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7 Noise Exposure May Diminish the Musician Advantage for Perceiving Speech in Noise

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25 **ABSTRACT**

26 *Objective:* Although numerous studies have shown that musicians have better speech perception
27 in noise (SPIN) compared to non-musicians, other studies have not replicated the “musician
28 advantage for SPIN.” One factor that has not been adequately addressed in previous studies is
29 how musicians’ SPIN is affected by routine exposure to high levels of sound. We hypothesized
30 that such exposure diminishes the musician advantage for SPIN.

31 *Design:* Environmental sound levels were measured continuously for one week via body-worn
32 noise dosimeters in 56 college students with diverse musical backgrounds and clinically-normal
33 pure tone averages. SPIN was measured using the Quick Speech in Noise Test (QuickSIN).
34 Multiple linear regression modeling was used to examine how music practice (years of playing a
35 musical instrument) and routine noise exposure predict QuickSIN scores.

36 *Results:* Noise exposure and music practice were both significant predictors of QuickSIN, but they
37 had opposing influences, with more years of music practice predicting better QuickSIN scores and
38 greater routine noise exposure predicting worse QuickSIN scores. Moreover, mediation analysis
39 suggests that noise exposure suppresses the relationship between music practice and QuickSIN
40 scores.

41 *Conclusions:* Our findings suggest a beneficial relationship between music practice and SPIN that
42 is suppressed by noise exposure.

43 **Keywords:**

44 Speech perception in noise, musicians, noise exposure

45 **Abbreviations**

46 HINT, Hearing In Noise Test

47 PTA, pure tone average

48 QuickSIN, Quick Speech in Noise Test

49 SNHL, sensorineural hearing loss

50 SPIN, speech perception in noise

51 TTS, temporary threshold shift

52 WIN, Words in Noise test

53

54 **INTRODUCTION**

55 Communicating in noisy environments is universally difficult, although some individuals fare
56 better than others. While hearing thresholds are one important factor that can affect speech
57 intelligibility in noise, individual differences in hearing thresholds cannot explain the full range of
58 performance observed on clinical measures of speech perception in noise (SPIN) (Anderson et al.
59 2013). Performance on such tests is known to depend on a multitude of auditory and non-auditory
60 factors, including general cognition (Anderson et al. 2013; Boebinger et al. 2015), the listener's
61 ability to use top-down knowledge to fill in acoustic details obscured by noise (Elliott 1995;
62 Pichora-Fuller 2003), vocabulary knowledge (Anaya et al. 2016), the ability to store and recall
63 linguistic item(s) from memory (Gordon-Salant and Fitzgibbons 1997), as well as the ability to
64 attend to the target signal while inhibiting auditory distractors (Passow et al. 2012). In addition,
65 lifestyle and experiential factors can also positively or negatively influence performance on SPIN
66 tests (Anderson et al. 2013; Skoe and Karayanidi 2018; Van Engen and Bradlow 2007).

67 Playing a musical instrument is one experiential factor that has been identified as
68 potentially positively influencing SPIN, although the extent to which music practice benefits SPIN
69 is a subject of some controversy. We begin with a review of the literature on music practice and
70 SPIN. (For a more in-depth, systematic review of the literature, including the neurophysiological
71 correlates of SPIN, we refer the reader to Coffey et al. (2017)). Following our review of the
72 literature, we offer a hypothesis to explain the mixed results, which we test in a sample of college
73 students with clinically normal audiograms.

74 **Evidence for and against musical training having a positive influence on SPIN**

75 Parbery-Clark et al. (2009) were the first to report a potential musician advantage for SPIN. They
76 reported that classically-trained adult instrumentalists who began training at an early age and
77 practiced for at least 13 years outperformed those with less than three years of music practice on
78 two clinical tests of SPIN, the Quick Speech in Noise Test (QuickSIN, Etymotic, Inc.) and one but
79 not all of the conditions of the Hearing in Noise Test (HINT) (Nilsson et al. 1994). For the HINT,
80 the musician advantage was observed when the speech and masker (speech-shaped noise) were
81 spatially co-located (HINT-Front condition), but not for the two conditions where the speech and
82 masker were spatially separated. In the same study, when the data were treated continuously, a
83 correlational relationship emerged between total years of music practice and SPIN performance
84 for the QuickSIN and the HINT-Front condition but not the spatially-separated HINT conditions.
85 Similarly, Ruggles et al. (2014) found a relationship between years of music practice and SPIN
86 scores (QuickSIN and HINT) among musically-trained young adults. Yet, as a group, the
87 musically-trained adults did not differ from non-musicians on these clinical tests or on variants of
88 these tests. Unlike Parbery-Clark et al. (2009), whose study participants were instrumentalists,
89 Ruggles et al. (2014) included both instrumentalists and vocalists. This is noteworthy given new
90 evidence suggesting that vocalists do not perform to the same level as instrumentalists on
91 QuickSIN (Slater and Kraus 2016).

92 Another set of studies explored the degree to which musician advantages in SPIN are
93 evident across the lifespan. Focusing on the younger end of the age spectrum, Strait et al. (2012)
94 found that school-age children who began private instrumental training before age five and had at
95 least four years of consistent practice (five days/week) had superior performance on the HINT
96 compared to demographically-matched peers who were not musically active but were involved in
97 other enrichment activities such as art classes. Examining the other end of the age spectrum, in

98 their large cross-sectional study, Zendel and Alain (2012) provided evidence to suggest that
99 musicians experience less age-related decline in QuickSIN scores than non-musicians. Moreover,
100 after controlling for age-related effects on the QuickSIN test, they found that better QuickSIN
101 scores were associated with more musical activity per week (measured in hours/week), although
102 an overall main effect of musicianship did not emerge for QuickSIN. In this study, the definition
103 of musician was broad and the sample also included amateur and professional musicians. In
104 contrast to the Zendel and Alain (2012) study, a more recent study by Yeend et al. (2017) did not
105 find an association between SPIN and music practice in their diverse sample of adults. However,
106 one key difference between the studies is that the Yeend et al. (2017) study did not define music
107 practice in terms of the total years of experience but instead asked participants to define the highest
108 level of training that they had completed. Adopting more stringent criteria for defining a musician
109 than either Zendel and Alain (2012) or Yeend et al. (2017), Parbery-Clark et al. (2011) focused on
110 older adults with at least 40 years of active engagement in music-making that began early in life,
111 during pre-school or early grammar school. This group of highly trained older adult musicians
112 outperformed age-matched non-musicians on QuickSIN, HINT, and Words in Noise (WIN). Thus,
113 the discrepant findings across studies could partially be attributed to differences in how “musician”
114 or “music practice” is being defined.

115 If music practice can benefit SPIN, as suggested by a large majority of the behavioral
116 studies (16 of 18) in the systematic review by Coffey et al. (2017), which specific sensory and/or
117 cognitive skills might be contributing to this advantage? Improved recognition of speech in noise
118 for musicians could be due to their possession of heightened psychoacoustic abilities as the result
119 of music practice (Yeend et al. 2017), such as heightened frequency discrimination (Boebinger et
120 al. 2015; Madsen et al. 2017; Meha-Bettison et al. 2017; Parbery-Clark et al. 2009; Ruggles et al.

