ACROSS-CHANNEL AUDITORY GAP DETECTION: A PSYCHOPHYSICAL CORRELATE OF MUSICAL APTITUDE AND INSTRUCTION

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IN STUDIES OF PERCEPTUAL AND NEURAL PROCESSING differences between musicians and nonmusicians, participants are typically dichotomized on the basis of personal report of musical experience. The present study relates self-reported musical experience and objectively measured musical aptitude to a skill that is important in music perception: temporal resolution (or acuity). The Advanced Measures of Music Audiation (AMMA) test was used to objectively assess participant musical aptitude, and adaptive psychophysical measurements were obtained to assess temporal resolution on two tasks: within-channel gap detection and across-channel gap detection. Results suggest that musical aptitude measured with the AMMA and self-reporting of music experiences (duration of music instruction) are both related to temporal resolution ability in musicians. The relationship between musical aptitude and/or duration of music training is important to music educators advocating for the benefits of music programs as well as in behavioral and neurophysiological research.

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TEMPORAL RESOLUTION IS ONE ASPECT OF temporal processing that has been studied extensively in musicians (e.g., Elangovan, Payne, Smurzynski, & Fagelson, 2016; Gaab et al., 2005; Mishra, Panda, & Herbert, 2014; Mishra, Panda, & Raj, 2015; Strait, Kraus, Parbery-Clark, & Ashley, 2010; Zendel & Alain, 2012). Temporal resolution—also called temporal acuity—concerns one's capacity to discriminate between signals that vary over time (Abel, 1972; Fitzgibbons, Pollatsek, & Thomas, 1974; Ries, Woods, & Smith, 2013). Temporal resolution is thought to play an important role in music perception and in speech understanding, particularly in the presence of background noise (Irwin & McAuley, 1987; Snell, Mapes, Hickman, & Frisina, 2002; Tyler, Summerfield, Wood, & Fernandes, 1982).

Various methods have been used to assess temporal resolution ability in research and clinical practice. These methods include duration discrimination (Elfenbein, Small, & Davis, 1993; Morrongiello & Trehub, 1987), backward masking (Oxenham & Moore, 1994), auditory fusion (Keith, 2000), and temporal order judgment tasks (Hirsh, 1959; Warren & Obusek, 1972). Additionally, different types of gap detection including gap duration discrimination (Fitzgibbons & Gordon-Salant, 1994), speech-gap detection (Pichora-Fuller & Souza, 2003), and narrow-band noise gap detection (Lister, Roberts, Shackelford, & Rogers, 2006; Weihing, Musiek, & Shinn, 2007).

GAP DETECTION MEASUREMENTS

Gap detection tests are receptive tests that require detection of a small gap between two acoustic signals. In gap detection measurement, the sound that precedes the gap can be spectrally similar to the sound following the gap (within-channel gap detection; WC), or the sound preceding the gap can be spectrally different (across-channel gap detection; AC). Smaller gap detection thresholds (GDT) indicate better temporal resolution. Many important cues for speech and music perception require AC temporal processing (Phillips, 1999). For example, a listener's ability to process voice onset timing is influenced by their AC gap detection ability (Phillips, 1999).

It has been suggested that WC and AC gap detection involves different neural processing mechanisms (Phillips, 1999). Specifically, it has been suggested that WC gap perception entails detection of simple discontinuity of activity in fibers activated by the stimulus. In contrast, in AC tasks, a central computation is required to compare the relative timing of activity of different neural channels.

Several findings support the view that central processes are required in AC gap detection. These include

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larger gap detection thresholds in AC tasks than in WC tasks (Phillips & Smith, 2004; Elangovan & Stuart, 2008) and higher intersubject variability (Elangovan et al., 2016). Higher intersubject variability is consistent with the view that individually unique central processing factors such as innate differences and experience-dependent plasticity play a role in AC gap detection.

The Adaptive Tests of Temporal Resolution (ATTR) software was selected to measure WC and AC gap detection thresholds in the present study. The ATTR was developed initially as a temporal processing test to be used in auditory processing evaluations (Lister, Roberts, Krause, DeBiase, & Carlson, 2011; Lister et al., 2006). It can be administered easily and quickly in a clinical setting, and it measures both WC and AC GDTs. The ATTR utilizes an adaptive two-alternative forced choice task that targets 70.7% correct gap detection on the psychometric function (Levitt, 1971) and yields results that are comparable to those obtained with psychophysical laboratory procedures. It has high test-retest reliability for both the WC and the AC tasks (Lister et al., 2006; Wong & McPherson, 2015).

In addition to its use in auditory processing assessment, the ATTR has been utilized in temporal processing testing in aging adults and in studies of musicians (Elongovan et al., 2016; Mishra & Panda, 2014; Mishra, Panda, & Herbert, 2014). In a recent planned clinical research protocol (Hudak et al., 2019), the ATTR was included with other measures to investigate effects of piano training of older adults.

