University of Connecticut
OpenCommons@UConn

Honors Scholar Theses
Honors Scholar Program

Spring 4-30-2019

The Impact of Musical Experience on Learning Non-native Speech Sounds

Brenna McNamee
brenna.e.mcnamee@gmail.com

Follow this and additional works at: https://opencommons.uconn.edu/srhonors_theses

Recommended Citation
McNamee, Brenna, "The Impact of Musical Experience on Learning Non-native Speech Sounds" (2019). *Honors Scholar Theses*. 624.
https://opencommons.uconn.edu/srhonors_theses/624

The Impact of Musical Experience on Learning Non-native Speech Sounds

Author: Brenna McNamee
Faculty Advisor: Susan Buraceski, Physiology & Neurobiology
Honors Advisor: Li Wang, Physiology & Neurobiology
Thesis Mentor: Emily B. Myers, Psychological Sciences and Speech, Language and Hearing Sciences
Date submitted: April 30, 2019

ABSTRACT

Adult non-native speech perception is susceptible to influence from a variety of factors, including those that go beyond the linguistic domain, such as musical experience. Several studies have been interested in the pronounced link between long-term music training and linguistic processing. The aim for the current study is to further investigate this link, and demonstrate the impact of musical experience on the learning of non-native speech sounds, particularly following sleep consolidation. In addition to looking at musical training experience, an objective measure of musical skills including melody, tuning, accent, and tempo was incorporated to allow for more specific analyses of the correlations between various musical skills and language acquisition. Data indicates that there is a significant positive correlation between participants' phonetic discrimination and performances with melody and tempo assessments following a night's sleep. This suggests that individuals who are more attuned to melody and tempo parameters of music are better able to demonstrate retention of discrimination of non-native phonetic sounds, particularly following sleep-dependent consolidation.

INTRODUCTION

Musical training is certainly a rich and versatile experience that has been found to generate positive changes in the brain. In the same manner that physical exercise impacts general body fitness, music acts as “a resource that tones the brain for auditory fitness” (Kraus and Chandrasekaran, 2010). As such, the musician’s brain has been used in several studies as a model for neuroplasticity, suggesting that long-term music training induces certain structural and functional alterations, specifically in the auditory system (Hannon and Trainor, 2007; Musacchia et al., 2007; Kraus and Chandrasekaran, 2010). Findings such as these demonstrate how musicians tend to tune their minds and bodies using cues around them - using tactile cues to produce musical notes, using auditory cues to detect pitch, and visuomotor cues to harmonize with the musicians around them. The musician’s brain has functional adaptations for pitch and timbre perception, in addition to structural adaptations for auditory, visual, motor, and cerebellar regions of the brain (Hannon and Trainor, 2007).

Due to such functional adaptations, the typical musician’s brain is remarkably different than the typical nonmusician’s brain. For instance, due to the high precision abilities of subcortical centers of the brain to encode acoustic characteristics of sound, researchers were able to demonstrate that musicians, compared to nonmusicians, have more robust auditory brainstem responses to musical stimuli. For instance, exhibited earlier brainstem responses to a speaker saying “da” and a cellist bowing a G note, than did the nonmusician controls (Musacchia et al., 2007). However, as musical training is multisensory in nature, these improved auditory skills that come with musical experience are not exclusively related to music (Magne et al., 2006; Wong et al., 2007; Foregard et al., 2008; Parbery-Clark et al., 2009). For instance, as determined by

Foregard et al. (2008), children who received three or more years of instrumental musical training outperformed their control counterparts on two tasks closely related to music, auditory discrimination and fine motor skills, as well as two tasks distantly related to music, vocabulary and nonverbal reasoning skills. As the study of transfer of cognitive performance from one domain to another has been widely examined, it may seem clear why musically trained children are better able to demonstrate a close correspondence between the training domain and the transfer domain, i.e., learning to play a musical instrument and developing fine motor skills and auditory discrimination skills. However, difficulties arise when attempting to demonstrate an instance in which the resemblance between the training domain and the transfer domain is much less obvious, such as learning to play an instrument and understanding mathematical problems (Barnett and Ceci, 2002). Yet, evidence still reports the positive correlation between instrumental musical training and other areas, such as spatial, verbal, and mathematical skills, as well as general IQ (Foregard et al., 2008). Thus, music plays a considerable role in a range of cognitive abilities and overall individual development.

Long-term music training can certainly have a positive impact on speech processing, perhaps facilitated by the fact that some cognitive and perceptual processes are shared between music and speech. The processing systems behind both language and music are rather complex, and imply relationships with numerous cognitive abilities, including attention, memory, logic and reasoning, auditory and visual processing, and so on. Both language and music are comprised of several levels of processing. While language is comprised of morphology, phonology, semantics, syntax, and pragmatics, music involves levels of rhythm, melody, and harmony (Besson et al., 2011). Along with this, in both music and speech, the sound sequences involved are hierarchically organized, with speech requiring syllables, words, and sentences, and music involving notes, beats, and phrases. Consequently, there is the potential for a strong similarity between the organization of speech and music from a general standpoint. Furthermore, both speech and musical sounds depend on the same fundamental acoustic parameters, including duration (the length of time of the sound), frequency (how high or low on the musical scale a sound is), intensity (the strength of the sound), and timbre (the pitch and loudness of the sound) (Francois and Schön, 2011). In one study by Intartaglia et al. (2017), subcortical electrophysiological responses to an English syllable [thae] were recorded from three groups of participants: native English speakers, non-native French nonmusicians, and non-native French musicians. Strikingly, the results indicated that subcortical responses to non-native sounds in musicians resembled the neural processing of native speakers, suggesting that long-term musical training may allow one to compensate for the lack of language experience (Intartaglia et al., 2017). As such, researchers have taken quite an interest in the intimate relationship between speech and music, and have examined this relationship from several different perspectives.

