Published in final edited form as:

Am J Psychol. 2013 ; 126(1): 95–104.

Musical Experience Influences Statistical Learning of a Novel Language

Anthony Shook, Viorica Marian, James Bartolotti, and Scott R. Schroeder

Northwestern University

Abstract

Musical experience may benefit learning a new language by enhancing the fidelity with which the auditory system encodes sound. In the current study, participants with varying degrees of musical experience were exposed to two statistically-defined languages consisting of auditory Morse-code sequences which varied in difficulty. We found an advantage for highly-skilled musicians, relative to less-skilled musicians, in learning novel Morse-code based words. Furthermore, in the more difficult learning condition, performance of lower-skilled musicians was mediated by their general cognitive abilities. We suggest that musical experience may lead to enhanced processing of statistical information and that musicians' enhanced ability to learn statistical probabilities in a novel Morse-code language may extend to natural language learning.

Keywords

statistical learning; musical experience; auditory processing; language learning

Music appears to have a profound effect on cognition and can fine-tune the cognitive system, providing benefits in multiple domains. For example, musical experience has been linked to cognitive benefits such as higher IQ (Schellenberg, 2004), better working memory (Parbery-Clark, Skoe, Lam, & Kraus, 2009), and better verbal memory (Chan, Ho, & Cheung, 1998). In addition, musical experience has been associated with improvements in language (Schön, Boyer, Moreno, Besson, Peretz, & Kolinsky, 2008; Slevc & Miyake, 2006) and literacy skills (Anvari, Trainor, Woodside, & Levy, 2002; Standley & Hughes, 1997). Furthermore, musical processing appears to utilize neural substrates that are also active in processing aspects of language, including syntax and semantics (Koelsch, 2005). It is possible that musical experience may impact a person's language abilities by influencing the core processes that underlie both music and language processing.

In fact, musical experience has been shown to provide advantages in the encoding of auditory information (for a review, see Kraus & Chandrasekaran, 2010). Behavioral evidence seems to indicate that musical experience positively affects the ability to perceive subtle temporal cues (Rammsayer & Altenmüller, 2006; Yee, Holleran, & Jones, 1994). This

Address correspondence to Anthony Shook, Department of Communication Sciences and Disorders, Northwestern University, Evanston, IL 60208. Phone: 847-467-2709. a-shook@northwestern.edu.

Author Note Anthony Shook, Viorica Marian, James Bartolotti, and Scott R. Schroeder, Department of Communication Sciences and Disorders, Northwestern University.

finding is also supported by neurobiological evidence: Listeners with extensive musical experience show enhanced neurological encoding of temporal information (Musacchia, Sams, Skoe, & Kraus, 2007; Strait, Kraus, Skoe, & Ashley, 2009; van Zuijen, Sussman, Winkler, Näätänen, & Tervaniemi, 2005). It appears that listeners with a high degree of musical experience are better able to attend to the fine-grained details of the signal, resulting in a more comprehensive representation of the durational aspects of auditory information. Musicians' enhanced processing of auditory information may have important implications for language learning -- if a person with a high degree of musical experience is better equipped to parse out the minute details of sound information during processing, he or she may in turn be better at acquiring novel sound systems, such as a second language. For example, superior processing of the temporal aspects of an auditory signal may provide a listener with an increased ability to recognize durational aspects of novel spoken language (e.g., VOT, vowel length), which can be important for identifying words or phonemes. A beneficial relationship between music and language might imply that the underlying mechanisms of temporal processing that are enriched by musical training are also relevant for speech and, subsequently, language learning.

There does indeed seem to be a connection between musical experience, auditory processing, and language learning. For example, musically-trained children show an increased ability to discriminate between musical phrases with different temporal rhythms (Hyde et al., 2009), and to identify subtle changes in expected pitch patterns for both music and language (Besson, Schön, Moreno, Santos & Magne, 2007; Schön et al., 2004). Furthermore, musical ability seems to be positively associated with the recognition of unfamiliar lexical stress (Kolinsky, Cuvelier, Goetry, Peretz, & Morais 2009), prosodic decoding (Thompson, Schellenberg, & Husain, 2004), the acquisition of second language phonology (Slevc & Miyake, 2006), and phonetic production (Nardo & Reiterer, 2009). These results suggest that extensive musical experience may assist language learning by strengthening the essential skills required to parse out relevant linguistic information from the sound stream. However, these findings largely focus on the *connection* between music and language – how the underlying skills required for music and speech may be shared – rather than the *influence* of musical experience on learning language. In other words, the question of whether the processing advantages gained through musical experience can aid in the learning of a *novel* language remains unanswered.