DICHOTOMIZING OR QUANTIFYING MUSICAL ABILITY/EXPERIENCE

A large body of behavioral and neurophysiological research in auditory perception has revealed perceptual differences between musicians and nonmusicians (e.g., Coffey, Mogilever, & Zatorre, 2017; Nikjeh, Lister, & Frisch, 2008; Parbery-Clark, Skoe, Lam, & Kraus, 2009; Weaver, DiGiovanni, & Ries, 2017; Weaver, DiGiovanni, & Ries, 2019; Yee, Holleran, & Jones, 1994). These differences persist in the aging nervous system (Zendel & Alain, 2012). Research suggests that these perceptual differences are related to both experience-dependent plasticity (e.g., music instruction) and innate characteristics (Bidelman, Weiss, Moreno, & Alain, 2014; Coffey et al., 2017; Gaser & Schlaug, 2003; Habibi, Wirantana, & Starr, 2013; Kraus & Chandrasekaran, 2010; Musacchia, Sams, Skoe, & Kraus, 2007; Nikjeh et al., 2008; O'Brien, Nikjeh, & Lister, 2015; Ohnishi et al., 2001; Pantev et al., 1998; Parbery-Clark, Skoe, Lam, et al., 2009; Parbery-Clark, Tierney, Strait, & Kraus, 2012).

There is significant evidence that musicians' auditory systems benefit from music instruction, but the relative contributions of musical instruction and innate abilities remain unclear. Recent work in our lab identified that approximately 36% of the variance in a pitch temporal processing and patterning task was accounted by self-report of years of instrumental music instruction (Weaver et al., 2019).

CHARACTERIZING MUSIC EXPERIENCE

Various methods have been used to differentiate musicians from nonmusicians. Several validated receptive assessments are available to measure musical ability and/or aptitude (Law & Zentner, 2012). These include the Musical Aptitude Profile (MAP) which assesses melody, rhythm, and tempo skills (Gordon, 1965) and the Advanced Measures of Music Audiation (AMMA) test which assesses tonal and rhythmic elements (Gordon, 1989). More recent tests include the Musical Ear Test (MET), which assesses rhythm (Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010); and the Profile of Music Perception Skills (PROMS), in which four categories of skills are evaluated: tonal, qualitative (timbre or tuning), temporal, and dynamic loudness (Law & Zentner, 2012). The AMMA test used in the present study was developed specifically for college and university students and was designed as a brief test to objectively measure musical aptitude (Gordon, 1989). The AMMA appears widely in music perception literature. It provides established percentile-rank norms for young adults, objective and subjective validity measures, and high test-retest reliability.

Self-reported musical experience, based on duration of training, is also evaluated in the present study. Self-report is widely used in comparison studies of musicians and nonmusicians. There are several self-reported approaches to measuring duration of music training. The most basic format entails reporting age of training initiation and years of music instruction (Habib & Besson, 2009; Tirovolas & Levitin, 2011). Recent work indicates that self-identification as a "musician" is predictive of both a musical skill (singing) and participation in music activities (Demorest, Kelley, & Pfordresher, 2017). It is possible that self-reported musical experience may be more strongly related to temporal processing than standardized measures of musical aptitude (Elangovan et al., 2016; Law & Zentner, 2012; Mishra & Panda, 2014; Payne & Elangovan, 2012; Zendel & Alain, 2012).

THE CURRENT STUDY

In the present study, WC and AC gap detection thresholds (GDTs) were measured in young adults with and without self-reported music training. GDTs were obtained with the ATTR (Lister, Roberts, Krause, DeBiase, & Carlson, 2011; Lister et al., 2006). The aim was to determine the utility of the ATTR in measuring enhanced temporal processing in musicians identified with a validated measure of musical aptitude, as well as both a quantified and a dichotomized self-reported measure. The ATTR was selected, because it is a test that was developed to be administered in clinical and educational settings, and it can be included as part of a test battery for assessment of auditory processing skills. Preliminary independent samples *t*-tests, multivariate analysis of variance, correlations, and two hierarchical weighted least regression analyses were compared to address how the identification of music ability/instruction of participants relates to WC and AC GDTs. We hypothesized that there will be shared variance among both WC and AC GDTs and personal report music histories, but that the strength of the relationship will be more robust for AC GDTs than WC GDTs. Based on the AMMA test construction (with tonal items), we hypothesized that AMMA scores will have a stronger correlation to AC GDTs as this perceptual task relies on comparing across frequency, whereas the WC GDT does not.

TABLE 1. *Descriptive Statistics*

	Active Music Group ($n = 22$)	Non-Active Music Group ($n = 22$)
WC GDT at 30 dB SL		
Mean (SD)	5.45 ms (1.64)	6.31 ms (1.80)
Median	5.26 ms	6.40 ms
Range	2.45 ms - 8.12ms	2.57 ms - 10.73 ms
Grand Mean	**5.88 ms (1.75)**	
AC GDT at 30 dB SL		
Mean (SD)	43.26 (20.68)	66.48 (21.58)
Median	38.98	68.41
Range	11.53 ms - 88.60 ms	35.36 ms -103.11ms
Grand Mean	**54.87 ms (2.97)**	
AMMA		
Tonal	28.32 (4.03)	21.91 (3.83)
Rhythmic	29.59 (3.54)	24.05 (5.38
Total	57.91 (7.04)	46.86 (6.41
Music Instruction (Years)	10.55 (4.54)	0.68 (1.09)
Age in Years	21.82 (1.76)	21.41 (1.22)

Note. Means and *SD*, in parenthesis are reported for each experiment variable. Age in years is include for reference but was not used as variable of interest. Geometric means are reported for WC (within-channel) and AC (across-channel) GDT. AMMA = Advanced Measure of Musical Audiation

Method

PARTICIPANTS

The pool of participants consisted of 49 normal-hearing adults (40 females, 9 males) age range: 19–26 years ($M_{\text{Age}} = 22$ years). Participants included students majoring in music at Auburn University and students majoring in disciplines unrelated to music. Reported history of musical experience ranged from 0–19 years ($M_{\text{Age}} = 5.51$ years). The criteria for normal hearing for participants included normal hearing with pure-tone air-conduction audiometry ($\leq$ 20 dB HL for octave frequencies 250–8000 Hz) and normal word recognition testing (Nu–6 word lists; scores $\geq 90\%$ at 40 dB SL re: PTA). In addition, all participants met criteria for normal distortion product otoacoustic emissions. These criteria were: emissions greater than -5 dB SPL and a signal-to-noise ratio greater than 10 dB for all emissions measured in the frequency range of 1000–5000 Hz. The criteria for inclusion in the study also included no reported history of neurological problems. All participants signed an informed consent form. The protocol was approved by the Auburn University Institutional Review Board.