121 2014) and temporal resolution (Donai and Jennings 2016; Mohamadkhani et al. 2010). To help
122 isolate the factors that contribute to (potential) SPIN advantages in musicians, various studies have
123 compared musicians to non-musicians on versions of SPIN tests in which different acoustic
124 features of the target speech and/or noise were manipulated. Fuller et al. (2007), for example,
125 found that adult musicians performed slightly better than age-matched non-musicians for word
126 (but not sentence) identification tasks in which stimuli were processed through a cochlear implant
127 simulation (Fuller et al. 2014). This SPIN advantage was attributed to musicians' improved ability
128 to discriminate vocal pitch cues in degraded speech stimuli. A more recent study found that while
129 frequency discrimination was better for musicians than non-musicians, musicians did not derive a
130 greater benefit than did non-musicians on a SPIN task when the fundamental frequency (F0)
131 difference between the target and masker voices was increased (Madsen et al. 2017). In a similar
132 study, Başkent and Gaudrain (2016) used a speech-on-speech design in which they manipulated
133 two vocal characteristics of the competing sentence in a SPIN task: the F0 and the simulated vocal
134 tract length. Using this paradigm, they found that musicians had higher speech-on-speech
135 intelligibility scores than non-musicians across all test conditions, which they interpreted as
136 reflecting a generalized improvement in the auditory skills required for listening in noise that is
137 not specific to voice processing (for a similar finding see Donai and Jennings 2016). In another
138 study with a speech-on-speech paradigm, Swaminathan et al. (2015) presented masking stimuli
139 from different spatial locations. They found that musicians, relative to non-musicians, performed
140 similarly when the target and masker were co-located, but the musicians showed a greater boost
141 in performance, compared to the non-musicians, when the target and masker were spatially
142 separated. Yet, when Swaminathan et al. (2015) reduced the amount of informational masking by
143 time-reversing the speech masker, a significant group difference appeared for the co-located

144 condition but not the spatially-separated conditions, with the musicians having lower speech
145 recognition thresholds than the non-musicians in the co-located condition. This is reminiscent of
146 the findings by Parbery-Clark et al., (2009), in which a musician advantage emerged for the co-
147 located condition but not the spatially separated conditions when the speech signal was
148 energetically masked. Thus, this collection of studies indicates that the musician advantage for
149 SPIN may depend on the amount of informational masking present and that musicians' heightened
150 psychoacoustic abilities may impart a greater advantage on some but not all SPIN test conditions.

151 While the focus of investigation has largely been on the auditory skills that might
152 contribute to musician advantage for SPIN, a recent study by Anaya et al. (2016) examined the
153 possibility that the musician advantage for processing degraded sensory input is not limited to the
154 auditory modality but is instead domain-general. In support of this idea, the authors found long-
155 term music training to be associated with enhanced acuity for a visual analog of SPIN in college
156 musicians compared to non-musicians, using a test that involved reading printed sentences where
157 pixels were removed from each printed letter to create a visually fragmented stimulus (Anaya et
158 al. 2016). This study also found a positive association between years of music practice and
159 (auditory) SPIN in their musician group; however, while the group difference for the visual analog
160 of SPIN was statistically different between musicians and non-musicians, the group difference for
161 the SPIN test was only marginally significant (Anaya et al. 2016). This study suggests that
162 musicians may be relying on domain-general skills to process sensory input, in addition to
163 reinforcing the idea that continuous-level data on musical training (e.g., years of playing a musical
164 instrument) may be more sensitive to illuminating the association between music practice and
165 SPIN than group comparisons that dichotomize participants into musicians and non-musicians.

166 Another explanation for why musicians might have better speech perception in noise is that
167 musicians have better domain-general working memory and selective attention (Brochard et al.
168 2004; Moradzadeh et al. 2015; Rodrigues et al. 2013). Thus, musicians might have better speech
169 perception in noise because they are better able to attend to target speech amid background noise,
170 and then remember the target speech stimulus. Consistent with this interpretation, Parbery-Clark
171 et al. (2009) found a correlation between auditory working memory and both QuickSIN and HINT
172 performance. In addition, follow-up work to the Swaminathan et al. (2015) study performed by
173 Clayton et al. (2016) found that performance in a spatial SPIN task related to performance on an
174 auditory working memory task and selective (visual) attention task. If higher-level (non-auditory)
175 cognitive factors mediate the SPIN advantage, this could explain why musicians and non-
176 musicians have been found to have equivalent speech-recognition thresholds across a variety of
177 masking conditions (i.e., clear speech masker, spectrally-rotated speech, speech-amplitude-
178 modulated noise, and speech-spectrum-steady-state noise) when they are matched with respect to
179 higher-level factors, such as non-verbal IQ, auditory working memory, selective attention, and
180 mental flexibility (Boebinger et al. 2015).

181 To summarize, while numerous studies have shown an association between musical
182 training and SPIN, the effect of musical training does not always translate into a group difference
183 when participants are categorized as musicians and non-musicians. From these mixed findings, a
184 debate has emerged about whether a musician advantage for SPIN exists, and if it does exist, what
185 conditions bring it about. A variety of factors have previously been proposed to account for the
186 mixed evidence that musical training benefits SPIN, including variation in how a “musician” is
187 defined (e.g., instrumentalist, vocalist, professional, hobbyist, etc.), the extent to which the

188 participant is currently active in musical activities, and inadequate control of linguistic factors and
189 cognitive factors in study participants that may positively or negatively influence SPIN.

190 **The negating effects of noise exposure on SPIN**

191 Another critical, but surprisingly underexplored, factor that could provide a further explanation of
192 the mixed results linking musical training and SPIN is noise exposure. Musicians, especially those
193 who play amplified music or practice and perform with large groups or in poor acoustic conditions,
194 are regularly exposed to sound levels that place them at risk for noise-induced hearing loss (NIHL)
195 (Miller 2007; Tufts and Skoe 2017; Washnik et al. 2016). Even before NIHL emerges on standard
196 clinical measures of hearing, routine exposure to high levels of sound can compromise auditory
197 processing (Hope et al. 2013; Liberman et al. 2016; Skoe and Tufts 2018). This leads us to
198 hypothesize that routine noise exposure undermines the SPIN advantage accrued through music
199 practice. The primary goal of the current study was to investigate this hypothesis by examining
200 how music practice and noise exposure relate to SPIN in young adults with clinically-normal
201 hearing. To do so, we administered the QuickSIN test, and obtained information about the
202 participants' current noise exposure using a small body-worn sound level meter, called a noise
203 dosimeter, that was worn for one week.

204 While the link between noise exposure and hearing loss is well-characterized (Rabinowitz
205 2000; Sliwinska-Kowalska and Davis 2012), the relationship between routine noise exposure and
206 SPIN in individuals with clinically-normal hearing has only recently received attention. In a small
207 study from 2013, Hope and colleagues reported that military pilots with a history of high levels of
208 occupational noise exposure had worse SPIN than an age-matched peer group of Royal Air Force
209 administrators, who were not routinely exposed to occupational noise and who were
210 audiometrically similar to the pilots with respect to the pure tone average (PTA) of 0.5, 1, 2 and

211 4 kHz (Hope et al. 2013). This finding serves as preliminary evidence that routine noise exposure
212 compromises SPIN, even when hearing threshold levels are accounted for, although we
213 acknowledge that the 0.5-1-2-4 PTA may be insensitive to NIHL. Liberman et al. (2016) found
214 that young adults at risk for NIHL due to routine exposure to loud sounds had poorer speech
215 recognition scores in noisy but not quiet conditions compared to an age-matched group that was
216 considered to be at low risk for NIHL. In this case, the groups were audiometrically matched over
217 the standard audiometric range (octave intervals from 0.25-8 kHz); however, there were
218 statistically significant group differences in high-frequency audiology, with the at-risk group
219 having poorer high-frequency hearing than the low-risk group. Of note is that most, but not all, of
220 the participants in their at-risk group were pursuing degrees in music performance; however,
221 Liberman et al. (2016) did not examine the inter-relations between noise exposure, years of
222 musical training, and SPIN. This motivates the current work, which uses multiple linear regression
223 and mediation analysis to examine the relationships between QuickSIN, years of playing a musical
224 instrument, noise exposure levels, and pure tone audiometric averages. Like Liberman et al.
225 (2016), we focus on college students but we expand on their methodology by using a dosimeter to
226 objectively measure noise exposure over a 1-week period of the academic semester.