To examine the effect of musical experience on language learning, the present study employed a statistical-learning paradigm to teach novel languages to musicians of varying skill levels. We chose to use statistical-learning because it closely resembles an immersive language learning experience, where there are few overt cues to phonotactic features or word boundaries. In addition, statistical learning has been demonstrated in a wide variety of domains for both infants and adults (Conway & Christiansen, 2005; Kirkham, Slemmer, & Johnson, 2002; Saffran et al, 1996; Saffran et al., 1999), and is potentially sensitive to individual differences (Misyak & Christiansen, 2007). In a standard statistical-learning paradigm, participants are passively exposed to auditory streams where the only available cue for word-segmentation arises from statistical probabilities within the stimuli. For example, if an auditory signal contains the sequences ABC, LMN and XYZ, the likelihood

that B is followed by C is one-hundred percent, while the likelihood that C is followed by X is fifty percent. Humans are able to use these cues to accurately segment nonsense speech and non-linguistic tonal stimuli (e.g., Saffran, Newport, & Aslin, 1996; Saffran, Johnson, Aslin, & Newport, 1999). The enhanced encoding of auditory information seen in musicians could result in more detailed representations not only of the individual elements within the stream, but also of how multiple elements co-occur over time. Indeed, musicians have recently been shown to have advantages in implicit sequence-learning tasks (Bergstrom, Howard, & Howard, 2011; Ettlinger, Margulis, & Wong, 2011; Schön & François, 2011). Highly-skilled musicians may therefore be better equipped to recognize patterns within a signal, which could lead to an advantage over less-skilled musicians at learning words in a novel language via statistical information.

The statistical learning paradigm in the current study used a novel language based on the International Morse-code, wherein the distinguishing characteristics of the language are based upon temporal differences in the signal (e.g., patterns of dots and dashes, and the pauses between them). By using Morse-code, we are able to focus on musicians' ability to segment a temporally-defined sound sequence, while limiting the potential effects of musicians' enhanced frequency processing (Alexander, Wong, & Bradlow, 2005; Schön, Magne, & Besson, 2004), or the participants' previous linguistic experience. If musical experience confers a benefit to tracking the probabilities of the temporal sequences in a statistical learning task, then highly-skilled musicians should outperform lower-skilled musicians. In addition to the Statistical learning condition, we also manipulated task complexity by including a second condition in which the auditory stream contained Conflicting cues to word boundary. The purpose of the Conflicting condition was to investigate whether a potential statistical-learning advantage driven by musical-experience would extend to more cognitively demanding situations. Bergstrom, Howard, and Howard (2011) suggest that the implicit learning advantages found in musicians are domain-general, which could result in better learning, independent of cognitive demand. However, in studies where participants attempt to learn novel sequences with two conflicting sets of cues to word boundary, additional cognitive skills appear to be important for learning (Bartolotti, Marian, Schroeder, & Shook, 2011; Weiss, Gerfen, & Mitchel, 2010). The Conflicting condition allows us to investigate whether musicians' implicit learning advantage, if present, is sufficient to benefit learning of a more complex, conflicting language, or if other cognitive abilities are required for learning.

Our Conflicting condition was modeled after Weiss, Gerfen, and Mitchel (2010), who presented listeners with a novel word stream in which word-boundaries could be determined either by statistical probabilities, or by a 50 ms pause embedded between the second and third syllable of the statistically-defined words. In their study, only participants who displayed enhanced attentional capabilities (as measured by an inhibitory-control task) consistently chose *either* the statistical strategy or the pause strategy, indicating that the inclusion of a conflicting cue may help tease apart the influence of individual differences, like musical experience.

In summary, the present study investigates the influence of musical experience on statistical learning in a novel language based on Morse-code. We hypothesized that highly-skilled

musicians would outperform lower-skilled musicians in the statistical learning paradigm. If extent of musical experience positively influences novel language learning, it could suggest that the skills required for music and language processing may be shared, and that language learning could be influenced by non-linguistic training.