Several brain imaging studies have investigated the involvement of a working memory with regards to musical tasks (i.e., pressing a button to indicate whether two tones from a sequence presented are the same or different), all demonstrating greater neural activation of the superior temporal gyrus (the primary auditory cortex responsible for processing sound) and longer immediate memory spans in musicians compared to nonmusicians (Tierney et al., 2008; Schulze et al., 2009). In attempts to further account for the differences between musicians and nonmusicians, the Tierney et al. (2008) study used skilled musicians, as well as subjects from comparison groups. The comparison groups included skilled gymnasts to account for another highly structured activity involving repeated practice of specific motor movements, and daily video game players to account for a group that practices a skill daily involving control of fine finger movements and focused attention. By comparing the performance of skilled musicians on a test of verbal memory span to the performance of the two nonmusician groups of gymnasts and video game players, differences in sequence memory between the groups could be measured. Such studies suggest that musicians display longer immediate memory spans than their control groups of nonmusicians, specifically with conditions involving auditory presentation (Tierney et al., 2008). Thus, musicians are able to hold more information, sometimes for longer periods of time, in auditory memory compared to nonmusicians. Similar studies have found that prolonged musical training enhanced selective auditory attention and strengthened working memory (Besson et al., 2011; Strait and Kraus, 2011). For instance, in the Strait and Kraus study, researchers deduced that musicians exhibited strengthened neural networks for selective auditory attention, indicating a potential benefit for individuals who experience a wide range of attention-based language, listening, and learning impairments, by acting as a preventive measure against such impairments and promoting habilitation thereafter. Based on such evidence, it is certainly conceivable that musical training can tune the brain's executive control network for auditory processing in areas that advance far beyond the musical domain.

In addition to the advantages of musical training on memory, recent studies have also investigated the effects of long-term music training associated with advantages that extend to other cognitive abilities, such as linguistic processing. For example, musicians appear to demonstrate stronger neural encoding of speech sounds compared to nonmusicians (Wong et al., 2007; Chandrasekaran et al., 2009; Kraus and Chandrasekaran, 2010). Through the examination of brainstem encoding of linguistic pitch, musicians demonstrate more prominent subcortical activation in response to non-native speech sound stimuli than nonmusicians, implying that long-term musical training can influence basic sensory circuitry. In addition to this, neuropsychological evidence reveals that certain brain regions thought to be language-specific (i.e., the inferior frontal gyrus, Broca's area) are additionally involved in musical processing (Maess et al., 2001; Levitin and Menon, 2003; Tillmann et al., 2003). Results such as these provide potential neurophysiological explanations for musicians' more robust language-learning ability over their nonmusician counterparts. Along with this, musicians outperform nonmusicians on tasks involving recognizing speech embedded in noise (Parbery-Clark et al., 2009; Strait and Kraus, 2011). Due to musicians' increased awareness of tempo changes, they demonstrate higher accuracy at rate-varied vowel length perception, compared to nonmusicians (Cooper et al., 2017). This particular study investigated the effects of musical experience on the normalization of speaking rate regarding the perception of non-native speech sound contrasts. Results revealed that non-native musicians performed similarly to native nonmusician listeners, and were able to more accurately identify and discriminate between vowel length distinctions across variations in speaking rates. Thus, musicians' attunement to different rhythmic and temporal stimuli in music can be transferred to promote the normalization of speaking rate and perception of non-native temporal speech sound contrasts. Musical experience also appears to benefit listeners with tasks such as categorizing lexical pitch patterns, suggesting that musicians demonstrate enhanced cognitive processing with regards to categorical decisional judgements compared to nonmusicians (Smayda et al., 2015; Wu et al., 2015). More specifically, musicians tend to use a multidimensional optimal decision strategy, incorporating both pitch height and pitch direction when making categorization judgements. Nonmusicians tend to use a unidimensional strategy, in which their decision is based solely on one dimension, typically pitch height. This suggests that musicians have more advanced cognitive processing strategies to support their judgements of varying speech categories. Moreover, musical training has been associated with enhanced perception and production of non-native speech sounds (Slevc and Miyake, 2006; Chobert and Besson, 2013). Even when controlling for other factors, long-term musical training predicted second-language proficiency, in terms of both perception and production. A common explanation of this enhanced phonological ability is due to the fact that musicians have a trained ear for analyzing and discriminating "foreign" sounds such as musical stimuli, and as such may be better equipped than nonmusicians to learn various aspects of a non-native language, especially regarding pronunciations of non-native speech sounds. In other words, through formal musical training musicians are often taught to replicate a singer's note onto their respective instrument, in a playing-by-ear fashion. Through such practice, musicians learn to improvise, allowing them to play along with the chords of other musicians around them, or replicate songs heard on the radio, without ever seeing the sheet music. Thus, it is not surprising that trained musicians would also be able to pick up on various nuances of language, such as speaker intonation and variations in pronunciation, that are critical for learning foreign languages. As such, relative to nonmusicians, musicians exhibit stronger non-native speech discrimination (Gottfried et al., 2004; Marie et al., 2011) and overall foreign language learning (Gottfried and Riester, 2000; Alexander et al., 2005; Wong and Perrachione, 2007; Lee and Hung, 2008). Based on such results, it is not surprising that the experience of learning and perceiving one category of sounds, i.e. music, can facilitate the learning and perception of another category of sounds, i.e. speech.

However, despite the abundance of research on musical training and linguistic processing, relatively no prior work has dealt with the effects of musicianship on overnight consolidation of speech learning. Particularly, research has not yet investigated the impact of sleep, in addition to the benefits of musical experience, on the ability to process non-native speech contrasts. Since musical training appears to be related to improvements in other cognitive abilities, as demonstrated by the numerous studies previously mentioned, such musical experience is particularly relevant in perceiving non-native speech contrasts. Thus, the latest question at hand is whether there is any difference in musicians' ability to retain non-native speech information via overnight consolidation. Since sleep has been deemed beneficial for overnight consolidation and non-native language learning (Earle and Myers, 2015a), it is plausible that musicians can even further benefit from sleep following learning.