227

228 **MATERIALS AND METHODS**

229 The study was approved by the Institutional Review Board at the University of Connecticut and
230 prior to starting the experiment, written consent was obtained from all participants. Participants
231 received financial compensation for their participation in this weeklong study. In the laboratory,
232 hearing thresholds, and the QuickSIN test were all administered in a single-walled sound-
233 attenuating chamber, prior to the dosimetry measurements. We adopted the U.S. Department of

234 Labor, Occupational Safety and Health Administration requirement of a 14-hour quiet period prior
235 to performing a baseline hearing assessment in noise-exposed populations. This quiet period was
236 mandated for all participants to minimize the likelihood of a temporary threshold shift due to recent
237 noise exposure affecting the audiogram and QuickSIN test.

238 For all participants, dosimetry occurred during the academic semester, when curricular and
239 extracurricular activities were underway, with the goal of generating a representative snapshot of
240 noise exposure during the academic semester. Data collection was distributed across the academic
241 semester and we specifically avoided testing participants during the first two weeks of the
242 semester, during the mid-semester break, or during finals week. We also factored in the
243 performance schedules of the music ensemble participants to ensure that their testing occurred
244 before the end of their performance schedule.

245 *Participants*

246 Participants consisted of 56 college students (13 males), aged 18-24 years, at the University of
247 Connecticut with no history of neurological or otologic disorders. All participants were native
248 speakers of American English, had clinically normal or near-normal QuickSIN scores, and had
249 pure-tone average (PTA) audimetric thresholds <20 dB HL when averaged across 10 frequencies
250 between 125 and 8000 Hz (see below).

251 Participants completed a questionnaire about their current and past musical activities.
252 Across the group of 56 participants, all but eight had some experience playing a musical instrument
253 or singing. We operationally defined the ‘years of playing a musical instrument’ variable as the
254 total number of years that the participant had played a musical instrument, with voice treated as an
255 instrument. Across the entire participant sample, the total years of playing a musical instrument

256 ranged from 0 to 17 years (mean = 7.80 years, standard deviation = 5.16 years) (Table 1), and the
257 age that formal instrumental playing started ranged from 4 to 16 years (mean = 8.60 years, standard
258 deviation = 2.25). Two participants, whose primary instrument was voice at the time of testing,
259 reported that they starting singing before age 2, which is well before formal vocal training typically
260 begins. In these two cases, *Years of Playing a Musical Instrument* was computed based on when
261 the participant reported first starting formal music lessons on an instrument other than voice. Eight
262 participants reported that they had never played a musical instrument. For the purposes of
263 performing group-level comparisons between “musicians” and “non-musicians”, the dataset was
264 grouped based on the Years of Playing a Musical Instrument variable, with “musicians” being
265 defined as having ≥ 7 years (n=35) and “non-musicians” defined as having < 7 years of music
266 training (n=21) (Table 1). This cutoff was selected because it represents the lowest number of
267 years of music training among the subset of 24 participants who were currently active in music
268 ensembles at the time of study enrollment. These 24 participants were active in the UConn pep
269 band, marching band, wind ensemble, drumline, concert band, color guard, symphonic band,
270 and/or one of several different choirs (Table 1). Unlike the students in the Liberman et al. (2016)
271 study, most of the college students in our sample were pursuing degrees in fields outside of music
272 (all but 1).

273 [Table 1]

274 *Hearing Thresholds*

275 In the laboratory, participants were screened using otoscopy and tympanometry to rule out outer-
276 and middle-ear pathology. Air conduction thresholds were then obtained bilaterally at octave and
277 semi-octave frequencies (125, 250, 500, 1000, 1500, 2000, 3000, 4000, 6000, 8000 Hz) using ER-
278 2 insert earphones connected to a Grason-Stadler GSI 61 audiometer. Sheft et al. (2012) found

279 that QuickSIN scores were strongly correlated with the average of the pure-tone thresholds at 0.5,
280 1.0, and 2.0 kHz (i.e., the pure-tone average or PTA) in their investigation into the effects of age
281 and hearing loss on QuickSIN, using a sample that ranged more broadly in age and hearing
282 configuration than our sample. In addition to using the bilateral PTA of 0.5, 1.0, 2.0 kHz (PTA
283 0.5-1-2) in our analyses, we incorporated the bilateral PTA of 3.0, 4.0, and 6.0 kHz (PTA 3-4-6),
284 given that within the standard audiometric range, the indicators of NIHL often emerge first at these
285 frequencies (Niskar et al. 2001).

286 *QuickSIN*

287 The Quick Speech in Noise test (QuickSIN, Etymotic Research Inc.) was delivered from a CD via
288 a GSI 61 audiometer through ER-2 insert earphones. The first four sentence lists from the corpus
289 of 20 were presented. Each list contains six sentences, spoken by the same female voice. An
290 example sentence is: The square peg will settle in the round hole (key words underlined). The
291 sentences are presented at 70 dB HL, mixed with four-talker (three women, one man) babble. The
292 starting level of the babble is 45 dB HL, increasing in 5-dB steps with each subsequent sentence
293 presentation. Thus, the first sentence is presented with a signal-to-noise ratio (SNR) of 25 dB and
294 the final (sixth) sentence is presented with an SNR of 0 dB.

295 One practice sentence list was given at the outset of testing to provide an opportunity for
296 the participant to become familiarized with the test procedures. During the test, participants were
297 instructed to repeat back each sentence immediately after it was played, and the number of key
298 words correctly repeated was recorded, with each sentence containing five key words. The score
299 for each sentence list was reported as an ‘SNR loss’, derived by subtracting the total number of
300 correct key words (out of a possible 30) for that list from 25.5. The lower the SNR loss, the better
301 the performance, with the lowest (i.e., best) possible score for each list being -4.5 dB. The SNR

302 loss was averaged across the four sentence lists to compute the final QuickSIN score used in the
303 statistical analyses. SNR loss \leq 2 dB is considered clinically normal based on data provided by
304 the test developers. QuickSIN scores in the current sample ranged between -1.25 and 2.25 dB
305 SNR Loss, with four participants scoring above 2 dB SNR Loss.

306 *Noise Dosimetry*

307 At the end of the test session in the lab, participants were trained to use a noise dosimeter (ER-
308 200DW8 personal noise dosimeter; Etymotic, Inc.) and to manually record their daily activities
309 into an activity logbook (Tufts and Skoe 2017). Participants were instructed to wear the dosimeter
310 on their clothing, near the ear, and to leave the microphone inlet uncovered. When sleeping or
311 showering, or during activities when the device might be damaged (e.g., sports), participants were
312 told they could remove the dosimeter but to keep it nearby if possible.