Musician designation. Participants completed a musical background form that asked them to self-identify as a musician, report enrollment in current music instruction, and indicate completed years of music instruction. Both music aptitude and duration of music experience were quantified on a continuous scale. Each individual was assigned to either the Active Music group or to the Non-Active Music group. To be designated in the Active Music group, individuals self-reported as a music major and musician and confirmed ongoing music instruction over the last 12 months. Two quantitative measures of music experience were determined for each participant: 1) duration of years of music instruction via self-report, and 2) scores on a validated receptive measure of musical aptitude (AMMA). Table 1 provides descriptive statistics for questionnaire responses as well as experimental measures.

DATA COLLECTION PROCEDURES

All testing was conducted in a double-walled sound-treated booth. Audiometric testing was conducted with a calibrated Madsen Aurical audiometer. Distortion product otoacoustic emissions were measured using the GSI Audera system. The ATTR (Lister et al., 2011; Lister et al., 2006) was run on a standard Dell Latitude D505 laptop computer equipped with an Intel Celeron Processor, 1.5 GHz speed, a Sigmatel STAC9750 sound card.

Gap detection procedure. The ATTR uses a two-alternative forced choice task with feedback design to adaptively measure gap detection thresholds. The participant is told that one stimulus contains a gap and the other does not. The participant is asked to select the box that corresponds to the stimulus containing a gap. Once a selection has been made, the test provides visual feedback. The test then continues with the gap durations determined with a two-down/one-up stepping rule, with gap duration changing by a factor of 1.2, and testing ending after eight reversals occur. The ATTR targets 70.7% correct gap detection performance on the psychometric function (Levitt, 1971; Lister et al., 2006). The gap detection threshold is calculated by the ATTR software as the geometric mean of the gap durations for the last six reversals. The 2000 Hz narrow-band noise (NBN) WC subtest of the ATTR was used for the WC portion of the present study, and the NBN-AC subtest of the ATTR (2000 Hz before the gap and 1000 Hz after the gap) was used for the AC portion of the study.

Presentation levels. The presentation level used in this study was 30 dB SL and was selected on the basis of previous research indicating that WC and AC gap detection thresholds measured with the ATTR are asymptotic between 30 and 40 dB SL (Fitzgibbons, 1983; Hess, Blumsack, Ross, & Brock, 2012). The 30 dB SL presentation level used during testing was determined based on each participant's noise threshold that was obtained prior to data collection. Specifically, before testing began, each participant's detection threshold for NBN was found using the WC ATTR practice stimulus (2000 Hz before the gap and 2000 Hz after the gap). These thresholds were obtained with a modified Hughson-Westlake procedure. Increments of 1 dB were used for determination of noise detection thresholds. Once threshold was determined, presentation levels were calculated as detection level added to the designated 30 dB sensation level to produce the presentation level in dB HL. For example, for a participant with a -8 dB HL noise detection level, the 30 dB SL presentation level was presented at 22 dB HL. No rounding was utilized. The mean threshold for the ATTR 2000 Hz narrow band noise was -4.8 dB HL (range: 10 dB HL to 7 db HL). It should be noted that the lowest possible threshold of the ATTR noise was limited to -10 dB HL due to the limits of the audiometer).

Data collection for the ATTR. The ATTR clinical protocol was followed during data collection. Accordingly, determination of the presentation level was followed by practice for the WC task, assessment with the WC task, practice for the AC task, and assessment with the AC test, sequentially. The starting gap duration for both practice tasks was 80 ms at 30 dB SL (re: WC narrowband noise threshold). During gap detection testing, the starting gap duration for the WC portion of the study was set at 40 ms, and the starting gap duration for the AC portion was set at 80 ms at 30 dB SL (re: WC narrowband noise threshold). This protocol is used when the ATTR is administered in clinical settings or as part of a battery of tests (Hudak et al., 2019).

Gap detection stimuli. Stimuli were generated by ATTR software, see Figure 1 for examples of stimuli (Hudak et al., 2019; Lister et al., 2011; Lister et al., 2006). The stimuli consist of narrow band noise geometrically centered on 1 or 2 kHz. The leading noise burst is 300 ms in length and the following noise burst varies between 250 ms and 350 ms. For each trial, a standard stimulus and target stimulus are presented to the listener. In the standard stimulus, a 1 ms gap separates two noise bursts so that similar gating transients are present in both the standard and the target stimuli (in which the size of the gap separating the noise bursts is varied adaptively). The order of presentation of standard and target stimuli is varied randomly. The listener is instructed to select the target stimulus, and the smallest detectable gap is determined (Lister et al., 2006). The ATTR consists of two subtests: the within-channel (WC) subtest in which both noise bursts are centered on 2 kHz and the across-channel (AC) subtest in which the leading noise burst is centered on 2 kHz and the noise burst after the gap is centered on 1 kHz. Ten samples of noise bursts (rise time - fall time = 0) generated to prevent learning of noise characteristics were used to produce files with different gap durations (0–15 ms in 1 ms steps). Examples of ATTR generated time wave forms are shown in Figure 1 (Lister et al., 2006). Additional information regarding stimulus generation and characteristics and instrumentation is provided in (Lister et al., 2006).