In the current study, I hoped to investigate these issues by comparing how musicians and nonmusicians perceive non-native speech contrasts. In doing so, I was able to determine the extent to which long-term musical training may transfer to the linguistic domain to better facilitate the perception of non-native speech sounds. Specifically, the current study compared the performance of musicians and nonmusicians, all of which are native American English speakers, on their perception of the Hindi dental retroflex voiced stop contrast. Due to the finding that variability in training can be considerably more difficult for learners that lack adequate perceptual abilities (Amitay et al., 2005; Antoniou and Wong, 2015; Perrachione et al., 2011), I chose to provide both groups with a rather consistent training, in which stimuli was presented in a “Two Vowel Blocked Training” manner, in which a single vowel context was presented at a time (/u/ and /i/) and spoken by a single talker. In doing so, both musicians and nonmusicians will be learning the dental and retroflex stops in both the context of /u/ (i.e., /d̪ug/ and /ɖug/) and /i/ (/d̪ig/, and /ɖig/). This lack of variability in training was chosen in order to increase the likelihood that all participants, musicians and nonmusicians alike, would benefit from training. In the current study, I intended to analyze whether or not musical experience will further benefit a participant, compensating for the introduced variability, and thus allow them to better demonstrate overnight gains.

MATERIALS AND METHODS

Participants.

This study included a total of 24 participants (3 male, 21 female, ages 18 to 22). All participants were recruited through the University of Connecticut’s Daily Digest posting and flyers throughout the University of Connecticut campus. Participants were paid $10 per hour for their participation. The study was advertised to strictly only native American-English speakers. All participants reported normal hearing and vision, and did not report any history of speech or language disorders. Additionally, all participants gave informed consent to take part in this study.

Of the 24 participants, 10 were classified as musicians, and the other 14 were nonmusicians. Musicians were classified based on a self-report of at least 7 years of musical training.

Stimuli.

The audio and visual stimuli used in this study were presented using E-Prime 2.0 [Psychology Software Tools (2012), Pittsburgh]. All audio stimuli were presented at a comfortable listening level via over-the-ear headphones. Participant responses were indicated via keys on the computer keyboard. The audio stimuli consisted of acoustically distinct recordings of /d̪ug/, /ɖug/, /d̪ig/, and /ɖig/, all recorded by a single speaker, a native Hindi female. This same stimulus set was previously used in Fuhrmeister and Myers (2017), therefore, the reader may refer to that article in order to find a more detailed description of the stimulus creation.

Training and assessments.

Training. Prior to training, participants were familiarized with both sounds by corresponding each to a novel visual stimulus.

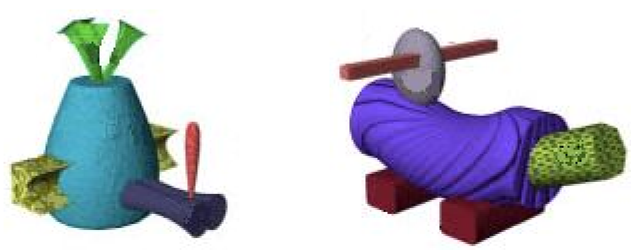


Figure 1. Representation of novel visual stimuli used in training and testing.

During this familiarization, each of the above novel visual stimuli were presented on screen separately, while participants listened to different recordings of each corresponding word. During the training task that followed, the two novel visual stimuli both appeared on the screen, side by side. Participants were trained on the dental and retroflex tokens first in the /u/ vowel context (/d̪ug/ and /ɖug/, respectively), and then trained on the same dental and retroflex tokens in the /i/ vowel context (/d̪ig/ and /ɖig/, respectively), in a “blocked training” manner.

Participants listened to words beginning either with the dental or retroflex sound and were asked to pair the given word with the correct visual stimulus on screen. During training, participants received feedback for each trial ("Correct" or "Incorrect"). Training consisted of 200 trials for each vowel context, /u/ and /i/, for a total of 400 trials, with 2-minute breaks halfway through each. The reader may refer to Figure 2 for a visual representation of the ordering of tasks.

Discrimination task. In order to assess discrimination of the trained Hindi sounds, participants were presented with a task consisting of either two "same" tokens beginning with speech sounds from the same category yet from different audio files of the same sound, or two "different" tokens beginning with speech sounds from different categories. Following the familiarization task, and prior to training, participants received a discrimination pre-test consisting of 128 trials. During this pre-test, participants were presented with a pair of two sounds, beginning with either dental or retroflex consonants, and asked to determine whether the sounds are the "same" or "different" by clicking different keys on the computer keyboard. Trials for each of the vowel contexts, /u/ and /i/, were randomized. Following training, participants performed a discrimination posttest, identical to the discrimination pre-test procedure.

Identification task. The identification assessment consisted of 50 trials and was identical to the training procedure. However, feedback was not provided during the identification test.

Musical ability assessment. In addition to a self-report musical experience questionnaire, each participant's musical ability was assessed using the Profile of Musical Perception Skills (mini-PROMS) (Zentner and Strauss, 2016). The mini-PROMS is a 15-minute computerized test consisting of four parts - melody perception, tune detection, accent perception in a rhythmic sequence, and a speed test to measure tempo skills. This method allows a more objective definition of musicianship to be used, enabling the recognition of untrained “nonmusicians” that appear to possess musical skills (referred to as “musical sleepers”), as well as those that have limited musical ability despite extensive musical training (Strauss et al., 2015). Additionally, the different subtests of PROMS (i.e., melody, tuning, accent, and tempo) allow for greater specificity in terms of analyses, and offers greater interpretations than are available when basing musicianship solely off of self-report. Previous studies have provided evidence in support of the internal consistency and reliability of the PROMS assessment (Kunert et al., 2016; Law and Zentner, 2012; Zentner and Strauss, 2017). Most recently, Zentner and Strauss (2017) determined that correlating total PROMS score with external indicators of musical training and proficiency (i.e., years of musical training, level of musical qualification, and self-reported musicianship status) yielded significant positive correlation ($p < 0.001$). Thus, the mini-PROMS is a reliable and valid tool for the assessment of musical perception skills.