313 Before the participant left the lab, the experimenter turned on the dosimeter and
314 immediately recorded the time of day. Participants were instructed to contact the research team if
315 any issues relating to the dosimeter arose during the week. The turnoff button was disabled so that
316 participants could not accidentally shut off the dosimeter. After seven full days, they returned to
317 the lab to hand in the dosimeter and the daily activity log and to receive compensation for their
318 participation in the study.

319 The dosimeters were configured to an 85-dBA criterion level and 3-dB exchange rate, in
320 conformance with the National Institute for Occupational Safety and Health criteria (NIOSH,
321 1998), and a 75-dBA threshold. The measurement period was set to seven consecutive 24-hour
322 days. During the measurement period, the dosimeters obtained dose values every 220 msec and
323 summed these values over 3.75-minute increments to facilitate data visualization and analysis.

324 The calibration of all dosimeters was periodically checked during the data collection period to
325 ensure that the instruments were operating properly. This was done by generating a continuous
326 1000-Hz narrowband signal at a nominal level of 90 dB SPL in an Audioscan Verifit test box, and
327 measuring its level with a calibrated Type 1 sound level meter (Larson-Davis 824) and with each
328 dosimeter in “QuickCheck” mode. For each measurement, the microphone of the device was
329 positioned at the same location in the test box. Measured dosimeter levels fell within 2.5 dB of
330 the mean of three sound level meter measurements.

331 Dosimetry data were downloaded to .txt files, one per participant, using the ER200D Utility
332 Suite software (version 4.04). The data were then processed individually for each participant using
333 an in-house MATLAB routine (release 2016a, The Mathworks, Inc.) that separated the data by
334 date, using the dosimeter start time recorded by the investigator. The noise dose for each
335 measurement date was calculated using NIOSH procedures, and doses were averaged across days.
336 This serves as our measure of ‘Noise Exposure.’ The participant sample displayed a wide range of
337 Noise Exposures from 1% to 902% average noise dose (Figures 1 and 2). The participants with
338 the highest exposures were predominantly, though not exclusively, individuals who were active in
339 large music ensembles at the time of testing. Note that in reference to the dosimeter, noise refers
340 to exposure to high-intensity sound, whereas for QuickSIN, noise refers to a distracting
341 background sound that energetically and informationally masks the target signal.

342 *Statistical analysis*

343 The Kolmogorov-Smirnov test was used to test for normality of the dependent variables. All
344 variables except the Noise Exposure measure met the condition of normality. The Noise Exposure
345 measure was log-transformed so that it would conform to normality, and the statistical analyses
346 were carried out on the transformed data. Statistical analyses were performed in SPSS (version

347 24, IBM, Inc.) or, when specifically noted, in the R programming language (version 3.3.1).
348 Relations among variables were first examined using Pearson correlations. This was followed
349 by multiple linear regression. Multiple linear regression was used to model the relationship
350 between QuickSIN SNR Loss score (the response variable) and two explanatory variables (Years
351 of Playing a Musical Instrument, and Noise Exposure). R^2 values (both adjusted and unadjusted)
352 are reported.

353 Partial correlations were performed in SPSS to measure the association between two
354 variables after adjusting for the influence of an additional variable. To generate a partial
355 correlation plot between QuickSIN and Years of Playing a Musical Instrument that adjusts for the
356 influence of Noise Exposure on both variables (Figure 2C), we did the following: (1) we computed
357 the standardized residuals (i.e., the difference between the predicted and response variables) when
358 regressing QuickSIN against Noise Exposure, (2) we computed the standardized residuals when
359 regressing Years of Musical Training against Noise Exposure, and then (3) we plotted the two
360 residuals against each other. The same process was repeated to create a partial correlation plot
361 between QuickSIN and Noise Exposure that adjusts for the influence of Years of Playing a Musical
362 Instrument (Figure 2D).

363 We tested for an interaction between Noise Exposure and Years of Playing a Musical
364 Instrument on QuickSIN SNR Loss score, as part of a moderator regression analysis performed in
365 SPSS. Finally, we tested whether Noise Exposure has a suppressive effect on the relationship
366 between Years of Playing a Musical Instrument and QuickSIN SNR Loss score, in the R
367 programming language (version 3.3.1) using R Studio version 1.1.423 (R Core Team, Boston, MA,
368 USA) via the Mediation package. A suppression effect, also referred to as an inconsistent
369 mediation, is present when the direct and mediated effects of the predictor variable (Years of

370 Playing a Musical Instrument) on the dependent variable (QuickSIN SNR Loss score) have
371 opposite signs (MacKinnon et al. 2007; MacKinnon et al. 2000). The indirect (suppressive) effect
372 was tested using a bootstrap estimation approach with 10,000 samples (Hayes and Scharkow
373 2013).

374 **RESULTS**

375 ***Group Comparisons***

376 The non-musician group had a mean noise dose of 41% (SD = 69), with a range of 1 to 294%. By
377 contrast, the musician group had a mean noise dose of 293% (SD = 315), with a range of 7 to
378 902%, a statistically significant difference compared to the non-musician group, $F(1,55) = 12.96$,
379 $p < .01$ (Figure 1B).

380 Noise doses $>100\%$ are associated with increased risk for hearing loss (NIOSH, 1998).
381 The mean noise dose of the musicians (293%) suggests that, on average, they are at greater risk of
382 NIHL than are the non-musicians (mean dose = 41%), although it is not possible to predict a given
383 individual's likelihood of developing NIHL from population data. Examination of the activity
384 books filled out by the participants in conjunction with the dosimetry data revealed that high noise
385 levels were most often associated with social activities for the non-musicians and with both music
386 and social activities for the musicians. Our sample size did not permit a meaningful comparison
387 of doses as a function of instrument(s) played for the musicians (Table 1). We note, however, that
388 the four musicians with low noise doses ($< 50\%$) played relatively quiet instruments at the time of
389 study participation (voice, piano, bassoon). Moreover, of these four, only one was involved in
390 more than one musical ensemble; this participant was active in a choir but also participated in color
391 guard, a non-musical section of the UConn Marching band that uses visual flags, mock rifles, and
392 other equipment to move rhythmically to the music.

Despite being at greater risk for NIHL, the musician group did not differ significantly from the non-musician group with respect to either the lower-frequency (0.5, 1.0, 2.0 kHz) (Figure 1C) or the higher-frequency (3.0, 4.0, 6.0 kHz) (Figure 1D) pure-tone average (F(1,55) = 0.01, p = 0.94; F(1,55) = 1.50, p = 0.23, respectively). For lower-frequency range, the musician group had a PTA of 6.78 dB HL (SD = 3.92) and the non-musician group had a mean PTA of 6.71 dB HL (SD = 3.55) (Figure 1C). For the higher-frequency range, the musician group had a PTA of 5.28 dB HL (SD = 3.86), compared to 4.04 dB HL (SD = 3.23) for the non-musician group (Figure 1D). Given the typically gradual progression of NIHL over time, the relative youth of the participant sample, and the imperfect relationship between noise dose and lifetime noise exposure, this finding not surprising (Jin et al. 2013).

