Musical Experience Influences Statistical Learning of a Novel Language

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Musical experience may benefit learning of a new language by increasing 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 that varied in difficulty. We found an advantage for highly skilled musicians, relative to lower-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 improve 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.

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 et al., 2008; Slevc & Miyake, 2006) and literacy skills (Anvari, Trainor, Woodside, & Levy, 2002; Standley & Hughes, 1997). Furthermore, musical processing appears to rely on neural substrates that are also active in processing aspects of language, including syntax and semantics (Koelsch, 2005). It is possible that musical experience may affect 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 improves the ability to perceive subtle temporal cues (Rammsayer & Altenmüller, 2006; Yee, Holleran, & Jones, 1994). This finding is also supported by neurobiological evidence: Listeners with extensive musical experience show greater neurological encoding of temporal informa-

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tion (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' superior 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 a greater ability to recognize durational aspects of novel spoken language (e.g., voice onset time, 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 a greater 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, Magne, & Besson, 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 needed to parse out relevant linguistic information from the sound stream. However, these findings focus largely on the connection between music and language—how the skills that underlie 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 used 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, Johnson, Aslin, & Newport, 1999; Saffran, Newport, & Aslin, 1996) 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 100%, and the likelihood that C is followed by X is 50%. Humans are able to use these cues to accurately segment nonsense speech and nonlinguistic tonal stimuli (e.g., Saffran, Newport, & Aslin, 1996; Saffran et al., 1999). The improved 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, 2012; 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 on 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' superior 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 et al. (2012) suggested 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 whether other cognitive abilities are needed for learning.

Our conflicting condition was modeled after that of Weiss et al. (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 syllables of the statistically defined words. In their study, only participants who displayed greater 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, such as 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 needed for music and language processing may be shared and that language learning could be influenced by nonlinguistic training.

EXPERIMENT

METHODS

Participants

Thirty college students participated in the study: 15 highly skilled musicians and 15 lower-skilled musicians. Participants completed the nonverbal 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 1–10, with 10 = *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 10) 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" (440 Hz for 100 ms) and long tones, or "dashes" (440 Hz 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 1,100 ms in length (Table 2), and each letter

TABLE 1. Participant Table

	Highly skilled musicians (N = 15)	Lower-skilled musicians (N = 15)	P
Age (yr)	22.3 (SD = 3.65)	21.5 (SD = 2.03)	*ns*
Wechsler Scale of Abbreviated Intelligence	112.7 (SD = 11.7)	108.1 (SD = 8.5)	*ns*
Digit Span subtest of Comprehensive Test of Phonological Processing	17.5 (SD = 2.13)	16.7 (SD = 2.58)	*ns*
Simon effect (ms)	24.0 (SD = 19.9)	36.4 (SD = 14.2)	*ns*
Self-rated musicianship	6.1 (SD = 0.26)	3.6 (SD = 0.51)	$p < .001$
Lessons (yr)	11.0 (SD = 3.39)	2.1 (SD = 1.71)	$p < .001$

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, and between-word probabilities were a constant .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 (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.

TABLE 2. Novel Morse Words

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

Participants were seated in front of a computer and listened to stimuli over headphones. A continuous stream of Morse words was presented for approximately 12 min (three 4.2-min 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 WASI, 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) with 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 et al., 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

