maintain increased representations of the ignored speech stream during selective listening and that this is associated with superior parietal lobe areas i.e., the left motor cortex, and left inferior frontal regions. The latter brain regions generate input predictions of both the attended and ignored speech streams during cocktail party listening, thus facilitating ongoing stream segregation and, potentially, listening "in the dips" of the perceptual background (Puschmann et al., 2019) The results indicate that life-long experience with stream segregation improves neural signal encoding and enhances representation of the speech signal in comodulated noise (Coffey et al., 2017)

According to Zhang et al., (2021) the strength of the MEG-based FFR-f0 attributed to structures including the auditory cortex in each hemisphere and is positively correlated with SIN accuracy suggesting that basic periodic encoding is enhanced throughout the auditory system in people with better ability to perceive speech under challenging noise condition. The performance can depend on the cues offered to the listener in the SIN paradigm [e.g., spatial cues and amount of information masking (Swaminathan et al., 2015)]; the extent to which an individual's experience has enhanced abilities and

mechanisms related to the available cues; and how well individuals can adapt to use alternative cues and mechanisms when more than one cues become inaccessible either through masker related variables like levels of noise (e.g.,Li et al., (2021)) or due to deterioration in the functioning of the auditory structures (Anderson & Kraus, 2011). Listeners with inferior auditory working memory performance may not have the capacity to keep and process representations of both input streams, and therefore may only rely on predictions of the to-be-attended stream.

Li et al., (2021) documented the structures that contribute to SIN abilities in musicians. They explored the Arcuate Fasciculus in musicians as it shows greater structural connectivity. The right arcuate fasciculus is a key tract of musical experience dependent plasticity. Also, the oxygenation level dependent activity in the auditory areas of right superior temporal gyrus code for SIN accuracy in musicians. The fractional anisotropy is a global measure of structural ordering and integrity of fibres. This study reveals the white matter substrates involved in speech processing in adverse listening conditions. This finding highlights the benefits of musical training in young adults through functional objective evidences.

4.2.2 Older adults

Faster neural response timing, less noise related degradation and better subcortical representation of the information were found to be the contributing factors to enhanced performance in noise on speech evoked ABR (Parbery-Clark et al., 2013). Middle-aged musicians have stronger representation of envelope, stimulus-to-response and harmonic encoding than non-musicians. The strengthened encoding of spectral features may provide them an advantage for speech-in-noise perception. Musician advantages were observed

for neural response timing, spectral encoding, and neural response consistency-all those factors known to decline with age. It is hence clear from these studies, that extensive musical practice facilitates listening abilities in a longer run.

4.3 Effect of Musical training in children

4.3.1 Behavioral measures

According to a study by Strait et al., (2013) musical training during early childhood mitigated the time delay caused by noise in the auditory brainstem response to speech. Auditory attention and working memory were found to correlate with auditory brainstem response properties. Musical training facilitates the development of speech-in-noise perception by first targeting on easier listening conditions. Introduction of musical training during early childhood years is hypothesized to have a developmental importance for all children by providing strength to the neural functioning that cover auditory perceptual and cognitive performance.

Slater et al., (2015) provided longitudinal evidence for improved hearing in noise with music training. Musicians are adept at using the fine-grained acoustic cues to segregate different streams, as well as at retaining information in working memory, making meaning from patterns and regularities within the signal, and recollecting prior experience and context to process the degraded input.

4.3.2 Objective measures

Neural encoding of speech in noise arises early in life by three years of age. It can be observed in children with as little as one year of training. Absence of adult like outcomes suggests the requirement of training and development (Strait et al., 2013). Significant

musician effect was observed for adolescents for melodic contour training and the musician effect was robust, and persisted even when the signal was spectro-temporally degraded. (Başkent et al., 2018)

Studies also report no significant musician effects for children with 1 year of musical training suggesting further development to play a role in later age of life. (MacCutcheon et al., 2020)

4.4 Effect of short-term musical training using behavioral measures

4.4.1 Young adults

With short-term perceptual training, good correlation was observed between the ability to identify ragas and behavioral speech perception in noise scores (Jain et al., 2015). The study highlighted the improvement in SIN scores post training in young adults who were given training with 2 Carnatic ragas. These findings too suggest that there is a possible crossover in the domains of music and speech processing that is positively facilitated on the basis of perceptual experiences.