Methods

Participants

Thirty college students participated in the study, fifteen highly-skilled musicians and fifteen lower-skilled musicians. Participants completed the non-verbal subtest of the Wechsler Abbreviated Scale of Intelligence (*WASI*; PsychCorp, 1999) and the Digit Span subtest of the Comprehensive Test of Phonological Processing (*CTOPP*; Wagner, Torgesen, & Rashotte, 1999). A Musicality Questionnaire was administered (adapted from Musacchia et al., 2007) and responses were used to group participants according to two musical criteria: Self-rated musical proficiency in a musician's dominant instrument (scale of 1-7, with 7 being "highly proficient") and years of formal lessons in the dominant instrument. Specifically, participants were considered highly-skilled musicians if they reported their self-rated musicianship as 6 or higher, and had taken at least 6 years of lessons in their dominant instrument. The lower-skilled musicians were defined as having self-reported musicianship values no higher than 4 (out of seven), and no more than 4 years of lessons in their dominant instrument. Information about the participants can be found in Table 1. Participants reported experience with a variety of instruments, such as piano, violin, and flute; no participants reported experience with percussive instruments, such as drums. Participants reported no history of hearing difficulties.

Stimuli

Morse Code Languages—Two artificial languages were created from the international Morse code alphabet and contained the Morse-translations of the letters A, E, I, M, N, and T. In Morse code, letters are composed of combinations of short tones, or 'dots' (440Hz for 100 ms) and long tones, or 'dashes' (440Hz for 300 ms). Two letters that were used in our artificial languages were made up of a single tone each (E /./ and T /-/), and four letters were made up of exactly two tones in sequence (A /.-/, I /../, N /-./, and M /--/), with 100 ms of silence between tones. Each language consisted of three two-letter words, where each word was a constant 1100 ms in length (*see* Table 2), and each letter within a word was separated by a 300 ms silence. In both languages, the transitional probability for letters within-words was a constant 1.0, while between-word probabilities were a constant 0.5.

Statistical and Conflicting Conditions—In the Statistical condition, the pause between words was identical to the pause between letters (300 ms). The only cue to word-boundaries was the transitional probability between words. In the Conflicting condition, the pause between words was identical to the pause between elements within a letter (100 ms), thus highlighting the pause between *letters* (300 ms) as a potential word boundary. This yielded a conflicting cue in which the location of word-boundaries could be determined either by statistical information, or by pause information. These two possible strategies would lead to distinct word-boundary segmentation (*see* Figure 1).

Procedure

Participants were presented with both the Statistical and Conflicting Cues conditions in separate Morse-languages (i.e., if the Statistical condition was presented with Morse-Language 1, then the Conflicting-condition was presented in Morse-Language 2), and the order of presentation was counterbalanced. Participants were seated in front of a computer, and listened to stimuli over headphones. A continuous stream of Morse-words was presented for approximately twelve minutes (three 4.2-minute blocks) for both the Statistical and Conflicting conditions. Within a block, no word was followed by itself, and each word was followed by the other two words an equal number of times (example of a Morse-stream: ... *TaInMeTaMeInTa...*). After each condition, participants performed an unrelated task (the *Wechsler Abbreviated Scale of Intelligence*, the digit span task, or the musicality questionnaire).

Testing consisted of a two-alternative forced-choice task where participants heard two sequences and were asked to indicate which sounded more familiar by pressing '1' for the first sequence or '9' for the second sequence. There were 12 trials for each condition. The critical comparison in the testing phase entailed comparing statistically defined tone-sequences (e.g., ME) to sequences that were defined by the location of a pause boundary (e.g., EN as derived from ME/NI). In the Statistical condition, these part-words served as control items – Morse-words appeared twice as often as Morse part-words; in the Conflicting-condition, the part-words served as an alternative to participants who segmented the stream according to pause information. In other words, the two options represented two different potential strategies for segmenting the sound-stream.