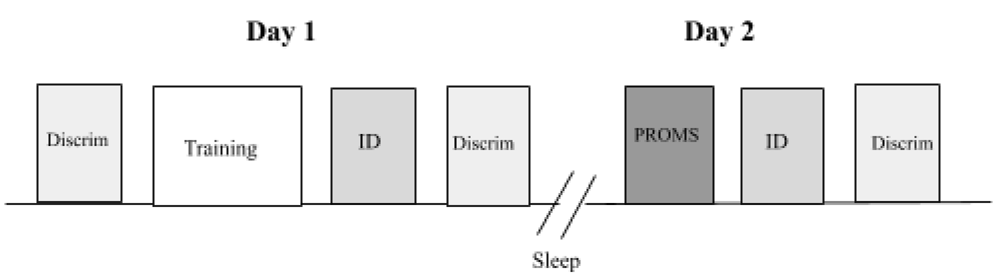


Figure 2. Training and testing schedule for each participant.

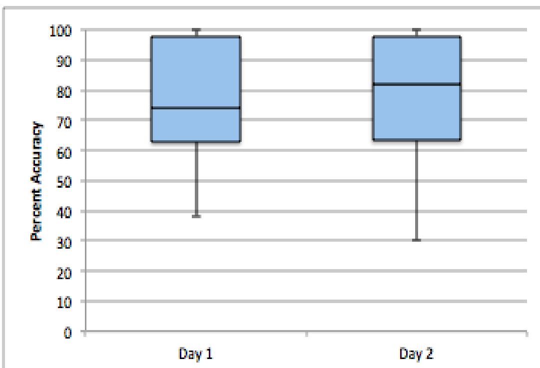
Schedule.

All participants participated in two sessions, on two consecutive days. Session 1 consisted of a baseline discrimination task, following by training, and identification and discrimination posttests. Session 2 consisted of identification and discrimination reassessments, as a measure of retention of learning following the overnight interval. Additionally, the mini-PROMS assessment was administered during Session 2.

RESULTS AND ANALYSES

Identification task.

(A)



(B)

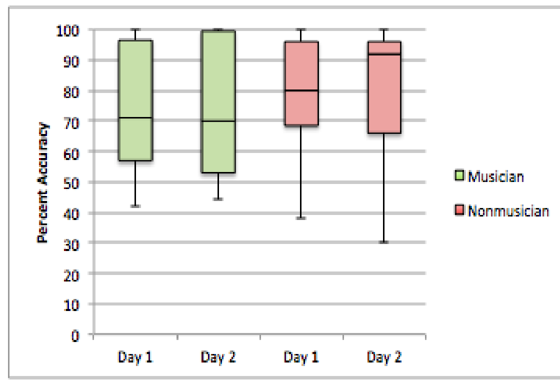


Figure 4. (A) Shows percent accuracy in identification posttest assessments performed on Day 1 and for reassessment on Day 2. Data represents the entire participant pool. (B) Shows percent accuracy in identification posttest assessments for musicians, with musical experience of at least 7 years (green), and nonmusicians (red).

To assess changes in identification performance over time, percent accuracy scores were obtained for Day 1 and Day 2 posttests. For the entire participant pool, there was very little change in identification performance from Day 1 to Day 2. Welch two sample t-tests were performed in order to measure overnight improvement (i.e., Day 1 posttest scores were subtracted from the Day 2 posttest scores) in the musician and nonmusician groups: $t = -1.2531$, p-value = 0.2234. Based on such t-tests, the two groups did not show significant differences in overnight improvement. This lack of significant difference suggests that neither musicians or nonmusicians greatly benefitted from sleep-dependent consolidation.

Discrimination performance.

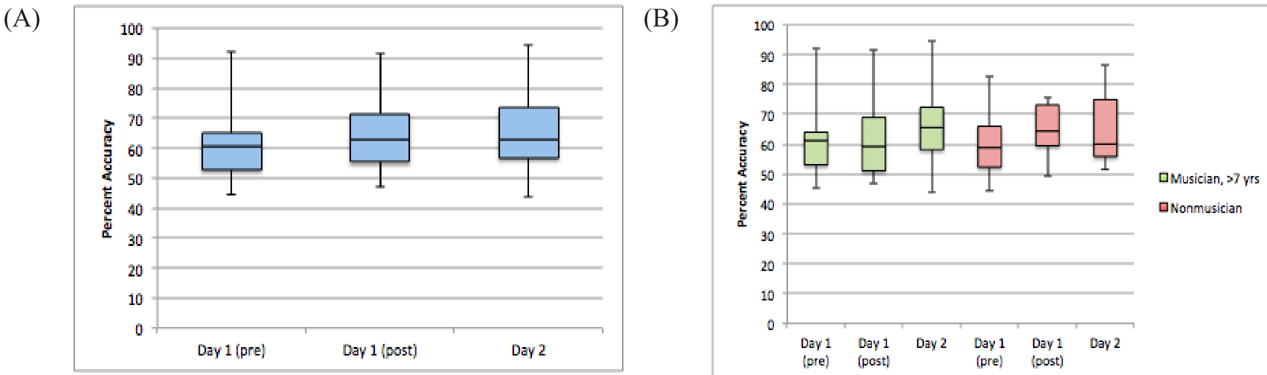


Figure 3. (A) Shows percent accuracy in discrimination assessments performed before training (Day 1 pre), following training on the first day (Day 1 post), and for reassessment on Day 2. Data represents the entire participant pool. (B) Shows percent accuracy in discrimination assessments for musicians, with musical experience of at least 7 years (green), and nonmusicians (red).