4.4.2 Older adults

In older adults, the effect of music listening training has persisted even after the termination of the training, which pertains to some amount of perceptual learning in older adults (Amemane et al., 2020). Dubinsky et al., (2019) demonstrated experimentally that short-term choir participation can be used as an intervention to target and improve speech-in-noise perception in older adults.

Despite of these evidences, no clear effect of training on behaviour was documented in a study by Fleming et al., (2019) and also, they add that quiet condition produces more accurate scores than noisier backgrounds. In quieter noise there was no interference with understanding, while the cue provided by the noise signalled the upcoming trial. The no-noise condition did not have this cue. The long inter-stimulus onset interval (10 s) might have led to an attentional 'drifting' during the no-noise trials, possibly affecting the ability to understand the start of the sentence.

4.5. Objective measures

4.5.1 Older adults

Fleming et al., (2019) found that 6-months of musical training did not show clear improvement in behavioral responses but appeared to increase the response to speech in bilateral frontal (left Middle Frontal Gyrus and right Medial Frontal Gyrus), left parietal (left Supramarginal Gyrus), and right temporal (Superior/Middle Temporal Gyrus) cortical regions. These findings present with a possibility that 6 months of musical training could transfer to speech perception in the presence of noise, by neural response modulation of speech input to facilitate perception under noisy circumstances. Increased response in areas responsible for auditory working memory and top-down control speak for the observed training related plasticity in older adults. Failure to find improvement in behavioral task was attributed to the use of single word stimuli without contexts and for the objective measures (i.e., f MRI) complete sentence stimuli were used. Hennessey et. al. (2021) studied the effect of 12-week choir musical training on older adults and found an effect of on the auditory evoked potential N1 response in an Active and Passive Syllable-in-Noise task. N1 wave is associated with encoding of physical properties of

sound and it marks the arrival of potentially important sounds to the auditory cortex, it is hence modulated by the attentional requirements. The group difference was observed only in the passive condition which may be due to the sequential events of task and interaction with music training. Whereas during the active condition due to a ceiling effect as both the groups were putting equal amount of attention, no group differences were evident. These findings mark the enhanced coding of sounds that takes place in older adults as a result of musical training which is also reflected by increased attention in the task. There was no latency improvement observed on the oddball task because training exhibited a greater impact on the top-down processing in individuals. The behavioral task involved the BKB-SIN task which might not be sensitive to the potential changes post training. The experimenters used 2 talker babble while recording the potentials whereas BKB-SIN involved a four-talker babble, which could be a reason for not finding any behavioral changes.

CHAPTER V

SUMMARY AND CONCLUSION

The present systematic review was taken up for understanding speech perception in noise in musicians and to justify the lack of consensus found in the literature. The articles were selected by preparing a set of keywords that was used to search articles on various search engines. The articles were screened at various stages and those relevant to the stated research question were selected and included in this study. This entire procedure was done using PRISMA. 46 studies were finalized at the end of this procedure.

The full text articles were studied and the results were taken for further analysis. A trend across the studies suggested improvement in speech perception in the presence of noise, whereas some studies did not show the presence of musician' advantage at all. The results give an overview of what positive effects musical training can bring about in an individual as far as communication is concerned.

The review gave an understanding of possible factors that are influencing the speech in noise processing in musicians and the reasons to why there is no consensus in the literature. Hence the answer to the research question, there is an effect of musical training on speech in noise processing across all the ages. Also, the fact that improvements advance with the increasing number of years of musical experience is clear through this review. To conclude, introduction of music in an individual's life has a positive influence on communication through improvement of the cognitive (top-down) abilities in an individual.

5.1 Clinical application of the current review

Existing policies of inclusion of music training at the schooling level is therefore justified as far as the findings of this review exist. Music has a role in building an individual across all the domains of development and its advantage in communication is also well known. Music could be involved in intervention programmes for individuals who complain difficulty in understanding speech in the presence of noise.

5.2 Future directions

It was observed that there are very few studies that have made an attempt to study musical training to population with difficulty in understanding speech in the presence of noise. The findings of this review would be strengthened by experimenting on other populations. More studies are required to provide a concrete conclusion to understand factors specific to each population.