403 For QuickSIN, the non-musician group had a mean SNR Loss score of 0.86 (SD =0.58),
404 with a range of 0.25 to 2.00. For the musician group, the mean was 0.61 (SD =0.75), with a range
405 of -1.25 to 2.25. The QuickSIN SNR Loss scores were not statistically different between the two
406 groups, $F(1,55) = 1.59$, $p = 0.21$, until Noise Exposure was added as a covariate $F(1,53) = 6.17$,
407 $p = 0.02$ (Figure 1A).

408 [Figure 1, color]

410 *Correlations among Variables*

411 The next set of analyses treated musical training as a continuous variable, using the Years of
412 Playing a Musical Instrument variable. To explore the inter-relations among variables, pairwise
413 correlations were performed between QuickSIN SNR Loss scores, PTAs, Noise Exposure and
414 Years of Playing a Musical Instrument. We begin with the correlations between PTAs and the
415 other variables. The relation between QuickSIN SNR Loss scores and PTA-0.5-1-2 kHz was not

416 statistically significant ($r = 0.01$, $p = 0.93$), nor was the relation with the PTA-3-4-6 kHz ($r = -$
417 0.13 , $p = 0.35$) significant. With respect to Noise Exposure, significant relations were not found
418 with either PTA metric ($r = 0.04$, $p = 0.77$; $r = 0.14$, $p = 0.3$, respectively for PTA-0.5-1-2 and
419 PTA-3-4-6 kHz). Likewise, for Years of Playing a Musical Instrument, significant relations did
420 not emerge with either PTA ($r = 0.04$, $p = 0.77$; $r = 0.14$, $p = 0.34$, respectively for PTA-0.5-1-2
421 and PTA-3-4-6 kHz).

422 Next, we consider the relations between Years of Playing a Musical Instrument and the
423 other variables. The relationship between Years of Playing a Musical Instrument and QuickSIN
424 SNR Loss scores was found to be statistically significant, with more years of music practice being
425 associated with better (lower) SPIN scores ($r = -0.27$, $p = 0.04$) (Figure 2A). However, the
426 relationships between QuickSIN scores and other measures of music practice are not significant
427 (years since playing a musical instrument, $r = -0.02$, $p = 0.87$; age that instrumental playing
428 started, $r = 0.16$, $p = 0.29$).

429 There was also a significant relationship between Years of Playing a Musical Instrument
430 and Noise Exposure ($r = 0.41$, $p < 0.002$), with more years of playing a musical instrument
431 associated with higher levels of Noise Exposure. The relationship between Noise Exposure and
432 Years of Playing a Musical Instrument can be explained as follows: The average age for starting
433 musical training in our dataset was 8.6 years, which is consistent with when most children begin
434 playing a musical instrument in school in the United States (Steinel 1990). Individuals who begin
435 musical activities as school-age children and continue with musical activities in college music
436 ensembles will generally have more years of playing a musical instrument than those who do not
437 continue playing into college. Since participation in college music ensembles was associated with

438 higher levels of exposure, it follows that participants with more years of playing an instrument
439 generally had higher levels of exposure.

440 Consistent with the possibility that noise exposure suppresses the relationship between
441 SPIN and musical training, the relationship between QuickSIN SNR Loss scores and years of
442 playing a musical instrument is stronger when Noise Exposure is added as a covariate ($r = -0.38$,
443 $p = 0.004$) (Figure 2C). Note, however, that the pairwise correlation between QuickSIN SNR Loss
444 scores and Noise Exposure is not statistically significant ($r = 0.18$, $p = 0.18$) (Figure 2B) until years
445 of playing a musical instrument is added as a covariate ($r = 0.33$, $p = 0.01$) (Figure 2D).

446 [Figure 2, color]

447 To examine how Years of Playing a Musical Instrument and Noise Exposure collectively
448 and independently predict QuickSIN scores, multiple linear regression analysis was performed,
449 using Years of Playing a Musical Instrument and Noise Exposure as the predictor variables. A
450 significant regression model emerged ($F(2,53) = 5.9$, $p = 0.01$), with an R^2 of 0.17 and an adjusted
451 R^2 of 0.14. Moreover, both measures were found to be independent, significant predictors of
452 QuickSIN SNR Loss scores. Consistent with our predictions, the regression analysis indicated
453 that Years of Playing a Musical Instrument is associated with better QuickSIN SNR loss scores
454 (standardized coefficients $\beta = -0.41$, $t = -3.02$, $p = 0.004$) but Noise Exposure was associated with
455 worse SNR Loss scores ($\beta = 0.35$, $t = 2.5$, $p = 0.01$). We then tested a reduced model, containing
456 only Years of Playing a Musical Instrument as a predictor. This reduced model, with an R of 0.26
457 and an adjusted R^2 of 0.05 ($F(1,54) = 4.00$, $p = 0.05$), had a significantly lower R^2 than the model
458 that included Noise Exposure as the second predictor (adjusted R^2 -change = .13, $F(1,53) = 5.77$, p
459 = 0.02). Thus, Noise Exposure is a significant, additional predictor of QuickSIN SNR Loss scores
460 beyond the predictive value of Years of Playing a Musical Instrument alone. For all models tested,

461 the variance inflation factor (VIF) was < 2 , suggesting that there were no indications of
462 multicollinearity.

463 ***Moderation and Mediation Analysis***

464 Moderation analysis was performed to evaluate whether Noise Exposure and Years of Playing a
465 Musical Instrument interact in predicting QuickSIN SNR Loss scores. A significant interaction
466 would indicate that the strength of the relationship between Years of Playing a Musical Instrument
467 and QuickSIN is different for lower compared to higher values of Noise Exposure. We did not
468 find evidence for an interaction. Using a step-wise regression approach we found that adding the
469 interaction term to the regression model did not increase the variance explained for QuickSIN SNR
470 Loss scores (R^2 Change = .01, $F(1, 51) = 0.524$, $p = 0.47$), nor was the beta weight of the
471 interaction term significant (standardized coefficients $\beta = 0.14$, $t = 1.04$, $p = 0.30$).

472 Next, we performed a mediation analysis. To test whether noise exposure has a suppressive
473 effect on the relationship between years of playing a musical instrument and QuickSIN, we tested
474 an “inconsistent” mediation model in which Years of Playing a Musical instrument was the
475 independent (predictor) variable, QuickSIN SNR Loss was the dependent variable, and Noise
476 Exposure was the suppressor variable. When Noise Exposure is included as a mediating variable,
477 the direct effect between Years of Playing a Musical Instrument is stronger ($b = -0.06$, 95% CI =
478 $-0.10, -0.02$, $p = 0.003$) than the total effect (i.e., model without the suppressor) ($b = -0.04$, 95%
479 CI = $-0.07, 0.00$, $p = 0.05$). Consistent with Noise Exposure acting as a suppressor variable, the
480 indirect path of the mediation model has an opposite sign ($b = .019$, 95% CI = $.003, 0.04$, $p = 0.01$)
481 from the direct path ($b = -0.06$). Thus, the mediation analysis suggests that musical training affects
482 SPIN abilities directly and indirectly. Through the direct path, it has a beneficial effect on SPIN.

483 However, through the indirect (mediated) path of Noise Exposure, musical training results in worse
484 QuickSIN performance (Figure 3).