To assess changes in discrimination performance, percent accuracy scores were obtained for the Day 1 pre-test, Day 1 posttest, and Day 2 posttest. In order to calculate change in performance within session (i.e., to measure how much participants benefited from training), we subtracted the pre-test score from the Day 1 posttest score. For the entire participant pool, there was no significant increase in percent accuracy for the discrimination task during Day 1, or during the overnight interval, as demonstrated in Figure 3A. To determine differences in these discrimination percent accuracy scores from baseline to Day 1 posttest between musicians and nonmusicians, a Welch two sample t-test was performed: $t = -1.3895$, p-value = 0.1795. Thus, there was no significant difference between musicians and nonmusicians in their ability to learn discrimination scores after training. Because we were interested in how musical training might differentially affect consolidation following a night's sleep, we performed t-tests to measure overnight improvement in both the musician and nonmusician groups: t = 0.49257, p-value = 0.1416. Based on such results, neither group showed significant differences in overnight improvement. This lack of significant difference suggests that both musicians and nonmusicians benefitted comparably from training and from sleep consolidation.

PROMS test.

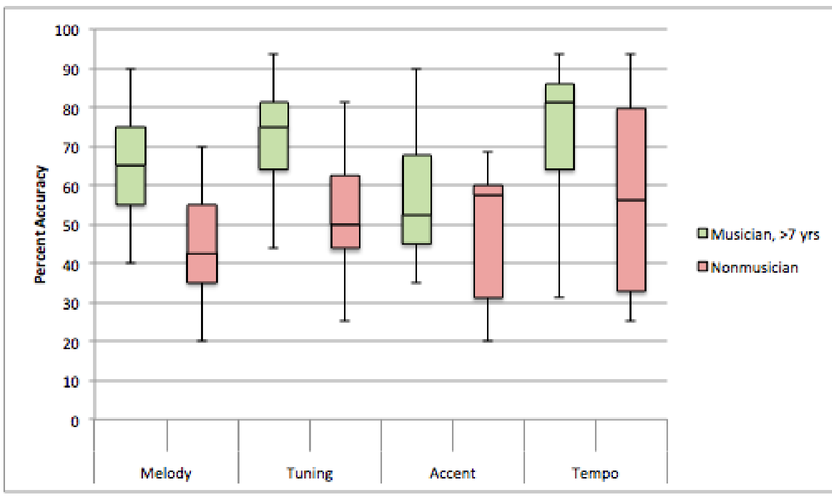


Figure 5. Average percent accuracy scores for each PROMS category, for both musicians and nonmusicians.

To further assess musical ability, percent accuracy scores from each of the four PROMS categories - melody, tuning, accent, and tempo - were obtained and averaged for each group. As expected, musicians outperformed nonmusicians. Two sample t-tests were performed to demonstrate the differences in performance between musicians and nonmusicians for each PROMS category and yielded the following results:

	Melody	**Tuning**	**Accent**	**Tempo**
t	3.4119	3.1847	1.2769	1.667
p-value	0.003022*	0.004424*	0.2168	0.1099

Figure 6. Welch two sample t-test scores for PROMS categories. Asterisk (*) indicates that the p-value is < 0.05, and is therefore significant.

Based on the t-test scores, Accent and Tempo scores did not vary significantly between musicians and nonmusicians. However, there were significant differences in performance between musicians and nonmusicians for both Melody (t = 3.4119, p-value = 0.003022), and Tuning (t = 3.1847, p-value = 0.004424). Because of the established similarities between parameters of both language and music (Francois and Schön, 2011), in addition to the previously investigated accuracy and reliability of the PROMS assessment (Zentner and Strauss, 2017), it is conceivable that a larger participant pool may additionally yield significant differences in the Accent and Tempo scores.

Correlations between musical ability and non-native speech learning.

In order to further investigate the relationships between the non-native learning assessments (i.e., discrimination and identification) and musical experience, both in terms of numbers of reported years of musical training and for each individual PROMS category (i.e., melody, tuning, accent, and tempo), a correlation matrix was generated.

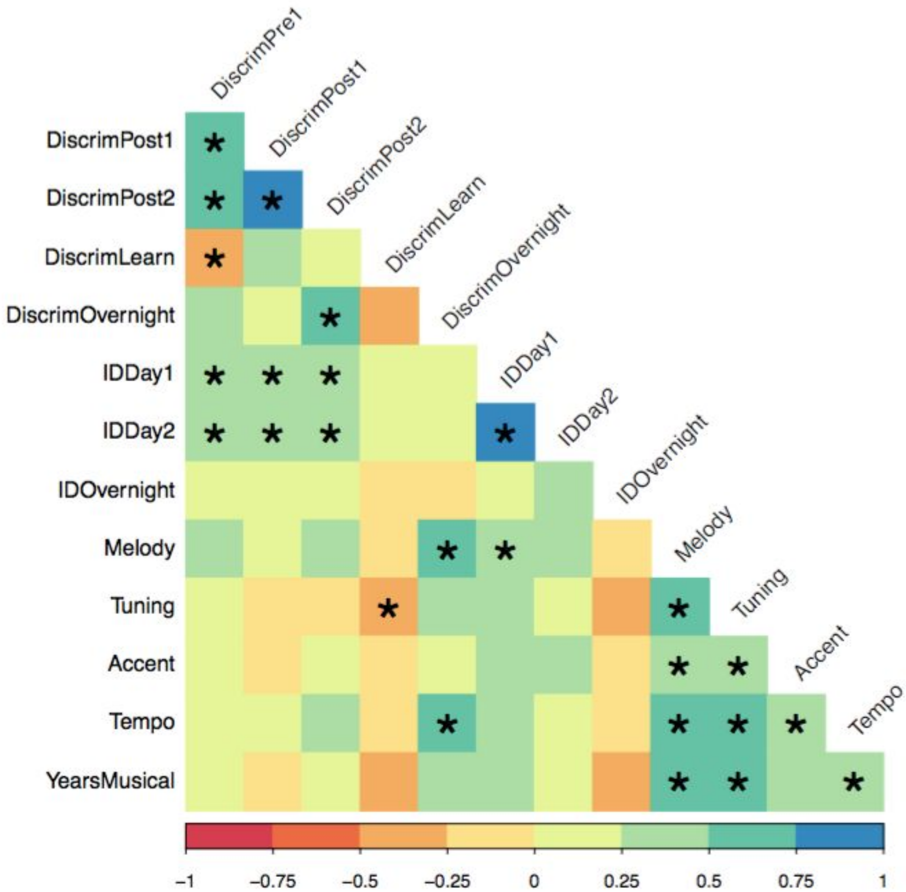


Figure 7. Correlation matrix for entire data set. Colors closer to blue represent a positive correlation, while colors closer to red represents a negative correlation. Significant correlations are marked with an asterisk (*). DiscrimLearn refers to difference in performance from discrimination pre-test (baseline measurement) to the discrimination posttest of Day 1. DiscrimOvernight and IDOvernight refer to difference in performance from discrimination and identification posttests, respectively, from Day 1 to Day 2. YearsMusical refers to the total number of years of musical training.