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APPENDIX-I:

Results of qualitative analysis.

Results of qualitative assessment of the included studies- long term musical training

SI No.	CASP	Soncini and Costa (2004)	Parbery Clark et al (2009)	Parbery-Clark at al (2009)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	No	No	No

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musicians performed better than non-musicians in the noise condition.	Musicians had robust ABR amplitude onsets and greater phase locking. This was related to their better performance on HINT	Musicians performed better in both QUICK SIN and HINT-F. Better auditory memory and frequency discrimination in musicians.
8	How precise are the results?	Very Precise	Very Precise	Very Precise
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Musical practice favors speech recognition in the adverse listening situations. The findings lead to develop interventions including musical training for patients presenting with speech	Brainstem activity may be a useful objective measure for evaluating the effectiveness of SIN-based auditory training programs.	The study provides evidence for musical training transferring to non-musical domains and highlights the importance of taking musical training into consideration

	comprehension difficulties, especially in noise.		when evaluating SIN ability.

SI No.	CASP	Strait and Kraus (2011)	Parbery-Clark et al (2011)	Parbery-Clark et al (2011)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes

5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	No	No	No
6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musicians performed better in noise due to selective attention. Decreased auditory-evoked response variability was observed at prefrontal electrode sites in the musicians' group	Musicians performed better in all the domains. Better AWM performance correlated to better performance on Quick SIN and HINT but not WIN.	Musicians demonstrated better perception of speech in noise than non-musicians. Greater subcortical enhancement of the fundamental frequency was observed in the predictable condition.
8	How precise are the results?	Very Precise	Very Precise	Very Precise
9	Do you believe the results?	Yes	Yes	Yes

10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Musical training is a potential natural and entertaining means for strengthening auditory cognitive processing. Pertaining to enhancement in selective attention, musical training could be a useful rehabilitation strategy in children with attention impairment.	Older adults with musical knowledge are better equipped to deal with the auditory perceptual demands in real-world situations that implies on music to be a skill for betterment in real-life communication needs.	The increase in neural sensitivity to speech in a predictable context relates to SIN perception, thereby representing a neural basis for musicians' behavioral advantage for hearing in noise

SI No.	CASP	Parbery-Clark(2012)	Zendel and Alain (2012)	Anderson et al (2013)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	No	No	No

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musicians performed better on HINT and rated less difficulty on SSQ as compared to non-musicians. Speech ABR neural encoding was robust in musicians. Musicians demonstrated enhanced onset and transition timing in quiet and limited degradative effects of background noise for all aspects of neural timing.	Musicians performed better and had lower thresholds compared to non-musicians. The rate at which speech in noise thresholds increase with age is slower in musicians compared to non-musicians.	Musicians performed better than non-musicians. Among non-musicians those with better life experiences such as high socioeconomic status, greater physical activity, and high intellectual engagement variables performed better than the others.
8	How precise are the results?	Very Precise	Very Precise	Very Precise
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes

11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Musician advantages for neural response timing, spectral encoding, and neural response consistency imply a slower age-related decline.	Lifelong musicianship influences age-related changes in some or all of the cognitive abilities	Central processing and cognition are factors that need to be considered when developing a treatment plan for older adults with complaints of hearing in noise difficulties.

SI No.	CASP	Parbery-Clark et al (2013)	Parbery-Clark et al (2013)	Ruggles DR; Freyman RL; Oxenham AJ (2014)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	No	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musicians demonstrated faster neural timing and more consistent ABRs to diotically presented sounds but no difference was found in the monoaural condition.	Middle-aged musicians with hearing loss demonstrated more precise neural encoding of speech in both quiet and noise. Musicians demonstrated better speech-in-noise ability and auditory working memory. Greater neural encoding of the fundamental frequency and smaller neural timing delays with the addition of background noise was noted. No musicians advantage on spectral encoding was observed	No significant effect of musical training.
8	How precise are the results?	Very Precise	Very Precise	Very Precise

9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Auditory training, such as music lessons strengthens the neural pathways involved in binaural processing. These can help overcome some of the classroom difficulties faced by children that involve understanding speech in noise.	Musical training may be included as a useful remediation tool for age-related deficits as well as for hearing-related deficits.	The differences between musicians and non-musicians are at best small and not robust, at least in a heterogeneous, but representative, sample of young adult musicians.