Gap detection instrumentation. In the present study, the volume control on the computer was set according to ATTR test setup recommendations as described in the manual. The setting of the computer volume remained unchanged from participant to participant during both the WC and AC testing. It is important to note that the output of the system was governed by the attenuator of the audiometer. The audio output of the laptop was connected to the audiometer with a 3.5 mm output to RCA L/R audio input cable. This cable was connected to the headphone jack on the laptop, and L/R audio ends were connected to external inputs on the audiometer. The signal was calibrated to ensure that it peaked at "0" on the VU meter. An external monitor was connected to the laptop. The monitor was placed outside of the sound booth window but positioned to allow the participants

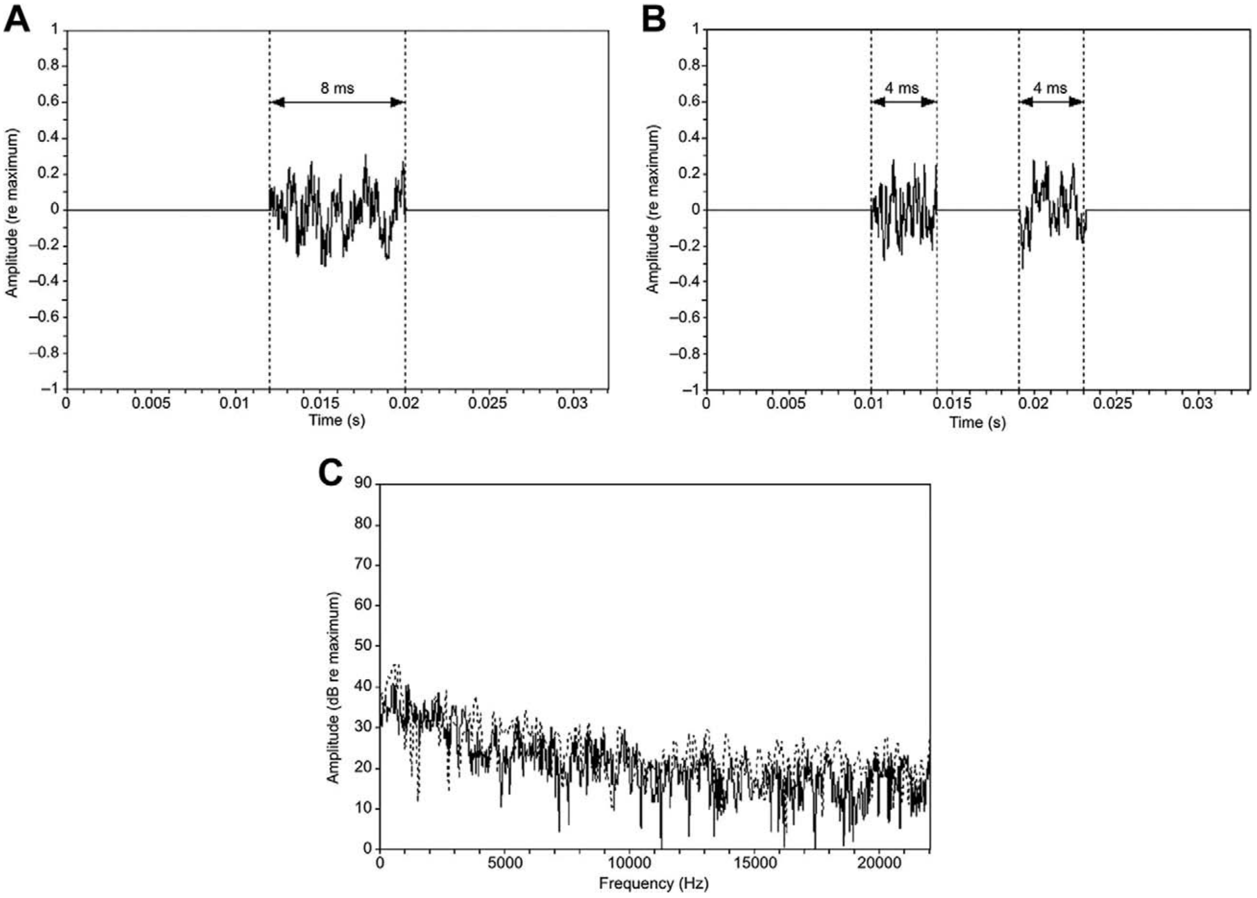

FIGURE 1. Time waveforms for the standard (A) and target (B) interval stimulus files, as stored on the computer. Magnitude spectra for the standard (dashed line) and target (solid line) stimuli (C). The *y*-axes in Panels A and B indicate amplitude relative to ±1, or the level above (or below) which the stimulus would have been peak clipped. The *y*-axis in Panel C indicates decibels, relative to a maximum range of about 90 dB possible for the 16-bit amplitude resolution of the files used. Standard and target spectral analyses used 356 samples (0.008 s) and 578 samples (0.013 s) respectively, resulting in frequency resolution of approximately 125 Hz for the standard spectrum and 77 Hz for the target spectrum. A fast Fourier transform using a rectangular analysis window was performed in each case; no window shaping was needed because the entire signal portion was saved to file and analyzed using one window in each case. Figure 1 and caption reprinted with copyright permission from Lister et al. (2006).

to view the visual elements of the ATTR. A USB 2.0 A-male to A-female extender cable was extended through the wall of the sound booth. Outside the booth, this cable was connected to the laptop.