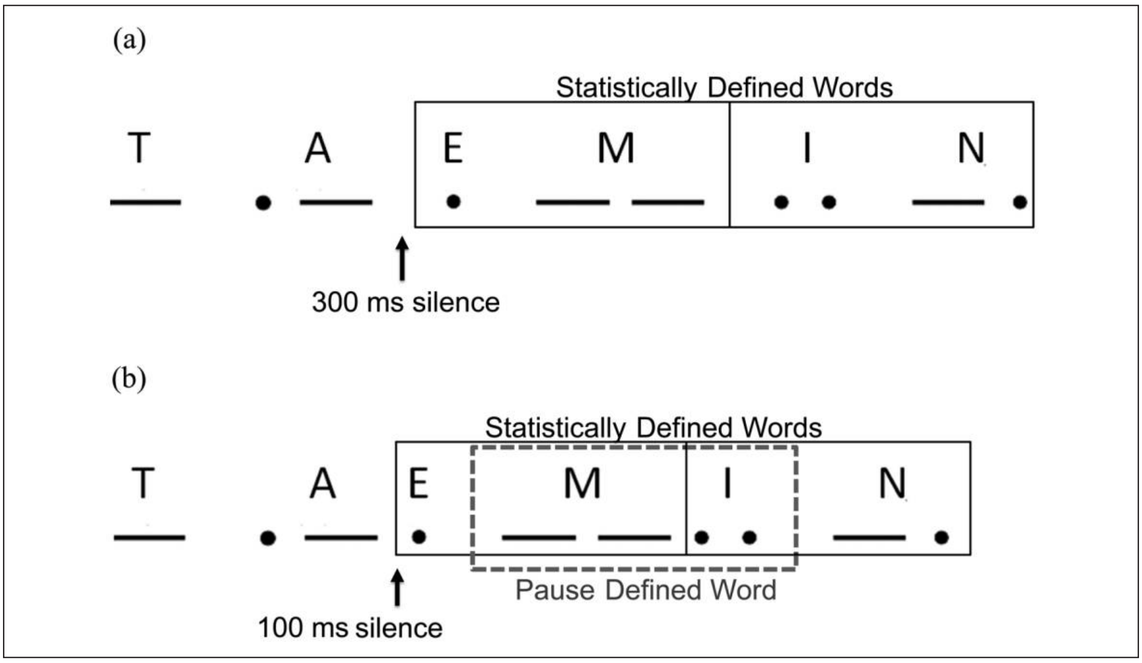

FIGURE 1. Morse code listening streams. Dots and dashes represent 100-ms and 300-ms tones, short and long gaps represent 100-ms and 300-ms silences. (a) In the statistical condition, words are marked by statistical probabilities between letters. (b) In the conflicting condition, the gap between words is reduced to 100 ms, and the statistically defined words (TA, EM, IN) compete with words defined by the long pauses (AE, MT, AI)

button on the right side of the keyboard when the rectangle was brown. The task contained 126 trials split evenly between 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), and 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 (RT) on congruent trials from the RT 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., 6 out of 12 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-subject factor and condition (statistical, conflicting) as a within-subject 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, $M = 2.03$, $SE = 0.65$, $t(14) = 3.14$, $p < .01$, but lower-skilled musicians did not, $M = 0.08$, $SE = 0.42$, $t(14) = 0.16$, $p > .1$. In contrast, neither the highly skilled musicians, $M = 0.1$, $SE = 0.65$, $t(14) = 0.21$, $p > .1$, nor the lower-skilled musicians, $M = 0.17$, $SE = 0.63$, $t(14) = 0.26$, $p > .1$, differed from chance in the conflicting condition. The repeated-measures ANOVA revealed a marginally significant group × condition interaction, $F(1, 28) = 3.63$, $p = .067$, $\eta_p^2 = .12$. Planned post-hoc comparisons revealed a significant difference between highly skilled and lower-skilled musicians' performance on the statistical condition, $t(28) = -2.55$, $p < .05$, with highly skilled musicians scoring significantly higher than lower-skilled musicians, but indicated that the groups performed similarly on the conflicting condition, $t(28) = 0.08$, $p > .1$. Highly skilled musicians also scored significantly higher in the statistical condition than in the conflicting condition, $t(14) = 2.79$, $p < .05$, whereas lower-skilled musicians' performance did not differ across conditions, $t(14) = -0.12$, $p > .1$.

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) and 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, $M = 1.83$, $SE = 0.39$, $t(14) = 4.64$, $p < .001$, and the higher-skilled musicians, $M = 1.57$, $SE = 0.24$, $t(14) = 6.439$, $p < .001$, 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 although both groups learned in the conflicting condition, lower-skilled musicians' performance was directly correlated with WASI performance, $r_s(15) = 0.58$, $p < .05$, whereas higher-skilled musicians' performance was not, $r_s(15) = .21$, $p > .1$ (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 *p*s > .1.

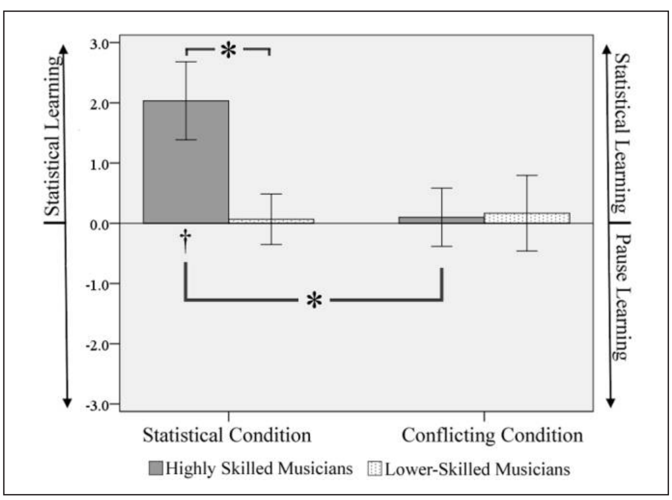

FIGURE 2. The effect of musical experience on performance in the statistical and conflicting conditions. Zero represents learning at chance level. Asterisks indicate significant differences between groups or conditions, and the dagger indicates a significant difference from chance. α = 0.05 for both comparisons. Error bars represent 1 standard error