SI No.	CASP	Boebinger at al (2015)	Zendel et al (2015)	Swaminathan et al (2015)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	No effect of musicianship was noted	Musicians performed better in unfavorable SNR but no musician effect was observed in objective testing using N400 latency.	Collocated forward speech maskers yielded similar mean thresholds for musicians and non-musicians. However, the musicians achieved substantially lower thresholds than non-musicians when the forward maskers were spatially separated from the target Reversed collocated speech maskers yielded significantly lower thresholds than non-musicians.
8	How precise are the results?	Very Precise	Very Precise	Very Precise
9	Do you believe the	Yes	Yes	Yes

	results?			
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Masked speech has potential implications for therapeutic interventions for individuals who exhibit difficulties with comprehending speech in noisy environments. Remediation including the specific tasks such as working memory or selective attention can help in betterment of SIN.	Encoding of speech is robust in musicians and when there are high levels of background noise, musicians may rely on acoustic information to understand speech which is heavily loaded on lexical information.	Testing normal-hearing listeners with varying listening abilities in ecologically-realistic conditions using speech maskers with varying amounts of IM can further our understanding of the relative roles of cognitive and sensory factors in explaining individual differences in hearing speech in noise.

SI No.	CASP	Slater and Kraus (2016)	Başkent D; Gaudrain E (2016)	Esperanza et al (2016)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Yes	Yes
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	The combined musician group outperformed the non-musician group on the Quick SIN. The percussionist group performed relatively better on the Quick SIN than the WIN when compared to the vocalists.	The musicians showed overall better intelligibility than non-musicians, confirming a musician advantage for speech-on-speech perception.	Musicians performed better than non- musicians for speech perception in noise.
8	How precise are the results?	Very Precise	Very Precise	Very Precise
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes

12	What are the implications of this study for practice?	Rhythm and timing cues are important for the perception of novel speech patterns in degraded listening conditions.	Strong speech-on-speech perception advantage observed with musicians is more associated with stream segregation, rhythm perception, and auditory cognitive abilities	Musical experiences and perceptual abilities are said to be associated when it comes to identification of speech in challenging situations.

SI No.	CASP	Morse-Fortier et al (2017)	Rostami and Moossavi (2017)	Coffey et al (2017)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Yes	Yes
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musicians performed better than Non musicians	Musicians showed greater comodulated release from masking than non-musicians	Musicians performed better than non-musicians
8	How precise are the results?	Very Precise	Very Precise	Very Precise
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Musical training happens to sharpen the listening abilities needed to overcome	Musical training strengthens across-frequency	Better sound encoding likely improves SIN perception through better

	informational masking when pitch cues are available and the spatial cues are not.	modulation processing, auditory grouping and stream segregation that are vital for perceiving speech in degraded conditions.	representation of periodicity, which in turn leads to better stream segregation.

SI No.	CASP	Yeend et al (2017)	Madsen et al (2017)	Meha-Bettison K et al (2018)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Yes	Yes
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musicians performed better than non-musicians.	There was no significant difference between musicians and non-musicians	Musicians outperformed non-musicians on pitch discrimination, amplitude modulation and in the most challenging condition of the behavioral SIN. CAEP results showed N1 amplitude and P1 latency to be significantly different only at 0 dB SNR across the two groups
8	How precise are the results?	Very Precise	Very Precise	Very Precise
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes

11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Working memory, attention, generalized language skills and high frequency hearing all appear to be critical elements in determining performance in challenging listening environments.	The effects of musical training are sufficiently fragile as to confirm the relevance of musical training as a tool to enhance speech perception, at least among younger listeners.	Musicians are more adept at listening to relevant and selectively ignoring the irrelevant signals even when passively attending.