After participants completed the statistical learning tasks, they performed a Simon task (Simon & Small, 1969) to assess their inhibitory control abilities, which have been shown to influence statistical learning (Weiss, Gerfen, & Mitchel, 2010). Participants viewed blue and brown rectangles on a computer screen, and were asked to press a blue button on the left side of the keyboard when the rectangle was blue, and a brown button on the right side of the keyboard when the rectangle was brown. The task contained 126 trials split evenly among Neutral, Congruent and Incongruent trials, and all participants completed a practice session before the actual task. In Congruent trials, the stimulus and response locations matched (i.e., a blue rectangle on the left side of the screen), while in Incongruent trials, there was a direct mismatch between the irrelevant stimulus location information (i.e., where the box appears on the screen) and the response location, which was based on the color of the stimulus (i.e., a blue rectangle on the right side of the screen). In Neutral trials, the stimulus appeared in the center of the screen. The Simon Effect indexes the processing cost associated with the need to inhibit the irrelevant stimulus location. It was calculated by subtracting the reaction time on Congruent trials from the reaction time on Incongruent trials (after removing all incorrect trials). Thus, a positive Simon Effect (i.e., longer average RTs on Incongruent trials relative to Congruent trials) is taken as an index of less inhibitory control. The Highly-skilled and Lower-skilled Musicians' average Simon Effect scores are included in Table 1, along with their scores on the WASI and digit span tests.

Data Analysis

Participants' scores were coded on a scale in which zero (0) represented chance (50% correct) on the test (i.e., six out of twelve for each condition). Therefore, the possible range of scores was -6 to 6. In the Statistical condition, positive scores (significantly greater than 0) represented learning of the Morse words. In the Conflicting-condition, a positive response (significantly greater than 0) indicated learning of the language according to statistical information; in contrast, a negative response (significantly less than 0) indicated learning of the language according to pause information. Learning was measured by comparing group performance to chance (0) for each condition. Additionally, a 2×2 repeated-measures ANOVA, with Group (Highly-Skilled Musicians, Lower-Skilled Musicians) as a between-subjects factor, and Condition (Statistical, Conflicting) as a within-subjects factor was performed.

Results

The results indicate that musical experience influenced participants' ability to learn novel Morse-words using statistical probabilities (Figure 2). In the Statistical condition, highly-skilled musicians performed better than chance ($M = 2.03$, $SE = 0.65$; $t(14) = 3.14$, $p < 0.01$), but lower-skilled musicians did not ($M = 0.08$, $SE = 0.42$; $t(14) = 0.16$, $p > 0.1$). In contrast, neither the highly-skilled musicians ($M = 0.1$, $SE = 0.65$; $t(14) = 0.21$, $p > 0.1$) nor the lower-skilled musicians ($M = 0.17$, $SE = 0.63$; $t(14) = 0.26$, $p > 0.1$) differed from chance in the Conflicting condition. The repeated-measures ANOVA revealed a marginally-significant Group $\times$ Condition interaction ($F(1,28) = 3.63$, $p = 0.067$, $\eta_p^2 = 0.12$). Planned post-hoc comparisons revealed a significant difference between highly-skilled and lower-skilled musicians performance on the Statistical condition ($t(28) = -2.55$, $p < 0.05$), with highly-skilled musicians scoring significantly higher than lower-skilled musicians, but indicated that the groups performed similarly on the Conflicting condition ($t(28) = 0.08$, $p > 0.1$). Highly-skilled musicians also scored significantly higher in the Statistical-condition relative to the Conflicting-condition ($t(14) = 2.79$, $p < 0.05$), while lower-skilled musicians' performance did not differ across conditions ($t(14) = -0.12$, $p > 0.1$).

The finding that neither the lower-skilled nor higher-skilled musicians performed greater than chance in the Conflicting condition could result from one or both of the groups' scores being split between learning strategies. If half of the musicians had an average score of -2.0 (learning via pause information) while the other half had an average of 2.0 (learning via statistical information), then the group average would be zero, which would erroneously suggest that no learning occurred. One way to avoid this concern is by examining the participants' absolute performance, where scores above zero represent overall learning. One sample T-tests using the absolute scores revealed that both the lower-skilled musicians ($M = 1.83$, $SE = 0.39$; $t(14) = 4.64$, $p < 0.001$) and the higher-skilled musicians ($M = 1.57$, $SE = 0.24$; $t(14) = 6.439$, $p < 0.001$) scored significantly higher than chance, and no significant difference was found between the groups, $t(28) = 0.57$, $p > .1$ (Figure 3). Correlational analyses indicated that while both groups learned in the Conflicting condition, lower-skilled musicians' performance was directly correlated with WASI performance, $r_s(15) = 0.58$, $p < 0.05$, while higher-skilled musicians' performance was not, $r_s(15) = .21$, $p > 0.1$ (Figure 4).

