THE EFFECT OF SUBJECTIVE FATIGUE ON AUDITORY PROCESSING IN MUSICIANS AND NONMUSICIANS

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WE ASSESSED FATIGUE'S EFFECT ON TEMPORAL RESOLUTION and speech perception in noise abilities in trained instrumental musicians. In a pretest-posttest quasiexperimental research design, trained instrumental musicians ($n = 39$) and theater artists as nonmusicians ($n = 37$) participated. Fatigue was measured using a visual analog scale (VAS) under eight fatigue categories. The temporal release of masking measured the temporal resolution, and auditory stream segregation assessed speech perception in noise. Entire testing was carried out at two time-points: before and after rehearsal. Each participant rehearsed for five to six hours: musicians playing musical instruments and theater artists conducted stage practice. The results revealed significantly lower VAS scores for both musicians and nonmusicians after rehearsal, indicating that both musicians and nonmusicians were fatigued after rehearsal. The musicians had higher scores for temporal release of masking and lower scores for auditory stream segregation abilities than nonmusicians in the pre-fatigue condition, indicating musicians' edge in auditory processing abilities. However, no such differences in the scores of musicians and nonmusicians were observed in the post-fatigue testing. The results were inferred as the music training related advantage in temporal resolution, and speech perception in noise might have been reduced due to fatigue. In the end, we recommend that musicians consider fatigue a significant factor, as it might affect their performance in auditory processing tasks. Future researchers must also consider fatigue as a variable while measuring auditory processing in musicians. However, we restricted the auditory processing to temporal resolution and speech perception in noise only. Generalizing these results to other auditory processes requires further investigation.

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Key words: auditory processing, psychoacoustics, music training, subjective fatigue, speech perception

MUSIC TRAINING HAS RECENTLY GAINED interest, as many researchers have found a positive effect of such training on musicians' cognitive and auditory processing skills (Kraus, 2011; Kraus & Chandrasekaran, 2010; Merrett et al., 2013; Miendlarzewska & Trost, 2014). Musacchia et al. (2007) have reported enhanced subcortical auditory and auditory-visual processing of speech and music in musicians and demonstrated that music training caused such changes. Wong et al. (2007) examined the brainstem encoding of linguistic pitch and found that it was robust in musicians compared to nonmusicians. Such shaping enhanced the brainstem's role in speech encoding and frequency modulation. Jain, Mohamed, and Kumar (2015) had measured the effect of short-term music training on speech perception in noise abilities in younger adults. They found a significant enhancement in speech-in-noise abilities attributed to music training. However, they found no improvement in the frequency, intensity, and temporal resolution abilities after training (Jain et al., 2014). Dubinsky et al. (2019) measured the effect of short-term choir singing in older adults with hearing loss and found better speech perception in noise abilities and improved frequency difference limen and the frequency following responses in those individuals.

Du and Zatorre (2017) investigated how long-term music training contributes to enhanced speech perception in noisy environments. They found that musicians benefit in syllable in noise identification task relative to nonmusicians. Musicians' brain responses were associated with stronger activation of the left inferior frontal and right auditory regions, as observed in functional magnetic resonance imaging. Multivoxel pattern analysis showed that the musicians had greater specificity of phoneme representations in bilateral auditory and speech motor regions at higher SNRs and the left speech motor regions at lower SNRs. The intrahemispheric and interhemispheric functional connectivity between auditory and speech-motor regions were also enhanced in

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musicians. These findings suggest that music training may enhance auditory encoding, speech motor prediction, and auditory-motor integration, contributing to better speech perception in noisy situations.

Monteiro et al. (2010) had compared the temporal resolution abilities in musicians and nonmusicians. They, however, found no effect of training in music on the performance of the gap in noise test. Suarez et al. (2016) also found no effect of music training on scanning ability, processing skills, and spatial memory. Thus, the extent to which such training contributed to neurocognitive processing was unclear.

Many factors such as age, motivation, working hours, environmental conditions, exhaustion, and fatigue might have affected the earlier studies' findings. Among those factors, in one of our previous studies, we found that fatigue reduced the effect of music training on working memory (Jain & Nataraja, 2019). We have recommended considering fatigue as a variable in research related to musicians' processing abilities.