SI No.	CASP	Slater et al (2018)	Yates et al (2019)	Bidelman and Yoo et al (2019)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Yes	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musicians performed better than non-musicians. Percussionists performed better among the group of musicians.	Musical training has an effect on speech perception in the presence of noise.	Musicians demonstrated better performance than non-musicians on cognitive measures including IQ, working memory, and attention. Benefit of musicianship on signal-in-noise processing is largely limited to more complex SIN tasks requiring sentence-level recognition with linguistic maskers.
8	How precise are the results?	Yes	Yes	Very Precise
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to	Yes	Yes	Yes

	the local population?			
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	The study provides neural and behavioral evidence of musicians' advantage on some tasks but this was apparent only at the most difficult listening conditions.	A stronger beat and rhythm perception plays a role in strengthening speech in noise perception along with auditory working memory.	Music-related plasticity comprises of multifaceted domains including cognition associated and it extends beyond the auditory domain to improve broader cognitive function.

SI No.	CASP	Madsen et al (2019)	Puschmann et al (2019)	Zhang et al (2019)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Yes	Yes
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	There was a significant benefit of musicianship for F0DLs, ITDLs, and attentive tracking. Speech scores were not significantly different between the two groups. No musician advantage for understanding speech in background noise or talkers under a variety of conditions	Musicians performed better than non-musicians in the behavioral SIN task and showed enhanced cortical activity.	On BMLD the score in musicians was better than the non-musicians' group for the right ear for the SoNo condition, but there was no statistical difference between groups for the SπNo condition.
8	How precise are the results?	Yes	Yes	Yes
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes

11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Musician advantage in understanding speech in noise or other background sounds is not robust and is not readily replicated.	The positive effect of musical training on speech-in-noise perception extends to selective listening in a cocktail party setting.	This study found that musicians have benefits in signal-in-noise perception assessed with BMLD test has suggested that music training can be used to enhance signal-to-noise detection.

SI No.	CASP	Yoo and Bidelman(2019)	Escobar et al (2020)	Zhang et al (2021)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Trained musicians are superior to their non-musician peers in segregating speech from noise. Musicians had faster and better target speech recognition in the presence of up to almost eight simultaneous talkers and demonstrated less noise-related decline in performance with increasing masker counts relative to musically naïve listeners	Individuals with higher working memory capacities performed better than those with lower working memory capacities	Older musicians outperformed older non-musicians in auditory working memory and all SIN conditions (noise separation, noise colocation, speech separation, speech colocation), but such musician advantages were absent in young adults. Musical training offsets age-related speech perception deficit at adverse listening conditions by preserving auditory working memory.
8	How precise are the results?	Yes	Very Precise	Very Precise

9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	The findings confirm a relationship between musicianship and naturalistic cocktail party listening skills (stream segregation) but also suggest that cognitive factors may at least partially account for musicians' SIN advantage.	Listeners with better WM capacity, regardless of prior music training, have an advantage when listening to speech in background noise.	Musical training may be opted as an intervention to slow or attenuate cognitive decline and communication difficulty that often emerge later in life.

SI No.	CASP	Li et al (2021)
1	Did the study address a clearly focused issue?	Yes
2	Was the cohort recruited in an acceptable way?	Yes
3	Was the exposure accurately measured to minimize bias?	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes
6(a)	Was the follow up of subjects complete enough?	No
6(b)	Was the follow up of subjects long enough?	No
7	What are the results of this study?	Diffusivity values show both a significant group difference, as well as a significant partial correlation with SIN performance

8	How precise are the results?	Very Precise
9	Do you believe the results?	Yes
10	Can the results be applied to the local population?	Yes
11	Do the results of this study fit with other available evidence?	Yes
12	What are the implications of this study for practice?	Causal relationship between white matter plasticity and behavior is demonstrated.

Table 3.2

Results of qualitative assessment of the included studies- Short-term musical training

SI No.	CASP	Strait et al (2012)	Strait et al (2013)	Jain et al (2015)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes

5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	No	Yes	Yes
6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Musically trained children outperformed non-musicians on SIN perception when the two signals were spatially segregated, on auditory working memory, auditory and visual attention tasks. Less ABR degradation with the addition of background noise as compared to non-musicians.	Musically trained children demonstrated faster neural	Musical training improved the speech identification scores in noise.
8	How precise are the results?	Very Precise	responses to speech onsets and formant transitions in both quiet and noise conditions.	Very Precise

			Decreased quiet-to-noise timing delays and onset peak degradation was noted in musicians.	
9	Do you believe the results?	Yes	Very Precise	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Musical training in the developmental years demonstrates strengthened neural encoding of key acoustic ingredients for speech perception in challenging listening environments.	Yes	Short term musical training does improve speech perception in noise.