Neither group's performance correlated with CTOPP scores (lower-skilled musicians: $r_s(15) = 0.42$, highly-skilled musicians: $r_s(15) = 0.37$) or the Simon effect (lower-skilled musicians: $r_s(15) = -0.19$, highly-skilled musicians: $r_s(15) = 0.08$), all $ps > 0.1$.

Discussion

Musical experience appears to influence a person's ability to learn novel sound sequences using statistical information. Highly-skilled musicians showed a distinct advantage in learning a novel Morse-code language via statistical probabilities, relative to lower-skilled musicians. It is possible that the enhanced speech processing abilities gained from musical experience (Alexander et al., 2005; Schön et al., 2004; Strait et al., 2009; Wong et al., 2007; Yee et al., 1994) led our highly-skilled musicians to learn a novel Morse-language better than their less-skilled peers. The highly-skilled musicians may have developed more detailed representations of the novel sound streams due to their enhanced auditory encoding abilities, which could result in superior tracking of the statistical probabilities in the signal during exposure and/or easier recall during testing.

One possible explanation of the statistical learning advantage for musicians in the present study is that highly-skilled musicians may be better able to track the temporal information within an auditory signal than less-skilled musicians. This is consistent with previous research suggesting that musical experience can enhance learning of the rhythmic aspects of language (Hyde et al., 2009; van Zuijen et al., 2005), and that musicians show enhanced temporal encoding when auditory processing is automatic (Rammsayer & Altenmüller, 2006). In the Statistical condition, the highly-skilled musicians were able to segment the Morse-code signal by tracking the statistical relationships between elements within the stream, which were defined by temporal sequence information (length of the dots and dashes, and the pauses between elements). In the Conflicting condition, both the highly-skilled and the less-skilled musicians were able to learn; however, the results indicated that the two groups utilized distinct mechanisms to successfully parse the Morse-code signal. The highly-skilled musicians in our study likely relied on the same strategies used in the Statistical condition, namely an enhanced ability to track temporal information within the stream, which is reflected by the fact that the highly-skilled musicians' absolute performance in the Conflicting condition was not influenced by their cognitive abilities. In contrast, less-skilled musicians' ability to learn in the Conflicting task was dependent on their WASI performance, a measure of general cognitive abilities. In other words, less-skilled musicians, but not highly-skilled musicians, required additional cognitive resources to learn in the Conflicting condition. This result is consistent with the notion that musical experience can enhance statistical learning of a Morse-code language.

The finding that the less-skilled musicians were able to learn in the Conflicting condition but did not learn in the Statistical condition may be due to the less-skilled musicians' deployment of additional cognitive resources. When the task-complexity was increased, the less-skilled musicians may have needed to draw upon their underlying cognitive resources in order to parse the signal, which in turn may have resulted in a greater allocation of attentional resources, relative to the Statistical condition. Indeed, attention has been shown to influence performance on statistical learning tasks (Fernandes, Kolinsky, & Ventura,

2010; Toro, Sinnett, & Soto-Faraco, 2005). Furthermore, the complexity of the Conflicting condition itself may have helped the less-skilled musicians learn. Research indicates that difficulty during learning can result in better memory recall (Gardiner, Craik, & Bleasdale, 1973; Pyc & Rawson, 2009), and that long-term, cognitively demanding experience can preserve cognitive abilities later in life (Potter, Helms, & Plassman, 2007). Perhaps the complex nature of the task, coupled with the increased allocation of cognitive resources, helped the less-skilled musicians track either the statistical or pause-based cues in the Conflicting condition, while the easier Statistical condition did not require the same degree of cognitive energy. Regardless, the less-skilled musicians required extra resources to complete the task, while the highly-skilled musicians were able to parse the signal without utilizing additional resources.