485 [Figure 3, color]

486 **DISCUSSION**

487 Despite the well-recognized hearing hazards of music-making, the combined effect of music
488 practice and noise exposure on speech perception in background noise is understudied. This
489 motivated us to examine the relations between music practice, noise exposure, and SPIN. Our
490 analysis revealed three key findings: First, both variables — total years of playing a musical
491 instrument and noise exposure — were significant predictors of SPIN, after controlling for the
492 confounding influence of the other variable. Consistent with this, the group-level comparison did
493 not reveal a musician advantage for SPIN, until noise exposure was added as a covariate. Second,
494 we found that total years of playing a musical instrument and noise exposure have opposing
495 relationships with SPIN, with more music practice being associated with better QuickSIN scores
496 and more noise exposure being associated with worse QuickSIN scores. Third, years of playing a
497 musical instrument has both a direct and indirect influence on SPIN, with the indirect pathway
498 being mediated by noise exposure. Importantly, noise exposure was found to be a suppressor
499 variable on the mediating relationship between musical training and SPIN, suggesting that more
500 years of musical training can increase the likelihood of higher levels of noise exposure, which in
501 turn can yield lower SPIN abilities. The current study, thus, provides evidence to support our
502 hypothesis that noise exposure may undercut the beneficial influences that music practice can have
503 on SPIN. This analysis is consistent with the mixed reports of a musician advantage for speech in
504 noise in the extant literature. When taken in the context of the larger literature on SPIN in
505 musicians, our findings offer a new explanation for why the positive effect of music practice on

506 SPIN seen in some studies was not observed in others, given that none of the previous studies used
507 objective measures of noise exposure to account for the potentially negating influence of noise
508 exposure on SPIN (Boebinger et al. 2015; Madsen et al. 2017; Ruggles et al. 2014; Yeend et al.
509 2017).

510 Using a body-worn dosimeter, we measured noise exposure in college students
511 continuously over a week (seven consecutive days) during an academic semester. We compared
512 QuickSIN scores and noise exposure, with the presumption that the observed noise doses were
513 generally representative of the participants' typical noise exposure patterns during the academic
514 year. When interpreting our study outcomes, two important methodological details must be
515 considered: (1) for all participants, all auditory testing (including QuickSIN) took place following
516 a 14-hour quiet period to minimize potential contamination from a temporary threshold shift,
517 which would be a concern for participants who regularly engage in loud activities, and (2) the
518 noise dosimeters were turned on only after all auditory testing had been completed. Thus, poorer
519 performance on the QuickSIN test cannot be interpreted as the direct result of noise exposure
520 measured as part of the study, nor is it likely to be the direct result of noise exposure occurring
521 immediately prior to testing. When interpreting our findings, it should also be taken into account
522 that the QuickSIN scores were predominately in the clinically-normal range, with only a small
523 number of data points (4 out of 56) falling at the upper end of the normal range. Thus, we do not
524 observe any functional (i.e., clinically-significant) SPIN deficits, but rather a statistically-
525 significant decrease in performance within the normal range, within a young adult population
526 whose weekly noise doses ranged from 1% to 902%.

527 A strength of our study is that we have noise dosimetry on all of our participants over the
528 course of one week, and this dosimetry data has given us new insight into the relationship between

529 routine noise exposure and SPIN. However, methodological limitations of our study should be
530 noted. First, our noise dosimetry protocol does not capture sound exposure through headphones
531 or earphones, and therefore we likely underestimate the total noise exposure. Second, we did not
532 formally assess whether the presence of the dosimeters influenced participants' behavior in ways
533 that could have impacted their noise exposure. However, we explicitly instructed the participants
534 to go about all of their normal activities during the measurement period, and we saw no evidence
535 in the activity books suggesting they did otherwise. Third, we did not have the equipment needed
536 to obtain extended high frequency audiometric thresholds above 8 kHz, and the potential impact
537 of extended high frequency hearing on SPIN is, therefore, unknown in our study sample. This is
538 noteworthy given that there have been repeated demonstrations of high frequency hearing loss in
539 noise exposed populations in recent studies (Grose et al. 2017; Liberman et al. 2016; Prendergast
540 et al. 2017; Yeend et al. 2017). Another limitation is that we cannot validate whether the dosimetry
541 measurements are representative of longer-term or lifetime noise exposure in our participants,
542 which prevents us from making any conclusive statements about the relationship between SPIN
543 and lifetime noise exposure in our participants. However, recent studies investigating SPIN and
544 metrics of lifetime noise exposure have found no relation between the two, and/or no evidence that
545 a SPIN impairment is associated with noise exposure (Guest et al. 2018; Yeend et al. 2017). This
546 is not completely unlike the current study where the relation between QuickSIN and noise
547 dosimetry was not statistically significant, until years of playing a musical instrument was added
548 as a covariate. As with the present study, Yeend et al. (2017) explored the influences of music
549 practice and noise exposure on SPIN but they focused on lifetime noise exposure, as estimated
550 from responses to an online survey. As expected, the professional musicians in their sample had
551 greater estimated lifetime sound exposure than the non-musicians. However, across the sample,

552 estimated lifetime noise exposure was not predictive of SPIN nor was music practice predictive of
553 SPIN. In other words, neither a benefit of music practice nor a detriment of lifetime noise exposure
554 on SPIN was observed.

555 While the Yeend et al. (2017) study addressed a similar question as the current study, there
556 is little overlap in methodology. First, unlike the current study where the study sample was limited
557 to young adult college students with clinically-normal hearing, Yeend et al. tested a larger, more
558 diverse sample (aged 30-57 years), one-third of whom had mild hearing loss (the rest had clinically
559 normal hearing, i.e., thresholds ≤ 20 dB HL at 0.25-6 kHz). In addition, their study sample
560 included professional musicians, amateur musicians, and non-musicians, whereas ours included
561 no professional musicians. Second, in the Yeend et al. (2017) study, music practice was not
562 defined in terms of years of experience. Instead, music practice was operationalized using the
563 highest level of schooling at which the participant had received formal training, with the levels
564 being: primary, secondary, tertiary, post-secondary, or no training (Chin and Rickard, 2012). This
565 measure (at least, how it was described by Yeend et al. (2017)) is categorical and therefore may
566 be poorly suited to capture the relationships between music practice, noise exposure, and SPIN.
567 These methodological and demographic differences complicate our ability to draw conclusions
568 across the two studies.

569 Another factor that must be considered when examining differences in the study outcomes
570 is that the two studies used different SPIN tests: QuickSIN (current study) and one subset of the
571 Listening in Spatialized Noise–Sentences Test (LiSN-S) (Cameron et al. 2011) in the Yeend et al.
572 (2017) study. These two tests differ from each other on multiple dimensions, with the QuickSIN
573 arguably being a more difficult test. In QuickSIN, the target speech and background babble are
574 spatially co-located. By contrast, in the LiSN-S subtest, the target speech (a woman’s voice) is

575 spatially separated by 90 degrees from the distractors, with the distractors being two children's
576 stories spoken by female voices that loop continuously throughout the test. The LiSN-S test also
577 uses simpler vocabulary and syntactic structure than QuickSIN for both the target and distractor
578 speech. Unlike QuickSIN, the SNR is changed adaptively and the listener is cued (using a 1000-
579 Hz tone burst) that the next sentence is about to begin. While QuickSIN has been used previously
580 to examine the influence of musicianship on SPIN (e.g., Parbery-Clark et al. 2012; Parbery-Clark
581 et al. 2009; Ruggles et al. 2014; Zendel and Alain 2012), we are aware of only one other study to
582 have used the LiSN-S for this purpose (Meha-Bettison et al. 2017). In that study, Meha-Bettison
583 et al. (2017) administered all four subtests of the LiSN-S test to a small group of professional
584 musicians and non-musicians and found that the professional musicians outperformed the non-
585 musicians on only one of the subtests, the most challenging subtest. In this most challenging
586 subtest of the LiSN-S test, which was not part of the test battery in the Yeend et al. (2017) study,
587 the target sentence and distractor stories are spoken by the same voice. Thus, it is possible that no
588 musician advantage was seen by Yeend et al. (2017) because their measure of SPIN was not
589 sufficiently challenging to reveal an advantage.