SI No.	CASP	Slater et al (2015)	Baskent D et al (2018)	Mc Cutcheon et al (2019)
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Yes	Yes
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	Children who were given training right away performed better than the group which received training a year later. More the hours of training better the HINT performance.	Mean performance was better for musicians than non-musicians, although differences were sometimes small.	No significant differences between the groups in SIN performance.
8	How precise are the results?	Very Precise	Yes	Yes
9	Do you believe the results?	Yes	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications	A minimum of 2 years of	The study suggests	Cognitive skills can be

	of this study for practice?	music instruction in children can be expected to generate modest but clinically meaningful gains in the ability to understand speech in noise.	within-domain and potential cross-domain effects for musical training in adolescents that appear to persist even when signals are degraded in their spectral as well as temporal aspects.	useful when dealing with the more cognitively demanding maskers (i.e., informational maskers) and spatial conditions (i.e., collocated) Stronger cognitive abilities could potentially provide benefits.

SI No.	CASP	Dubinsky et al 2019	Fleming et al (2019)	Raksha et al 2021
1	Did the study address a clearly focused issue?	Yes	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Yes	Yes	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No	No
6(b)	Was the follow up of subjects long enough?	No	No	No
7	What are the results of this study?	The group receiving musical training performed better in SPIN and pitch discrimination task.	6-months of musical training appeared to increase the response to speech in bilateral frontal (left Middle Frontal Gyrus and right Medial Frontal Gyrus), left parietal (left Supramarginal Gyrus), and right temporal (Superior/Middle Temporal Gyrus) cortical regions. Music training increased the response to speech in the posterior left MFG.	There is a significant amount of improvement with music training
8	How precise are the results?	Yes	Yes	Very Precise
9	Do you believe the	Yes	Yes	Yes

	results?			
10	Can the results be applied to the local population?	Yes	Yes	Yes
11	Do the results of this study fit with other available evidence?	Yes	Yes	Yes
12	What are the implications of this study for practice?	Choir singing can be used as an effective intervention to mitigate age-related losses in auditory perceptual abilities, in as short a time as 10 weeks.	Musical training in old age may be a fruitful and enjoyable means of countering aspects of age-related decline in SPIN perception.	Short term Carnatic music listening training can be used as a viable tool/strategy for enhancing the ability to understand speech-in-noise.

SI No.	CASP	Worschech F et al (2021)	Hennessey S et al (2021)
1	Did the study address a clearly focused issue?	Yes	Yes
2	Was the cohort recruited in an acceptable way?	Yes	Yes
3	Was the exposure accurately measured to minimize bias?	Yes	Yes
4	Was the outcome accurately measured to minimize bias?	Cannot tell	Cannot tell
5(a)	(a) Have the authors identified all important confounding factors?	Yes	Yes
5(b)	Have the authors taken account of the confounding factors in the design and/or analysis?	Yes	Yes

6(a)	Was the follow up of subjects complete enough?	No	No
6(b)	Was the follow up of subjects long enough?	No	No
7	What are the results of this study?	The results of the present study show that after 6 months of musical training, binaural SRTs improved in both groups. Women showed more improvement as compared to men. Marked improvement was noted in the left ear and right ear no improvement was seen.	There was an effect of music training on the auditory evoked potential N1 response in an Active and Passive Syllable-in Noise task. no behavioral differences were observed
8	How precise are the results?	Very Precise	Very Precise
9	Do you believe the results?	Yes	Yes
10	Can the results be applied to the local population?	Yes	Yes
11	Do the results of this	Yes	Yes

	study fit with other available evidence?		
12	What are the implications of this study for practice?	Musical engagement should be considered as an auditory rehabilitation strategy in hearing loss and communication problems	12 weeks of choir singing produces enhancements in early sound encoding, as seen in earlier latencies and larger amplitudes of the N1 response, in a group of older adults with mild subjective hearing loss