Inside the booth, the cable was connected to a computer mouse, which was placed on a small table. This arrangement enabled the participant to respond to the test items from inside the test booth. A detailed description of the ATTR instrumentation is provided elsewhere (Lister et al., 2011; Lister et al., 2006). Presentation levels of the ATTR test stimuli were adjusted with the audiometer and routed monotically through a standard audiometric supra-aural headphone to the participant's preferred ear. Previous research has indicated no significant difference in gap detection performance with monotic presentation to left or right ears in young adults with hearing within normal limits (Weihing et al., 2007; Wong & McPherson, 2015).

MUSIC APTITUDE TESTING: INSTRUMENTATION AND PROCEDURES

The AMMA (Gordon, 1995) was selected to assess musical aptitude because it is an objective test with established predictive validity and test-retest reliability for undergraduate music majors and non-majors (Gordon, 1989). The AMMA manual provides additional details regarding the test reliability and validity (Gordon, 1995). The AMMA uses original music performance by a professional musician on a Yamaha Dx-7 synthesizer. The AMMA is considered to reflect stabilized musical aptitude, as it requires a listener to compare and contrast between musical pieces, relying on musical imagery for responses (Gordon, 1989). The test-retest reliability for the AMMA total score for undergraduate non-music majors and music majors is .83 and .89, respectively (Gordon, 1995). A study of the AMMA's predictive validity indicated that the total score has high predictive validity for college student success in music performance. The AMMA is appropriate for adults, and it requires a short time to administer (< 20 minutes). The AMMA appears widely in music perception literature. It provides established percentile-rank norms for young adults.

AMMA procedures. The AMMA commercially available CD was used for testing musical aptitude. The output of the CD was routed through the audiometer and presented monotically to the same ear that was used for gap detection testing. The AMMA consists of 30 pairs of brief music phrases that are presented to the listener. These pairs are items in which there is a music statement followed by a music answer. Some of the music answers differ with respect to duration, meter, or tempo, and some of the music answers differ in pitch, mode, or the tonal center of the melodic line. The listener is instructed to indicate if there is a rhythm or tonal difference between the phrases presented. The AMMA test provides a tonal score, a rhythm score, and a composite score. The composite score is the sum of the tonal and rhythm scores. During administration questions are randomized based on item difficulty and test category (Tonal/Rhythmic). The participant records answers on one of the answer sheets that was included with the test materials. The intensity of test presentation was controlled by the audiometer and was set at 50 dB SL (re: the participant's pure tone average (PTA) threshold for 500 Hz, 1000 Hz, and 2000 Hz) for each participant. After completion of the test, adjusted raw scores were tabulated according to manual instructions (Gordon, 1995).

DATA PREPARATION

ATTR GDTs obtained in the present study were compared to published means and standard deviations for a 30 dB SL presentation level (Hess et al., 2012). This process identified five participants with abnormal (> 11.91 ms) WC GDTs who were removed from formal data analysis. Distribution measures were performed, and one outlier case (+3 *SD*) was identified for AC gap detection. This value was transformed to the next lowest value obtained to reduce the influence of the case as the listener's WC GDT fell within normal limit. The transformed AC GDT fell within the reported for range using an adaptive technique with either NBN or tonal stimuli ($M = 30$ ms ± 11.95; (Lister et al., 2011; Lister et al., 2006) and ($M = 28.68$ ms ± 18.87; range = 87.09 ms to 128.80 ms; Phillips & Smith, 2004). Following data transformation, experimental variables met normality assumptions following visual inspections of histogram and Q-Q Plots.

STATISTICAL ANALYSIS

Statistical analyses were conducted in SPSS Statistics Version 25 (Corp, 2015). Alpha levels for all analyses were set at .05. Preliminary analysis compared the results of WC GDT for the study sample to prior data collected for this age range for presentation levels of 30 dB SL (Hess et al., 2012). Results indicated no significant difference among WC GDT obtained for Hess et al sample ($M = 5.28$, $SD = 1.28$) compared to the current sample ($M = 5.88$, $SD = 1.75$), $t = -1.50$; $SE = 0.40$; $df = 67$; $p = .14$ (Altman, 1991). Data were then analyzed using descriptive analyses of objective data and self-reported musical experience data. A multivariate analysis of variance (MANOVA) was completed to determine significant differences in GDTs obtained in the sample based on dichotomized Music Groups. Correlations and regression analyses were planned to determine the relationship between AMMA composite scores and self-reported duration of music instruction with respect to WC and AC gap detection thresholds. The planned analysis of 44 participants would have sufficient power to identify a small effect size (≥ 0.20) between groups as noted in literature comparing active musicians and nonmusicians (0.95; G*Power v 3.0.10; (Jacob Cohen, 1988; Jacob Cohen, 1992; Phillips & Smith, 2004; Taylor, Hall, Boehnke, & Phillips, 1999; Weaver et al., 2019).

Results

DESCRIPTIVE STATISTICS

Responses on the enrollment questionnaire indicated the following: 36.7% reported < 1 year of music instruction, 18.0% reported 1–4 years of instruction, 18.0% reported 5–9 years, and 27.0% reported greater than 10 years of music instruction. Across the participants in the study, the average AMMA tonal, rhythm, and total scores fell within 1 *SD* of the test means, respectively. No individual score fell outside the normal range for the AMMA subcategories and the total score. Participant demographics and questionnaire responses recorded prior to data collection, AMMA subcategory scores, and total score (columns 4–6) are summarized in Table 1.