Correlation of non-native learning assessments. As indicated, and as expected, several significant correlations exist between the non-native learning assessments. Not surprisingly, performing well on the baseline discrimination assessment predicts a strong performance during the discrimination posttests. Likewise, performing well during the identification posttest of Day

1 predicts a strong performance on the identification posttest the following day. The significant negative correlation between performance of the discrimination pretest of Day 1 and the difference in performance from the discrimination pretest and the discrimination posttest of Day 1 (i.e., DiscrimLearn), can be explained by the fact that the higher one scores on the pretest, the closer that individual is to a perfect score, and thus the less room there is for the individual to gain as a result of learning.

Correlation of musical assessments. Similarly to the phonetic learning results, the musical assessments exhibited several significant correlations among each other. Performing well on any of the four PROMS categories predicts a strong performance on each of the other PROMS categories. Additionally, there is a significant positive correlation between scoring well on each subtest of the PROMS assessment and total years of musical training, as expected, and duplicating the effects of the group-wise comparison of musicians vs. non-musicians.

Correlation between phonetic learning and music. The key question in this study is the degree to which measures of musical skill predict measures of phonetic learning. As the observed correlations between the non-native learning assessments and the correlations between the musical assessments were expected, the more interesting results appear when looking at the correlation between phonetic learning and music together. As indicated by the correlation matrix, there is a significant positive correlation between melody scores and the overnight change in discrimination scores. Likewise, there is a significant positive correlation between tempo scores and discrimination scores following overnight consolidation. Thus, participants who score higher on both the melody and tempo subtests of the PROMS assessment are more likely to demonstrate stronger retention of learning following a night's sleep. As shown in Figure 7, there is a significant negative correlation between tuning scores and the size of the learning effect (posttest 1- pre-test) in discrimination. This was an unanticipated finding that cannot yet be interpreted.

It is important to note that the only correlations drawn between PROMS scores were with overnight changes, and not with the raw scores at any time point. Thus, this study did not replicate the finding that individuals with musical ability are more sensitive to non-native contrasts, or that they are able to learn more within a session. However, the new finding of this study is that there is a relationship between musical ability and overnight retention.

DISCUSSION AND CONCLUSIONS

The present study examined whether or not long-term musical training would facilitate native English speakers' ability to perceive distinctions in the Hindi dental-retroflex voiced stop contrast, and if musicians would thus demonstrate improved overnight consolidation compared to nonmusicians. Results suggest that the number of years of musical training does not yield significant differences in non-native language retention. However, when looking at a more objective measure of musical ability, such as with the PROMS assessment, significant positive correlations were found between melody and tempo scores and the demonstration of discrimination of non-native speech contrasts following overnight consolidation.

It is conceivable that the positive association between certain musical components and non-native language learning may be due to a superior level of attentional control that is often attained through musical training, and which thus benefits both musical and linguistic processing (Kolinsky et al., 2009). However, because our results saw strong effects on the discrimination overnight change from the Day 1 posttest to the Day 2 posttest, this may suggest that auditory memory plays a more prominent role.

While this is merely a pilot study and data reflects only a small pool of participants, some limitations exist within this experiment. Previous work has found that increased interference from one's native language hinders a participant's overall improvement (Earle and Myers, 2015b). Results from Earle and Myers (2015b) suggested that participants trained in the evening were better able to recognize speech sounds coming from speakers other than those they were trained on, and thus demonstrated greater generalization across speakers than participants trained in the morning. This evidence suggested that sleep consolidation facilitates speaker generalization in the discrimination of non-native speech sounds, and that exposure to one's native language throughout the day interferes with their ability to learn non-native sounds following sleep. Thus, for the current study, since participants were only required to come into the lab on two consecutive days with no strict control over the time of day they came in, it is likely that there was some level of interference from the participant's native language throughout the period between each session. Because participants were not trained on a stricter schedule, involving only evening hours for Session 1 and only early morning hours for Session 2, it is plausible that measurement of sleep consolidation was not properly controlled. Future studies should incorporate a more rigid training and testing schedule in order to limit native language interference and better control measures of sleep consolidation. Along with this, a sleep questionnaire was administered, in which participants self-reported the number of hours of sleep they received over the course of the night, and whether or not they typically have difficulties falling or staying asleep. Thus, a stronger, more reliable sleep measurement tactic could be employed for future studies. Utilizing a sleep-tracking device would eliminate the need to rely on self-report of hours slept and could more accurately measure the quality of sleep. More fine-grained sleep measures such as this could ensure more accurate analyses of whether performance improvements are due specifically to sleep and overnight consolidation or due to other factors.

Still, further research still needs to be done in order to better understand the link between musical experience and speech processing. Another open question that remains is whether the correlation between PROMS subtest measures and overnight improvement in discrimination is specifically related to sleep-dependent consolidation, or just retention of learned auditory information in general. It is reasonable that musicians simply have better, or more accurate, auditory memories than their nonmusician counterparts, as demonstrated by prior studies (Wong et al., 2007; Chandrasekaran et al., 2009; Kraus and Chandrasekaran, 2010). Administration of more controlled and reliable measurements of the amount and quality of sleep, as previously explained, could certainly help to answer this question.