Though the current study indicates an advantage in processing statistical information for musicians, it does not directly inform the origin of this effect. On the one hand, musical experience may train the auditory processing mechanism for enhanced encoding of auditory information. Alternatively, prior expertise in signal processing may be both the source of the learning advantage, and also the main contributing factor to the pursuit of music among our good learners. In other words, language learning *and* musical expertise may result from an already enhanced temporal-processing ability. While the present study is unable to discriminate between these two accounts, we believe our results are consistent with the notion that musical experience contributes to improvements in temporal auditory processing, as suggested by previous research showing that even short term musical training can result in processing gains in children with no prior musical experience (Besson et al., 2007; Hyde et al., 2009).

Taken together, the results suggest that highly-skilled musicians show advantages in statistical learning of a Morse-code language. This advantage may rely on improved processing of temporal information, which is used to successfully segment words from novel sound streams. Advantages in tracking the statistical information in unfamiliar sound streams may extend to benefits in acquiring natural-language information. For example, an enhanced ability to track statistical information may help listeners identify words in novel languages, which has been shown to benefit subsequent learning of the words' meanings (Fernandes, Kolinsky, & Ventura, 2009; Mirman, Magnuson, Estes, & Dixon, 2008), ultimately resulting in improved acquisition of a novel language. Furthermore, skilled musicians' enhanced encoding may provide an advantage in processing fine-grained durational aspects of language (such as VOT and vowel length) that are critical to learning the sounds of language. This notion is consistent with research suggesting a link between musical training and language/literacy skills (Anvari et al., 2002; Koelsch, 2005; Schön et al., 2004; Slevc & Miyake, 2006). In conclusion, the interaction between musical experience and learning novel sound sequences may suggest that experience or expertise in non-linguistic domains can impact linguistic ability.

Acknowledgments

The authors would like to thank the members of the Northwestern Bilingualism and Psycholinguistics Laboratory for their helpful comments. This research was funded in part by grant R01HD059858 to the second author, and the John D. and Lucille H. Clarke Scholarship to the first author.

References

- Alexander, JA.; Wong, PCM.; Bradlow, AR. Lexical tone perception in musicians and nonmusicians. Proceedings of Interspeech' 2005 – Eurospeech– 9th European Conference on Speech Communication and Technology; Lisbon, Portugal. 2005.
- Anvari SH, Trainor LJ, Woodside J, Levy BA. Relations among musical skills, phonological processing, and early reading ability in preschool children. *Journal of Experimental Child Psychology*. 2002; 83(2):111–130. [PubMed: 12408958]
- Bartolotti J, Marian V, Schroeder SR, Shook A. Bilingualism and inhibitory control influence statistical learning of novel word forms. *Frontiers in Psychology*. 2011; 2:324. [PubMed: 22131981]
- Bergstrom JCR, Howard JH, Howard DV. Enhanced implicit sequence learning in college-age video game players and musicians. *Applied Cognitive Psychology*. 2011 Advance online publication. doi: 10.1002/acp.1800.
- Besson M, Schön D, Moreno S, Santos A, Magne C. Influence of musical expertise and musical training on pitch processing in music and language. *Restorative Neurology and Neuroscience*. 2007; 25:399–410. [PubMed: 17943015]
- Chan AS, Ho YC, Cheung MC. Music training improves verbal memory. *Nature*. 1998; 396:128. [PubMed: 9823892]
- Conway CM, Christiansen MH. Modality-constrained statistical learning of tactile, visual, and auditory sequences. *Journal of Experimental Psychology: Learning, Memory and Cognition*. 2005; 31(1):24–39.
- Ettlinger M, Margulis EH, Wong PCM. Implicit memory in music and language. *Frontiers in Psychology*. 2011; 2:211. [PubMed: 21927608]
- Fernandes T, Kolinsky R, Ventura P. The metamorphosis of the statistical segmentation output: lexicalization during artificial language learning. *Cognition*. 2009; 112(3):349–366. [PubMed: 19545864]
- Fernandes T, Kolinsky R, Ventura P. The impact of attention load on the use of statistical information and coarticulation as speech cues. *Attention, Perception, & Psychophysics*. 2010; 72(6):1522–1532.
- Gardiner JM, Craik FIM, Bleasdale FA. Retrieval difficulty and subsequent recall. *Memory & Cognition*. 1973; 1(3):213–216. [PubMed: 24214547]
- Hyde KL, Lerch J, Norton A, Forgeard M, Winner E, Evans AC, Schlaug G. The effects of musical training on structural brain development. *Annals of the New York Academy of Sciences*. 2009; 1169(1):182–186. [PubMed: 19673777]
- Kirkham NZ, Slemmer JA, Johnson SP. Visual statistical learning in infancy: Evidence for a domain general learning mechanism. *Cognition*. 2002; 83(2):35–42.
- Koelsch S. Neural substrates of processing syntax and semantics in music. *Current Opinion in Neurobiology*. 2005; 15(2):207–212. [PubMed: 15831404]
- Kolinsky R, Cuvelier H, Goetry V, Peretz I, Morais J. Music training facilitates lexical stress processing. *Music Perception*. 2009; 26(3):235–246.
- Kraus N, Chandrasekaran B. Music training for the development of auditory skills. *Nature Reviews Neuroscience*. 2010; 11:599–605.
- Mirman D, Magnuson JS, Graf Estes K, Dixon JA. The link between statistical segmentation and word learning in adults. *Cognition*. 2008; 108(1):271–280. [PubMed: 18355803]
- Misyak, JB.; Christiansen, MH. Extending statistical learning farther and further: Long-distance dependencies, and individual differences in statistical learning and language. In: McNamara, DS.; Trafton, JG., editors. Proceedings of the 29th Annual Cognitive Science Society; Austin, TX: Cognitive Science Society; 2007. p. 1307-1312.
- Musacchia G, Sams M, Skoe E, Kraus N. Musicians have enhanced subcortical auditory and audiovisual processing of speech and music. *Proceedings of the National Academy of Sciences*. 2007; 104:15894–15898.
- Nardo, D.; Reiterer, SM. Musicality and phonetic language aptitude. In: Dogil, G.; Reiterer, SM., editors. Language talent and the brain. de Gruyter; Berlin: 2009. p. 213-255.