590 Finally, and perhaps most critically, differences in the noise exposure measures used in the
591 two studies could also account for the disparate findings. Yeend et al. (2017) used a survey-based
592 estimate of lifetime noise exposure, whereas we used an objective measurement of current noise
593 exposure over a single representative week. Each measure has intrinsic limitations, and each
594 provides at best an incomplete representation of noise exposure. Estimating lifetime noise
595 exposure from a survey could provide a general picture of the number of years and/or types of
596 exposures, but, even in a clinical setting, such measures are taken with a grain of salt, because they
597 are subject to errors of recall, loudness judgment, etc. A one-week objective measurement,

598 assuming it was done correctly, provides quantifiable evidence of the amount of noise exposure,
599 but cannot be assumed to be representative of an individual's lifetime exposure.

600 Without dissecting each study further, it should be clear from the discussion above that
601 multiple possible explanations exist for why Yeend et al. (2017) came to a different conclusion
602 regarding the effects of music practice and noise exposure on SPIN than we did. Alternatively, it
603 could be argued that our study outcomes are not, in fact, fundamentally different from those
604 reported by Yeend et al. (2017), given that we did not observe any clinically significant SPIN
605 deficits in our participant sample. Nevertheless, to further explicate the relation between noise
606 exposure and SPIN, there would be value in augmenting our test protocol to include multiple
607 measures of SPIN (e.g., QuickSIN and LiSN-S) and multiple measures of noise exposure,
608 including dosimetry to assess current noise exposure levels, well-vetted survey-based approaches
609 to estimate lifetime noise exposure, and extended high frequency audiometry.

610 **Conclusions**

611 The results from this study suggest that noise exposure and music practice can both influence how
612 well a listener can understand speech in a noisy background, and we provide evidence that noise
613 exposure can suppress the positive effects of music practice on SPIN. Our study, thus, establishes
614 the need to consider noise exposure when investigating SPIN in musicians. However, a limitation
615 of the current investigation is that we did not evaluate the host of other variables that may affect
616 SPIN performance and presumably covary with music practice, including various measures of
617 cognition and language ability, socio-economic status, as well as other auditory abilities (Anaya
618 et al. 2016; Anderson et al. 2013; Boebinger et al. 2015; Le Prell et al. 2013; Reetzke et al. 2016).
619 Future studies should consider using structural equation modeling and other multivariate statistical
620 techniques to elucidate the degree to which clinical measures of SPIN can be predicted from a

621 broader constellation of auditory and non-auditory factors (Anderson et al. 2013), including
622 measures that better characterize lifetime noise exposure.

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629 *Statement of author contributions*

630 E.S. and J.T. designed the experiments. S.C. performed the experiments. E.S., J.T., and S.C.
631 analyzed data. E.S. and J.T. wrote the paper. S.C. wrote portions of the methods, and provided
632 critical feedback on the manuscript at all stages.

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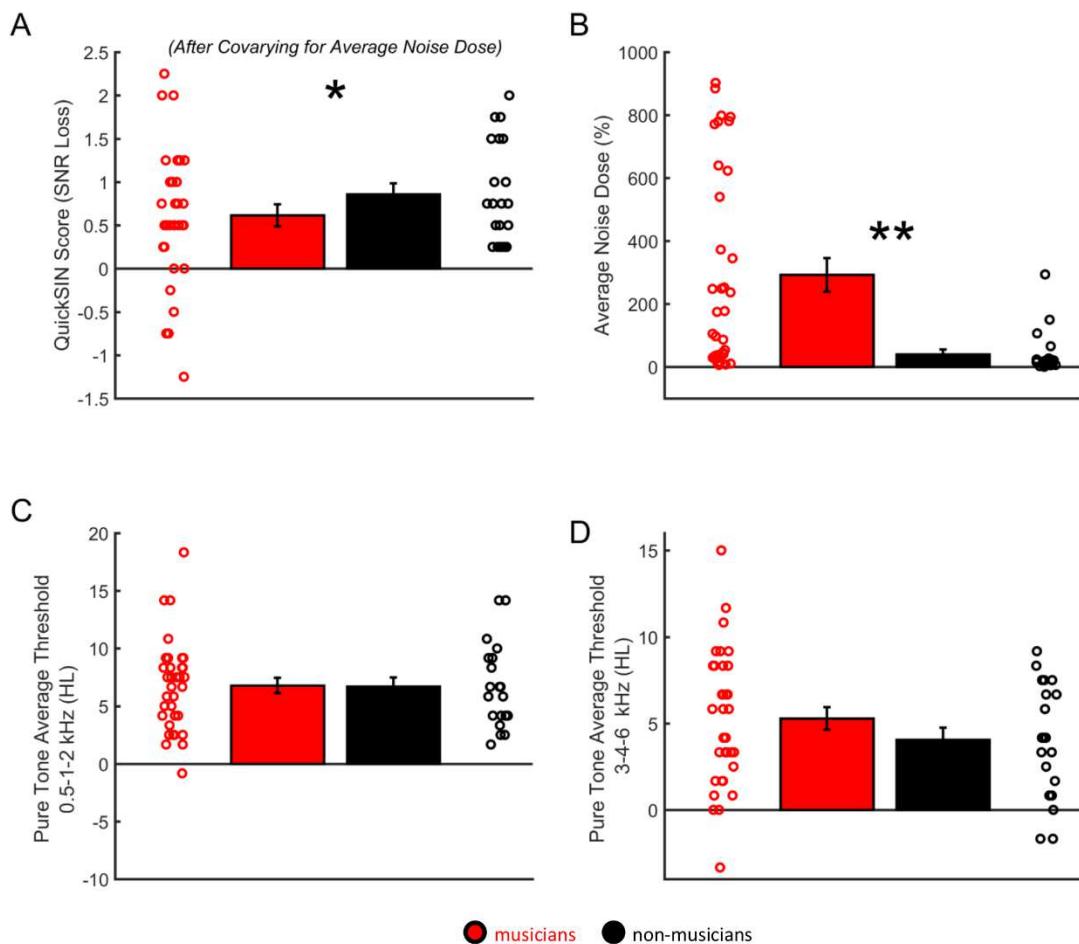
762 **TABLES**

763 **Table 1. Noise Exposure and Musical History.** Participants are grouped based on the total years
764 of musical training (Column B) into non-musician (<7 years) and musician (>=7 years)
765 groups. The musician group is further subdivided in this table based on whether they were active
766 in a musical ensemble at the time they participated in the study, with the total number of ensembles
767 listed in Column B. For each group, the participants are sorted based on Noise Dose (Column A),
768 rounded to the nearest integer value. Column C indicates whether the participant was active in
769 marching band or pep band, two ensembles that perform at loud sporting events on campus. For
770 the participants with current and/or past musical experience, the instruments are listed in Column
771 D in order of primary, secondary, (etc.) instrument. Instruments that were being played at the time
772 of study participation are denoted with a #.