Future studies may lay more focus on the type of musician at hand, such as those who play different families of instruments, those who are self-taught, or those that are considered professional musicians, and measure the learning patterns amongst these differing categories of musicians. Results from such studies may indicate that different types of musical training are deemed more valuable regarding speech processing and, more specifically, learning non-native speech contrasts. There is increasing evidence supporting the idea that skill transfer from extensive musical training may help to restore neural functioning and and language processing in individual suffering with conditions including dyslexia, dementia, or autism spectrum disorder (Chanda and Levitin, 2013). Along with this, it may be that exposure to music in general may be beneficial for speech processing. For example, it may be possible that individuals who do not regularly play an instrument, but report regularly (and actively) listening to music, may show enhanced performance compared to other nonmusicians who do not have the same level of exposure to music. As our results demonstrated, there were no significant measures of speech ability when grouping participants based on reported number of years of musical training, but there were significant measures of speech ability when using a more continuous measure of skill (i.e., the PROMS assessment). Some participants ended up being "musical sleepers" who had little to no prior musical training experience, yet performed rather well on the various PROMS subtests. In this study, two participants were noted as musical sleepers. In contrast, other participants reported extensive years of musical training, yet did not score well on the PROMS subtests. Four participants categorized as musicians, based on having more than 7 years of musical training, scored poorly on the PROMS assessment. Therefore, it is evident that experience does not equal skill.

Additionally, an interesting addition may be to reverse this experiment in a sense, by examining the effects of long-term linguistic experience on distinguishing acoustic features of music, such as pitch, tone, and so on. Considering the relationship between music and speech sounds, and the fact that musicians show advantages in speech processing, it is conceivable that linguists may demonstrate advantages in music processing. Comparing novice musicians who are monolingual to those who are bilingual could yield interest results and further delve into the link between music and language processing.

REFERENCES

Alexander, J.A., Wong, P.C., and Bradlow, A.R. (2005). Lexical tone perception in musicians and
nonmusicians. *Proceedings of Interspeech, Lisbon,* 397-400.

Amitay, S., Hawkey, D.J.C., and Moore, D.R. (2004). Auditory frequency discrimination learning is affected by stimulus variability. *Perceptions & Psychophysics, 67,* 691-698. https://doi.org/10.3758/BF03193525.

Antonious, M., and Wong, P.C.M. (2015). Poor phonetic perceivers are affected by cognitive load when resolving talker variability. *The Journal of the Acoustical Society of America, 138,* 571-574. https://doi.org/10.1121/1.4923362.

Barnett, S.M., and Ceci, S.J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128,* 612-637. https://doi.org/10.1037//0033-2909.128.4.612.

Besson, M., Chobert, J., and Marie, C. (2011). Transfer of training between music and speech: common processing, attention, and memory. *Frontiers in Psychology, 12.* https://doi.org/10.3389/fpsyg.2011.00094.

Chanda, M.L., and Levitin, D. (2013). The neurochemistry of music. *Trends in Cognitive Sciences, 17,* 179-193. https://doi: 10.1016/j.tics.2013.02.007.

Chandrasekaran, B., Krishnan, A., and Gandour, J. (2009). Relative influence of musical and linguistic experience on early cortical processing of pitch contours. *Brain and Language, 108,* 1-9. https://doi.org/10.1016/j.bandl.2008.02.001.

Chobert, J. and Besson, M. (2013). Musical Expertise and Second-Language Learning, *Brain Science, 3,* 923-940. https://doi.org/10.3390/brainsci3020923.

Cooper, A., Wang, Y., and Ashley, R. (2017). Thai Rate-Varied Vowel Length Perception and the
Impact of Musical Experience. *Language and Speech, 60,* 65-84. https://doi.org/10.1177/0023830916642489.

Earle, F.S. and Myers, E.B. (2015a). Overnight consolidation promotes generalization across talkers in the identification of nonnative speech sounds. *The Journal of the Acoustical Society of America, 137,* 91-97. https://doi.org/10.1121/1.4903918.

Earle, F.S. and Myers, E.B. (2015b). Sleep and native language interference affect non-native speech sound learning. *Journal of Experimental Psychology, 41,* 1680-1695. https://doi.org/10.1037/xhp0000113.

Francois, C., and Schön, D. (2011). Musical Expertise Boosts Implicit Learning of Both Musical and Linguistic Structures. *Cerebral Cortex, 21,* 2357-2365. https://doi.org/10.1093/cercor/bhr022.

Foregard, M., Winner, E., Norton, A., and Schlaug, G. (2008). Practicing a musical instrument in childhood is associated with enhanced verbal ability and nonverbal reasoning. *PLOS ONE, 3*. https://doi.org/10.1371/journal.pone.0003566.

Fuhrmeister, P. and Myers, E.B. (2017). Non-native phonetic learning is destabilized by exposure
to phonological variability before and after training. *The Journal of the Acoustical Society of America, 142.* https://doi.org/10.1121/1.5009688.

Gottfried, T.L. and Riester, D. (2000). Relation of pitch glide perception and Mandarin tone identification. *The Journal of the Acoustical Society of America, 108,* 2604. https://doi.org/10.1121/1.4743698.

Gottfried, T.L., Staby, A.M., and Ziemer, C.J. (2004). Musical experience and Mandarin tone discrimination and imitation. *The Journal of the Acoustical Society of America, 115,* 2545. https://doi.org/10.1121/1.4783674.

Hannon, E.E. and Trainor, L.J. (2007). Music acquisition: effects of enculturation and formal training on development. *Trends in Cognitive Sciences, 11,* 466-472. https://doi.org/10.1016/j.tics.2007.08.008.

Intartaglia, B., White-Schwoch, T., Kraus, N., and Schon, D. (2017). Music training enhances the
automatic neural processing of foreign speech sounds. *Scientific Reports, 7,* 12631. https://doi.org/10.1038/s41598-017-12575-1.

Janata, P., Tillman, B., and Bharucha, J.J. (2002). Listening to polyphonic music recruits domain-general attention and working memory circuits. *Cognitive, Affective, & Behavioral Neuroscience, 2,* 121-140.