- Parbery-Clark A, Skoe E, Lam C, Kraus N. Musician enhancement for speech-in-noise. *Ear & Hearing*. 2009; 30(6):653–661. [PubMed: 19734788]
- Potter GG, Helms MJ, Plassman BL. Associations of job demands and intelligence with cognitive performance among men in later life. *Neurology*. 2008; 19(2):1803–1808. [PubMed: 18077796]
- PsychCorp. Wechsler Abbreviated Scale of Intelligence (WASI). Harcourt Assessment, Inc; San Antonio, TX: 1999.
- Pyc MA, Rawson KA. Testing the retrieval effort hypothesis: Does greater difficulty correctly recalling information lead to higher levels of memory? *Journal of Memory and Language*. 2009; 60:437–447.
- Rammsayer T, Altenmüller E. Temporal information processing in musicians and nonmusicians. *Music Perception*. 2006; 24:37–48.
- Saffran JR, Newport EL, Aslin RN. Word segmentation: The role of distributional cues. *Journal of Memory and Language*. 1996; 35:606–621.
- Saffran JR, Johnson EK, Aslin RN, Newport EL. Statistical learning of tone sequences by human infants and adults. *Cognition*. 1999; 70:27–52. [PubMed: 10193055]
- Schellenberg EG. Music lessons enhance IQ. *Psychological Science*. 2004; 15:511–514. [PubMed: 15270994]
- Schön D, François C. Musical expertise and statistical learning of musical and linguistic structures. *Frontiers in Psychology*. 2011; 2:167. [PubMed: 21811482]
- Schön D, Boyer M, Moreno S, Besson M, Peretz I, Kolinsky R. Songs as an aid for language acquisition. *Cognition*. 2008; 106(2):975–983. [PubMed: 17475231]
- Schön D, Magne C, Besson M. The music of speech: Music facilitates pitch processing in language. *Psychophysiology*. 2004; 41:341–349. [PubMed: 15102118]
- Slevc LR, Miyake A. Individual differences in second-language proficiency: Does musical ability matter? *Psychological Science*. 2006; 17(18):675–681. [PubMed: 16913949]
- Standley JM, Huges JE. Evaluation of an early intervention music curriculum for enhancing prereading/writing skills. *Music Therapy Perspectives*. 1997; 15:79–85.
- Strait DL, Kraus N, Skoe E, Ashley R. Musical experience and neural efficiency – Effects of training on subcortical processing of vocal expressions of emotion. *European Journal of Neuroscience*. 2009; 29:661–668. [PubMed: 19222564]
- Tervaniemi M, Just V, Koelsch S, Widmann A, Schröger E. Pitch discrimination accuracy in musicians vs. non-musicians: An event-related potential and behavioral study. *Experimental Brain Research*. 2005; 161(1):1–10. [PubMed: 15551089]
- Thompson WF, Schellenberg EG, Husain G. Decoding speech prosody: Do music lessons help? *Emotion*. 2004; 4(1):46–64. [PubMed: 15053726]
- Toro JM, Sinnott S, Soto-Faraco S. Speech segmentation by statistical learning depends on attention. *Cognition*. 2005; 97(2):B25–B34. [PubMed: 16226557]
- van Zuijlen TL, Sussman E, Winkler I, Näätänen R, Tervaniemi M. Auditory organization of sound sequences by a temporal or numerical regularity – A mismatch negativity study comparing musicians and non-musicians. *Cognitive Brain Research*. 2005; 23(2):270–276. [PubMed: 15820634]
- Wagner, RK.; Torgesen, JK.; Rashotte, CA. Comprehensive Test of Phonological Processing. PRO-ED, Inc; Austin, TX: 1999.
- Weiss DJ, Gerfen C, Mitchel AD. Colliding cues in word segmentation: The role of cue strength and general cognitive processes. *Language and Cognitive Processes*. 2010; 25(3):402–422.
- Wong PCM, Skoe E, Russo NM, Dees T, Kraus N. Musical experience shapes human brainstem encoding of linguistic pitch patterns. *Nature Neuroscience*. 2007; 10:420–422.
- Yee W, Holleran S, Jones MR. Sensitivity to event timing in regular and irregular sequences: Influences of musical skill. *Perception and Psychophysics*. 1994; 56:461–471. [PubMed: 7984401]