As cognitive processing is known to complexly interact with auditory processing (Tomlin et al., 2015), we thought it would be worthwhile to investigate the effect of fatigue on auditory processing abilities. In nonmusicians, fatigue negatively influenced word-finding abilities, and auditory learning capacities, and impacted complex auditory processing (Haig-Ferguson et al., 2009; Lange et al., 2005; Michiels et al., 1996; Moore et al., 2017). Simon et al. (2020) had found that even short-term cognitive fatigue affected the temporal order judgment in nonmusicians. Moore et al. (2017) had attributed attention-related problems as the underlying cause of auditory processing deficits secondary to fatigue. However, Simon et al. (2020) reliably found that the decline in the temporal order judgments was specific to temporal processing deficits and ruled out attention's role. Despite no agreement over attention as a cause of reduced auditory processing test scores, all the earlier researchers have agreed that long or short-term auditory input leads to fatigue.

Musicians are professionals highly exposed to auditory signals. Music training requires continuous exposure and attention to sound for long durations. Musicians' work schedules involve rehearsals and recording sessions during business hours, but live performances are often in the nights and weekends. In musicians, based on the U. S. Bureau of Labor Statistics 2021 report, insomnia, anxiety, stress, and fatigue are common complaints. Drinkwater and Klopper (2010) have investigated the effect of fatigue on prolonged music performance. They induced fatigue by asking the wind musicians to repeat a 10-minute performance playing a wind instrument three times. They measured heart rate, respiratory rate, blood pressure, blood lactate concentration, perceived exertion, and anxiety. The results revealed that prolonged music performance increased perceived exertion, anxiety, and fatigue, which adversely affected their performance. Thus, musicians are prone to fatigue. On one side, fatigue might reduce the auditory processing abilities in trained musicians, whereas on the other side, music training enhances such abilities. The effect of fatigue on auditory processing in trained musicians was not well defined. We hypothesized that fatigue might influence auditory processing abilities in trained instrumental musicians. However, as music training improves auditory processing, the effect of fatigue should be less pronounced. We compared the auditory processing abilities of musicians with that of nonmusicians. As nonmusicians were not trained and based on the earlier studies' findings, we expected a significant effect of fatigue on auditory processing in them. Thus, we tested the auditory processing abilities of trained musicians while considering fatigue as an intervening variable. It might help us gain insight that would allow us to better understand processing deficits experienced by musicians.

Method

PARTICIPANTS

We initially selected 69 trained instrumental professional musicians from a local music troop in the pretest-posttest quasiexperimental research design. All musicians had received formal training in musical instruments (string, keyboard, and/or percussion instruments). They were practicing instruments for the last ten years (for 5–6 hours/day, 4–5 days/week). We also selected 74 theater artists as nonmusicians. We selected theater artists as they had a similar work structure as musicians and were exposed to music as a part of theater arts, although not trained formally. They were involved in practicing theater arts for ten years (for 5–6 hours/day, 4–5 days/week) but had never received any formal or informal music training. The band/theater was the only source of income for both musicians and nonmusicians, and they were not involved in any other part-time job. All participants belonged to similar socioeconomic and cultural backgrounds. They had native-like proficiency in Kannada (L1) and "good" proficiency in English (L2/L3), as measured using Language Experience and Proficiency Questionnaire-Indian (Maitreyee & Goswami, 2016). The participants were able to read, write, and speak both Kannada and English.

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After taking approval from the institutional ethical board, we interviewed each participant, and no one reported having any history of associated sensory, neurological, psychological, or behavioral problems. They also reported having no family history of auditory or cognitive processing problems. We screened the participant's cognitive abilities using Addenbrooke's Cognitive Examination-Revised (Mioshi et al., 2006). We found that all participants had scores higher than 88/100, indicating no cognitive decline risk. We further tested their hearing sensitivity using pure tone audiometry (ANSI S3.21, 2009) and otoacoustic emissions. As 15 musicians and 17 nonmusicians had clinical/subclinical hearing loss (PTA$\geq$15 dB H.L.; OAE-SNR$\leq$6 dB for three or more consecutive frequencies), we excluded them. Evidence suggested that the subclinical hearing loss in adults affected the peripheral and central auditory structures (Skoe & Tufts, 2018). It may lead to auditory processing disorders (Moore, 2018). Thus, we excluded such participants. We measured fatigue for the remaining 54 musicians and 57 nonmusicians.