Kolinsky, R. Cuvelier, R., Goetry, V., Peretz, I., and Morais, J. (2009). Music Training Facilitates
Lexical Stress Processing. *Music Perception: An Interdisciplinary Journal, 26,* 235-246. https://doi.org/10.1525/mp.2009.26.3.235.

Law, L. and Zentner, M. (2012). Assessing musical abilities objectively: construction and validation of the Profile of Music Perception Skills. *PLoS One, 7,* e52508. https://doi.org/10.1371/journal.pone.0052508.

Lee, C.Y. and Hung, T.H. (2008). Identification of Mandarin tones by English-speaking musicians and nonmusicians. *The Journal of the Acoustical Society of America, 124,* 3235-3248. https://doi.org/10.1121/1.2990713.

Kraus, N., and Chandrasekaran, B. (2010). Music training for the development of auditory skills. *Nature Reviews Neuroscience, 11,* 599-605. https://doi.org/10.1038/nrn2882.

Kunert, R., Willems, R.M., and Hagoort, P. (2016). An independent psychometric evaluation of the PROMS measure of music perception skills. *PLoS One, 11,* 103. https://doi: 10.1371/journal.pone.0159103.

Levitin, D.J., Menon, V. (2003). Musical structure is processed in “language” areas of the brain: A possible role for Brodmann area 47 in temporal coherence. *NeuroImage, 20,* 214-2152.

Maess, B., Koelsch, S., Gunter, T.C., and Friederici, A.D. (2001). Musical syntax is processed in Broca's area: An MEG study. *Nature Neuroscience, 4,* 540-545.

Magne, C., Schön, D., and Besson, M. (2006). Musician children detect pitch violations in both music and language better than nonmusician children: behavioral and electrophysical approaches. *Journal of Cognitive Neuroscience, 18,* 199-211. https://doi.org/10.1162/089892906775783660.

Marie, C., Delogu, F., Lampis, G., Belardinelli, M.O., and Besson, M. (2011). Influence of musical expertise on segmental and tonal processing in Mandarin Chinese. *The Journal of the Cognitive Neuroscience, 23,* 2701-2715. https://doi.org/10.1162/jocn.2010.21585.

Musacchia, G., Sams, M., Skoe, E., and Kraus, N. (2007). Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. *Proceedings of the National Academy of Sciences of USA, 104,* 15894-15898. https://doi.org/10.1073/pnas.0701498104.

Parbery-Clark, A., Skoe, E., Lam, C., and Kraus, N. (2009). Musician enhancement for speech-in-noise. *Ear and Hearing, 30,* 653-661. https://doi.org/10.1097/AUD.obo13e3181b412e9.

Perrachione, T. K., Lee, J., Ha, L.Y.Y., and Wong, P.C.M. (2011). Learning a novel phonological

contrast depends on interactions between individual differences and training paradigm design. *The Journal of the Acoustical Society of America, 130*, 461-472. https://doi.org/10.1121/1.3593366.

Psychology Software Tools, Inc. [E-Prime 2.0]. (2012). https://www.pstnet.com

Schulze, K., Gaab, N., and Schlaug, G. (2009). Perceiving pitch absolutely: comparing absolute and relative pitch possessors in a pitch memory task. *BMC Neuroscience, 10*, 106. https://doi.org/10.1186/1471-2202-10-106.

Slevc, L.R., and Miyake, A. (2006). Individual Differences in Second-Language Proficiency: Does Musical Ability Matter? *Psychological Science, 17,* 675-681. https://doi.org/10.1111/j.1467-9280-2006-01765.x.

Smayda, K.E., Chandrasekaran, B., and Maddox, W.T. (2015). Enhanced cognitive and perceptual processing: a computation basis for the musician advantage in speech learning. *Frontiers in Psychology, 6,* 682. https://doi.org/10.3389/fpsyg.2015.00682.

Strait, D.L. and Kraus, N. (2011). Can you hear me now? Musical training shapes functional brain networks for selective auditory attention and hearing speech in noise. *Frontiers in Psychology, 2,* 1-10. https://doi.org/10.3389/fpsyg.2011.00113.

Strauss, H., Shakeshaft, N., Plomin, R., and Zentner, M. (2015). Introducing the Mini-Proms: A short and objective measure of musical ability. *International Convention of Psychological Science, Amsterdam.* https://www.uibk.ac.at/psychologie/fachbereiche/pdd/personality_assessment/research/download/minipromsposter_2015.pdf.

Tierney, A.T., Bergeson-Dana, T.R., and Pisoni, D.B. (2008). Effects of early musical experience on auditory sequence memory. *Empirical Musicology Review, 3,* 178-186.

Tillmann, B., Janata, P., and Bharucha, J.J. (2003). Activation of the inferior frontal cortex in musical priming. *Cognitive Brain Research, 16,* 145-161.

Wong, P.C.M. and Perrachione, T.K. (2007). Learning pitch patterns in lexical identification by native English-speaking adults. *Applied Psycholinguistics, 28,* 565-585. https://doi.org/10.1017/S0142716407070312.

Wong, P.C., Skoe, E., Russo, N.M., Dees, T., and Kraus, N. (2007). Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience, 10,* 420-422. https://doi.org/10.1038/nn1872.

Wu, H., Ma, X., Zhang, L., Liu, Y., Zhang, Y., and Shu, H. (2015). Musical experience modulates categorical perception of lexical tones in native Chinese speakers. *Frontiers in Psychology, 6,* 436. https://doi.org/10.3389/fpsyg.2015.00436.

Zentner, M. and Strauss, H. (2016). *PROMS homepage.* https://www.uibk.ac.at/psychologie/fachbereiche/pdd/personality_assessment/proms/take-the-test/.

Zentner, M. and Strauss, H. (2017). Assessing musical ability quickly and objectively: development and validation of the Short-PROMS and the Mini-PROMS. *Annals of the New York Academy of Sciences*, *1400*, 33-45. https://nyaspubs.onlinelibrary.wiley.com/doi/pdf/10.1111/nyas.13410.