Figure 1.

Morse code listening streams. Dots and dashes represent 100 ms and 300 ms tones, short and long gaps represent 100 ms and 300 ms silences. In the (A) Statistical condition, words are marked by statistical probabilities between letters. In the (B) Conflicting condition, the gap between words is reduced to 100 ms, and the statistically defined words (TA, EM, IN) compete with words defined by the long pauses (AE, MT, AI).

Figure 2.

The effect of musical experience on performance in the Statistical and Conflicting conditions. Zero represents learning at chance level. Asterisks indicate significant differences between groups or conditions, while the cross indicates a significant difference from chance. Alpha was set at 0.05 for both comparisons. Error bars represent one Standard Error.

Figure 3.

Absolute scores in the Conflicting condition for Highly-Skilled and Lower-Skilled musicians. The cross indicates a significant difference from chance (0). Error bars represent one Standard Error.

Figure 4.

Correlation of performance on the *Wechsler Abbreviated Scale of Intelligence* (WASI) and scores in the Conflicting Condition. No correlation was found for Highly-Skilled musicians, while a significant positive correlation was found in the Lower-Skilled musicians.

Table 1

Participant Table

	Highly-Skilled Musicians (N=15)	Lower-Skilled Musicians (N=15)	<i>P-values</i>
Age	22.27 (<i>SD</i> = 3.65)	21.47 (<i>SD</i> = 2.03)	n.s.
Wechsler Scale of Abbreviated Intelligence	112.7 (<i>SD</i> = 11.7)	108.1 (<i>SD</i> = 8.5)	n.s.
Digit Span subtest of CTOPP	17.5 (<i>SD</i> = 2.13)	16.7 (<i>SD</i> = 2.58)	n.s.
Simon Effect (ms)	24.0 (<i>SD</i> = 19.9)	36.4 (<i>SD</i> = 14.2)	n.s.
Self-Rated Musicianship	6.1 (<i>SD</i> = 0.26)	3.6 (<i>SD</i> = 0.51)	$p < 0.001$
Years of Lessons	11.0 (<i>SD</i> = 3.39)	2.1 (<i>SD</i> = 1.71)	$p < 0.001$

Table 2

Novel Morse Words

Language 1	Language 2
EM (• / - -)	ME (- - / •)
IN (• • / - •)	NI (- • / • •)
TA (- / • -)	AT (• - / -)