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 superior

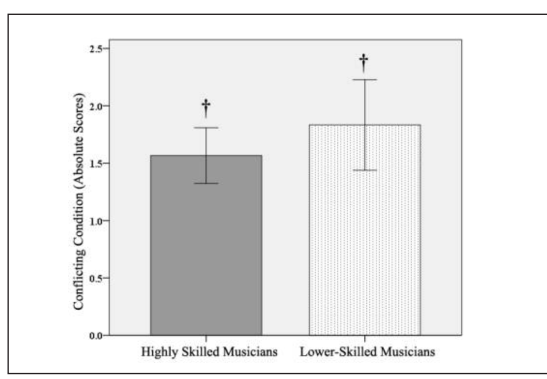

FIGURE 3. Absolute scores in the conflicting condition for highly skilled and lower-skilled musicians. The dagger indicates a significant difference from chance (0). Error bars represent 1 standard error

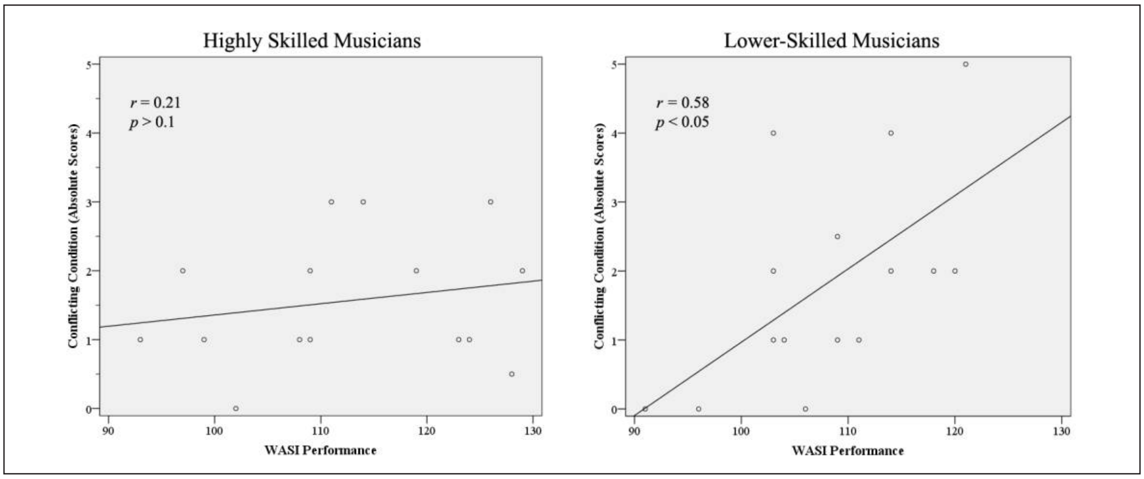

FIGURE 4. Correlation of performance on the Wechsler Abbreviated Scale of Intelligence (WASI) and scores in the conflicting condition. No correlation was found for highly skilled musicians, and a significant positive correlation was found in the lower-skilled musicians

speech processing abilities gained from musical experience (Alexander et al., 2005; Schön et al., 2004; Strait et al., 2009; Wong, Skoe, Russo, Dees, & Kraus, 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 greater auditory encoding abilities, which could result in superior tracking of the statistical probabilities in the signal during exposure 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 in an auditory signal than less-skilled musicians. This is consistent with previous research suggesting that musical experience can improve learning of the rhythmic aspects of language (Hyde et al., 2009; van Zuijen et al., 2005) and that musicians show greater 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 used distinct mechanisms to successfully parse the Morse code signal. The highly skilled musicians in our study probably relied on the same strategies used in the statistical condition, namely a greater ability to track temporal information within the auditory 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 depended on their WASI performance, a measure of general cognitive abilities. In other words, less-skilled musicians, but not highly skilled musicians, needed additional cognitive resources to learn in the conflicting condition. This result is consistent with the notion that musical experience can improve 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 result from the less-skilled musicians' deployment of additional cognitive resources. When the task complexity was increased, the less-skilled musicians may have needed to draw on 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, 2008). Perhaps the complex nature of the task, coupled with the greater allocation of cognitive resources, helped the less-skilled musicians track either the statistical or pause-based cues in the conflicting condition, whereas the easier statistical condition did not require the same degree of cognitive energy. Regardless, the less-skilled musicians needed extra resources to complete the task, whereas the highly skilled musicians were able to parse the signal without using additional resources.

Although the current study indicates an advantage in processing statistical information for musicians, it does not directly inform the origin of this effect. On one hand, musical experience may train the auditory processing mechanism for greater encoding of auditory information. Alternatively, prior expertise in signal processing may be both the source of the learning advantage and 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 superior temporal processing ability. Although 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 superior 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, a greater 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 improving acquisition of a novel language. Furthermore, skilled musicians' superior encoding may provide an advantage in processing fine-grained durational aspects of language (e.g., voice onset time, 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 or 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 nonlinguistic domains can affect linguistic ability.

NOTES

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