MEASUREMENT OF FATIGUE

A *visual analog scale* (VAS) was used to measure mental fatigue. The VAS (Guo et al., 2015) was for eight fatigue categories, which determined participants' concentration, anxiety, energy, confidence, irritation, nervousness, sleepiness, and talkativeness. We gave a 50 cm wooden scale, marked with 100 ticks (i.e., 100 points), each at an equal distance of 0.5 cm, to each participant. The 0 digit on the scale indicated minimum perception and 100 as maximum perception. We asked them to mark their perception of each category by sliding an arrow on the selected mark. The testing started after 4–5 practice trials.

We administered VAS for each participant twice: before rehearsal and immediately after rehearsal. Each participant's rehearsal lasted for 5–6 hours, comprising rigorous playing of musical instruments (for musicians) and stage practice (for nonmusicians). The stage practice involved rehearsing play actions, dialogues, and art forms. The stage practice had continuous auditory bombardment, and in that way, their auditory input was somewhat like that of musicians. Park et al. (2001) and Salve (2017) had reported a high correlation between long working hours and fatigue; we tested fatigue before and after rehearsal. We measured response reliability by administering VAS thrice (with a gap of at least 4–5 days between each successive session). Two musicians and five nonmusicians were unable to complete the retesting, and we removed their data from further analysis. We used the following formula (Parsey et al., 2000) for measuring test-retest reliability:

$$VAR = \sum \frac{|test_i - retest_i|}{(test_i + retest_i)/2} \cdot 100\%$$

Where VAR = within-subject variability.

The experimenter inspected the responses consistency and the maximum permissible criterion for variability (25%; as suggested by Robins et al., 2001). The response consistency was measured as, for example, high perceptual scores for anxiety but low scores for nervousness. As anxiety and nervousness were analogous, higher anxiety but lower nervousness perception indicated that the participants were confused or misunderstood the instructions. Based on the consistency and variability criterion, we excluded 13 musicians and 15 nonmusicians. After signing written informed consent, the remaining 39 musicians and 37 nonmusicians underwent temporal resolution and speech perception in noise testing. Table 1 shows the demographic details of these participants.

MEASUREMENT OF AUDITORY PROCESSING ABILITIES

We assessed auditory processing in terms of temporal resolution and speech perception in noise. We opted to measure temporal resolution as it helps in music perception (Nakajima et al., 2018; Rajendran et al., 2018) and aids in discrimination of musical notes (Kumar et al., 2016). The temporal release of masking test measured the temporal resolution ability. We further selected speech perception in noise measurement as many researchers have reported enhanced speech perception in noise in trained musicians (Anaya et al., 2016; Dubinsky et al., 2019; Jain, Mohamed, & Kumar, 2015; Parbery-Clarket al., 2009). Thus, the auditory processing skills of musicians and nonmusicians can easily be differentiated based on speech perception in noise tests. Stream formation was essential for speech perception in noise (Bregman, 1990; Bregman & Campbell, 1971; Bregman & Pinker, 1978; Dannenbring & Bregman, 1976) and music perception (Micheyl et al., 2013; Ragert et al., 2014). Since stream segregation requires skills to discriminate the incoherence in the signal (Christiansen & Oxenham, 2014), it was sensitive to assess the speech perception in noise abilities in musicians.