773

774 **FIGURE CAPTIONS**

775 **Figure 1.** Comparisons between the musician (red) and non-musician (black) groups on (A) QuickSIN,
 776 (B) Noise Exposure, and (c) Pure Tone Average (PTA) threshold for 0.5, 1, 2 kHz and (D) PTA threshold
 777 for 3.0, 4.0, 6.0 kHz. In each panel, group means are plotted for each test, with error bars representing
 778 one standard error of the mean. One-dimensional scatter plots show the distribution of scores across
 779 groups. * $p < 0.05$, ** $p <= 0.01$

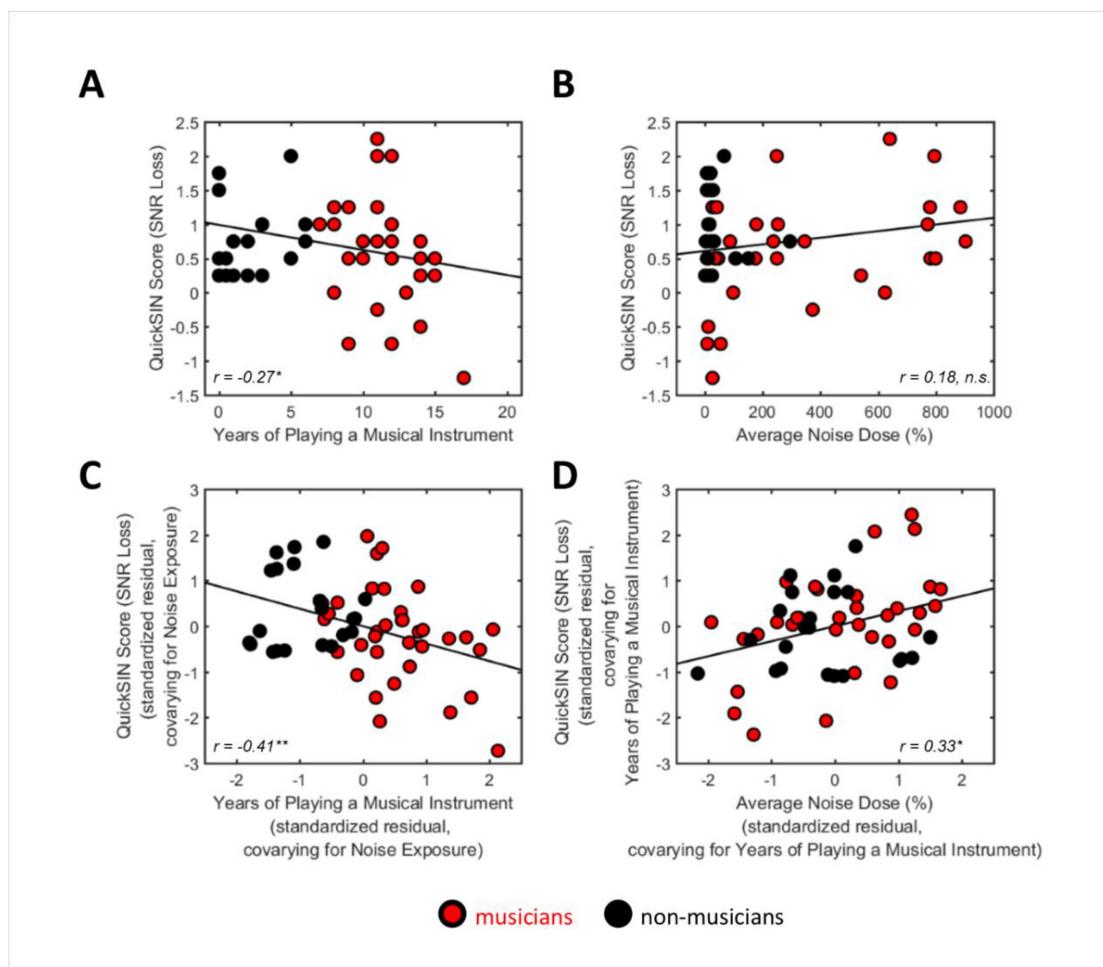


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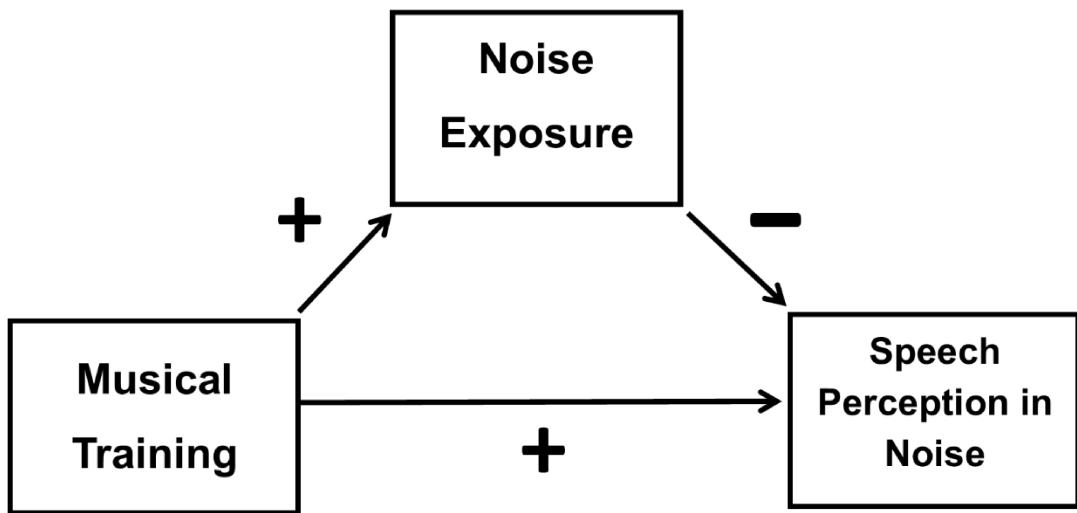
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783 **Figure 2. Relationships between Music Training and QuickSIN scores (A, C) and Noise**
 784 **Exposure and QuickSIN scores (B, D).** Top: Scatterplots illustrating the relationship between
 785 Years of Musical Training and QuickSIN SNR Loss scores (A) and the relationship between Noise
 786 Exposure and QuickSIN SNR loss scores (B). Bottom: Partial correlation plots between QuickSIN
 787 SNR Loss scores and Years of Playing a Musical Instrument, controlling for Noise Exposure (C),
 788 and between QuickSIN SNR Loss scores and Noise Exposure, controlling for Years of Playing a
 789 Musical Instrument (D). Note that for panels C and D abscissa and ordinate reflect standardized
 790 residual scores. To help visualize the trends in the data, the data point for each participant is color-
 791 coded to depict their group membership in Figure 1 (red = musicians, black = non-musicians). * p
 792 < 0.05 , ** $p <= 0.01$



793

794 **Figure 3. Schematic representing the direct (black) and indirect effects (light blue) of musical**
795 **training on speech perception in noise (SPIN).** Mediation analysis suggests that musical training
796 affects SPIN abilities directly and indirectly. Through the direct path, it has a beneficial effect on
797 SPIN. But through the indirect, mediated path of noise exposure, musical training results in worse
798 SPIN performance.



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