TABLE 2. *Univariate F-test Results for MANOVA for Active-Music Groups*

Comparisons	F	p	df	η^2	Observed power
WC GDT[a]	2.77	.104	1, 42	.06	.40
AC GDT[b]	13.27**	.001	1, 42	.27	.95
Wilks' $\lambda = .73$, F (2, 41) $= 7.59$, $p = .002$, $\eta^2 = .27$ (observed power =.93)					

Note. WC and AC GDT were obtained at 30 dB SL, in a fixed order across all participants. Nonparametric are not reported as results mirrored parametric results with equal variance assumed.

[a] $R^2 = .06$ (Adj. $R^2 = .04$); [b] $R^2 = .24$ (Adj. $R^2 = .22$)

*Significant at an alpha level of .01 (two-tailed)

**Significant at an alpha level of .001 (two-tailed)

TABLE 3. *Bivariate Correlations Between Experimental Measures*

Variables	WC GDT	AC GDT	AMMA Total Score
WC GDT (ATTR)			
AC GDT (ATTR)	− .06		
	.70		
AMMA Total Score	.01	−.42**	
	.985	.005	
Years of Music Instruction	−.11	−.54**	.65**
	.442	<.001	<.001

Note. WC (within-channel) and AC (Across-channel) gap detection thresholds. AMMA=Advanced Measure of Musical Audiation

**Significant at an alpha level of .01 (two-tailed; $N = 44$).

*Significant at an alpha level of .05 (two-tailed; $N = 44$).

DICHOTOMIZING MUSIC GROUPS

The MANOVA revealed a significant multivariate main effect for Music Group, Wilks' $\lambda = .73$, $F(2, 41) = 7.59$, $p = .002$, $\eta^2 = .27$ (observed power =.93). Univariate F-tests are reported in Table 2. Results indicated no significant difference among WC GDTs for the dichotomized music group ($M = 5.45$, $SD = 1.64$) than the group with limited music instruction ($M = 6.31$, $SD = 1.80$), $p = .104$. Univariate F-test results for AC GDTs indicated that the Active Music group ($M = 43.26$ $SD = 20.68$) produced smaller AC GDT compared to the Non-Active Music group ($M = 66.48.78$ $SD = 21.58$), $p = .001$.

QUANTIFYING MUSIC EXPERIENCE

Bivariate correlations among the dependent variables (i.e., WC and AC gap detection), and the continuous variables that reflect musical aptitude (AMMA) and duration of instruction (self-report in years) were conducted. Results are provided in Table 3. Significant inverse correlations were found between the AC GDT and AMMA total scores ($r = -.42$, $p < .01$), as well as years of music instruction ($r = -.54$, $p < .001$). The years of music instruction and the AMMA total scores were significantly positively correlated ($r = .65$, $p < .001$). No significant correlations were found between WC GDT and AMMA total scores or WC GDT and years of music instruction (see Table 3).

Planned regression analyses for WC GDTs were not conducted due to insignificant correlations and MANOVA results. Two multiple regression analyses were performed to investigate the potential predictors of AC gap detection performance with reference to controlling which quantitative measure of musical experience was entered first into the predictive model. This approach addresses the covariance among the variables identified during correlation analysis.

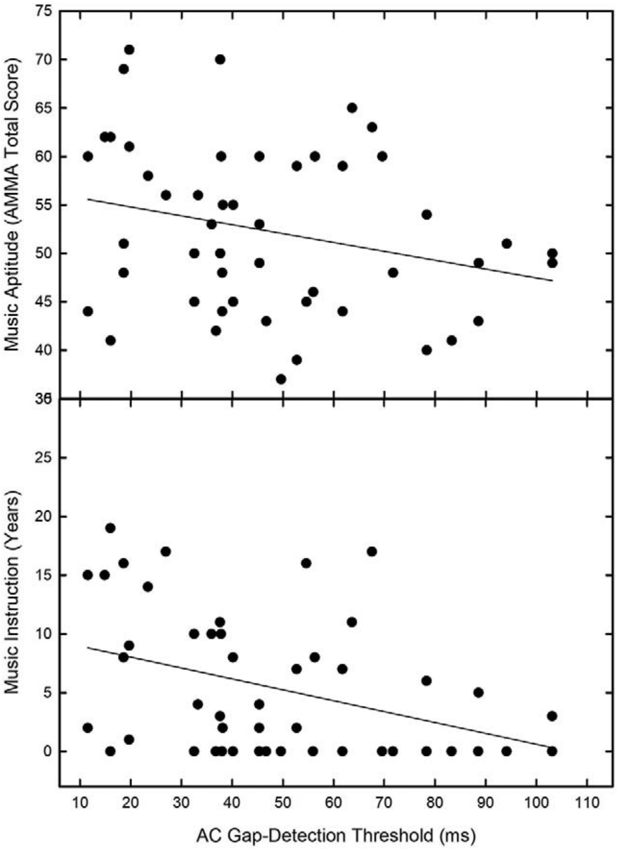

FIGURE 2. Scatter plots of AC gap detection thresholds as a function of AMMA Total Score (top panel), or Years of Music Instruction (Bottom Panel). Simple linear regression lines are shown, note heteroscedasticity years of music instruction for thresholds greater than 80 ms.

Models 1 and 2 used weighted least means hierarchical regression and were conducted due to heteroscedasticity identified in the simple regression line for years of music instruction (see Figure 2). For Model 3, a simple

TABLE 4. *Summary of Hierarchical Regression Analyses for Predicting AC GDTs (N = 44)*

	Model 1						
Variable	*B*	*SE B*	β	ΔR^{2a}	R^2	*F (df1, df2)*	*p value/Power*
AMMA	-1.22	0.38	-.44	.20**	.20	10.20 (1, 42)	.003 / .83
AMMAMusic Ins	-1.88	0.66	-.48	.13**	.33	8.22 (2, 41)	.007 /.92

	Model 2						
Variable	*B*	*SE B*	β	ΔR^{2a}	R^2	*F (df1, df2)*	*p value/power*
Music Ins	-2.21	0.50	-.57	.32***	.32	19.74 (1, 42)	< .001 / .96
Music InsAMMA	-0.36	0.46	-.13	.01	.33	0.62 (2, 41)	.434 / .10

	Model 3						
Variable	*B*	*SE B*	β	ΔR^{2a}	R^2	*F (df1, df2)*	*p value/power*
Music Group	-23.22	6.37	-.49	.24**	.24	13.27 (1,42)	.001 / .99

Note. B = Unstandardized coefficient B, and β = Standardized Beta. The alpha level was set at .05 for Model 1, .025 for Model 2, and .017 for Model 3. Variables bolded in column 1 significantly contributed to the Model reported.
*$p < .05$. **$p < .01$. ***$p = .001$

linear regression model was completed with Music group entered as the predictor. See Table 4 for summary of regression models.

To determine the unique contribution of each predictor for AC GDTs, AMMA total score was entered in step 1 and self-reported years of music instruction was entered in step 2 of regression Model 1. The AMMA total score accounted for 20% of the variance in AC GDT. Controlling for AMMA total score, the self-reported years of music instruction accounted for an additional 13% of the variance in AC GDT. Figure 2 provides scatter plots of the AC GDT ($p < .01$).

Predictors for Model 2 were entered with the experience-dependent variable first. Self-reported years of music instruction in step 1 and AMMA total score was entered into the model in step 2. An alpha level set at .025 for repeated analysis. The self-reported years of music instruction accounted for 32% of the variance in AC GDT. Controlling for the self-reported years of music instruction, the AMMA total score did not account for additional unique variance in AC GDT. Figure 2 provides scatter plots of the AC GDT ($p < .01$).

Model 3, provided for reference with alpha level set at .017 for consecutive analysis, determined that designation in the music group accounted for 24% of the variance in AC GDTs ($p = .001$). This was identified in the MANOVA analysis above, and is reported again as Model 3 for ease of comparison.

Discussion

The present results indicate a significant predictive relationship between AC GDTs and: 1) AMMA composite score, and 2) self-reported musical history.

AMMA AS A MEASURE OF MUSICAL ABILITY

Currently there are several highly regarded measures of music aptitude available; for example, the Musical Ear test (Wallentin et al., 2010), Goldsmith's Musical Sophistication Index (Müllensiefen, Gingras, Musil, & Stewart, 2014), and the Swedish Musical Discrimination Test (Ullén, Mosing, Holm, Eriksson, & Madison, 2014). The AMMA (Gordon, 1990) was chosen for the present study, because it is efficient and has been used widely for educational and research purposes. The AMMA yields three scores: a tonal score, a rhythm score, and a total score. Gordon's research utilized factor analysis to determine the independence of the tonal and rhythm elements. It is important to recognize that the AMMA measures constructs, and scores may reflect combinations of skills and not a single skill (Law & Zentner, 2012). For example, it has been noted that since the rhythm test in the AMMA is presented in a melodic form, the score on that subtest may be confounded by melodic skills (Law & Zentner, 2012). It also has been suggested that the use of human performers in the recording of the AMMA contributed to undesirable inconsistencies in the stimuli (Law & Zentner, 2012).

The Profile of Music Perception Skills (PROMS; (Law & Zentner, 2012) is also an objective measure of musical aptitude that has high internal and external validity. A strength of the PROMS is that it provides assessment of several music perception skills: melody, rhythm to melody, accent, standard rhythm, loudness, tuning tempo, pitch, and timbre. The complete PROMS battery requires a long time to administer (approximately 1 hour) and would not be a feasible measure for many educational and translational research purposes. A brief version of the PROMS has been developed and is being used increasingly for music education and research studies (e.g., Talamini, Carretti, & Grassi, 2016). Given the results of the present study, it is likely that AC gap detection measures would correlate with the PROMS composite score and with subtest scores.

COMPARISON WITH THE GAPS-IN-NOISE (GIN^C) TEST

The GIN Test (Musiek et al., 2005) is a gap detection test that is used widely for clinical and research purposes. It can be administered easily and quickly and is commercially available. In the GIN test, stimuli consist of bursts of broadband noise that contain up to three gaps. The gap lengths are drawn from a set of fixed durations ranging from 2 to 20 ms. The listener is asked to indicate detection of these gaps by pressing a button. Although the GIN tests yields an approximation of the gap detection threshold that correlates significantly with thresholds obtained with adaptive measures (Hoover, Pasquesi, & Souza, 2015), thresholds are less precise than those obtained with the ATTR and the test utilizes only WC stimuli.

It is important to note that tests that measure processing of temporal envelope cues, temporal fine structure, and spectral resolution, currently being investigated in the context of auditory processing disorder assessment (Peter et al., 2014), might be very useful in future study of temporal processing in musicians. These tests avoid confounding of temporal and spectral cues.

RELEVANCE TO RELATED WORK

Considerable evidence suggests that neural structure and function are different in musicians compared to nonmusicians. Imaging studies indicate grey matter volume differences in musicians in several auditory, motor, and visual structures in the brain (Gaser & Schlaug, 2003). Neurophysiological investigations indicate musicians' neural responses to music and other auditory stimuli are different from those of nonmusicians (e.g., Nikjeh et al., 2008; Pantev, Roberts, Schulz, Engelien, & Ross, 2001; Parbery-Clark, Skoe, & Kraus, 2009). In addition, evidence suggests that differences occur at subcortical as well as cortical levels (Bidelman, Villafuerte, Moreno, & Alain, 2014; Parbery-Clark et al., 2012).

It is likely that the observed differences in musicians result from a combination of inherent ability and music instruction. Studies are ongoing in efforts to delineate the contributions of both factors (e.g., Corrigall, Schellenberg, & Misura, 2013). In this regard, it is important to note that the present study uses a cross-sectional design and does not disentangle intrinsic individual differences in auditory processing abilities from effects of music training as contributors to the observed relationships (Mankel & Bidelman, 2018). In the present study music instruction accounts for 13–32% of that variance in AC GDTs in the study sample. This finding suggests that experience-dependent plasticity is driving enhancement in temporal processing, beyond that associated with musical aptitude.

COMPARISONS WITH PREVIOUS STUDIES

The present results are consistent with two studies indicating that WC GDT were not significantly related to musical ability (Law & Zentner, 2012) or self-reported musical experience (Elangovan et al., 2016). In one study that investigated temporal resolution in Carnatic-trained musicians; however, results indicated enhanced WC GDTs compared to nonmusicians (Mishra & Panda, 2014). The basis for these conflicting results is unclear. In both studies, participants were divided into two groups: musicians and nonmusicians (Mishra & Panda, 2014; Payne & Elangovan, 2012), but it is important to note that there were differences in the reported length of experience, age of onset of music training, and practice regimen criteria for assignment to the musician group (Mishra & Panda, 2014; Payne & Elangovan, 2012). Additionally, the specific musical backgrounds (Western vs. Indian classical) differed.

Results of the current work suggest that AC GDTs obtained with the ATTR were sensitive to enhancements to temporal processing mediated by the combination of musical aptitude and duration of music instruction. Prior work suggesting that WC gap detection is peripherally mediated (Phillips, 1999) is consistent with findings in the present study in that they support the view that WC GDTs are not related to central innate or experience-dependent plasticity associated with music instruction.

STATISTICAL ANALYSIS

To align with previous work, the dataset was compared in two methods related to designating the role of music history. The first method dichotomized music background based on self-report of music engagement. Individuals with active engagement in formal music instruction and self-identification as a musician produced significantly lower AC GDTs. No between-group differences were detected for WC GDTs; however, these results are preliminary, as the WC and AC task order was not counterbalanced.

The results of the first regression analysis tested the hypotheses that musical aptitude as measured with the AMMA is correlated with AC gap detection acuity. The outcomes of unstandardized coefficients suggested that, for every additional point scored of the AMMA total, the AC gap detection acuity is refined by 1.22 ms. Controlling for AMMA, for every additional year of music instruction reported, the AC gap detection acuity is refined by 1.88 ms. These values, which are aligned with standardized beta coefficients, are .44 and .48, indicating slightly stronger effect of instruction than musical aptitude. This model aligns with the perspective that instruction builds upon pre-existing abilities. Therefore, pre-existing factors in the present analysis were controlled first. The results suggest that AC gap detection thresholds may be of interest to music educators, music therapists, and other professionals interested in measuring a psychophysical correlate to musical aptitude and music instruction.

In the second model, experience-dependent plasticity was controlled by first entering years of musical instruction in step 1. The outcomes of unstandardized coefficients suggested that, for every additional year of music instruction reported, the AC gap detection acuity is refined by 2.21 ms. This model may overestimate the role of instruction by accounting for all the variance in AC GDTs. Figure 2 suggests that innate AC gap detection is not uniform prior to instruction. Model 3 was included for reference to demonstrate the effect of dichotomizing participants. The outcomes of Model 3 show that responses indicating majoring in music and self-identification as a musician on average refines AC gap detection acuity by 23.22 ms. Model 3 does not address the role of pre-existing factors or experience-dependent plasticity. Model 1 may provide a more appropriate estimation of the variance in AC gap detection than Model 2 or 3.

Although the present findings are consistent with previous work (Elangovan et al., 2016), the results are preliminary, in that musicians may have benefitted differentially from the sequential administration of the WC and the AC tasks. Evidence suggests that musicians are more efficient than nonmusicians in learning auditory tasks (Abrams & Kraus, 2009; Robinson & Summerfield, 1996), and adept learning during the WC task in the present study may have enhanced musician AC performance. Future work with a counterbalanced approach would provide clarification.

Conclusions

The results of the present study indicated both musical aptitude and music instruction are correlated to AC GDTs. Although both AC and WC gap detection tests were used as measures of temporal resolution in the present study, musical aptitude was related to the GDTs only when the AC stimuli were used. This study provides normal values that may be useful in clinical and educational settings. The ATTR protocol that was used in the present study entails sequential, rather than counterbalanced administration of the WC tasks and AC tasks and limits the application of these results for other purposes. Future work incorporating a counterbalanced administration of WC and AC GDT tasks would support additional applications.

Author Note

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