Temporal Release of Masking Test

We measured the participant's ability to identify the word in noise using standard bisyllabic Kannada words. Jain, Vasudevamurthy, and Raghavendra (2015) had developed 20 equalized word lists (25 words per list)

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TABLE 1. *Demographic Details of the Participants*

	Musicians	Nonmusicians
No. of participants	39	37
Age Range	24–40 years	27–39 years
Mean Age	32.68 + 4.19 years	35.085 + 3.43 years
Gender	33 Males & 6 Females	32 Males & 5 Females
Mean PTA[a]	11.62 + 2.5 dB HL	12.5 + 2.25 dB HL
Mean HF-PTA[b]	21.06 + 4.1 dB HL	19.54 + 3.6 dB HL
Mean SRT[c]	13.85 + 1.95 dB HL	14.6 + 1.9 dB HL
Mean SIS[d]	> 90%	> 90%
ACE-R[e]	93 + 3.27	92.15 + 2.77
Training (mean yrs)	12.71 years[f]	11.98 years[g]

Note: [a]Pure tone average calculated for 500, 1 K, 2 K, and 4KHz frequencies. [b]High frequency pure tone average for 9 K, 10 K, 11.2 K, and 12.5 K frequencies. [c]Speech recognition thresholds measured using standard paired Kannada words, developed at AIISH, Mysuru. [d]Speech identification scores measured using phonetically balanced words (Mayadevi, 1974). [e]Addenbrooke's Cognitive Examination-Revised (Mioshi et al., 2006) cumulative scores for attention and orientation, memory, fluency, language, and visuospatial abilities. [f]Taining in playing musical instruments. [g]Training in stage arts.

as a part of their research study, and we used the same word lists for the present study. We added continuous noise in ten lists of words and interrupted noise in the remaining ten lists, with every two lists at five SNR levels (-10, -5, 0, +5, & +10 dB SNR), using Matlab (The MathWorks Inc., 2017a). We adopted the SNR levels from the speech-in-noise test in Kannada (Methi, Avinash, & Kumar, 2009). We generated a continuous (steady-state) white noise using Audacity software (ver. 1.3.13 beta) and passed it through a 200–8,000 Hz bandpass filter with a roll-off frequency of 12 dB/octave. We also generated an interrupted noise by passing the white noise through on/off rectangular bandpass filters, using Matlab (The MathWorks Inc., 2017b). The intensity of the interrupted noise portion was 40 dB below that of white noise. Each single interrupted portion lasted randomly for somewhere between 5 ms to 95 ms duration, with a noise duty cycle of 0.50. Such interruptions resembled the acoustic elements of speech (Stilp, Donaldson, Oh, & Kong, 2016).

The noise was 1.2 times the word duration, with the word at the noise's temporal center. We presented the words and instructed the participants to repeat the word as they heard them. The repeated words were recorded as responses using Alvin software (ver. 3.12; Hillenbrand & Gayvert, 2005). Three judges (qualified speech-language pathologists) independently listened and analyzed the recorded responses and scored each word as correct (score = 1) or incorrect (score = 0). We calculated the percentage correct word identification scores in continuous and interrupted noise. The percentage difference in the word identification scores with continuous and interrupted noise at each SNR level was the temporal release of masking. We measured the temporal release of masking, using different lists, twice, i.e., once before rehearsal and once after rehearsal.

Auditory Stream Segregation Test

We used an ABA paradigm to measure auditory stream segregation, with synthesized vowel /ɑ/ as the stimulus. We synthesized the vowel while considering its acoustic characteristics, as suggested by Klatt (1980). The fundamental frequency was 100 Hz, first formant frequency was 700 Hz (bandwidth = 130 Hz); second formant frequency was 1,220 Hz (bandwidth = 70 Hz), third formant frequency was 2,600 Hz (bandwidth = 160 Hz), duration was 80 ms, and intensity was normalized to 70 dB SPL. The fundamental frequency (F_0) of the vowel in both "A" was 100 Hz, and in "B" it varied in semitones. The starting F_0 difference (Δf) was 15 semitones. We generated twelve such ABA triplets and placed them subsequently to form the stimuli sequence. The intratriplet interval (i.e., the time interval between "first A-B," and "B-second A") was 30 ms, and the intertriplet interval (i.e., between ABA) was 120 ms. The participants listened to the entire sequence and identified whether they heard one stream of sound with a galloping rhythm (integrated percept), two streams of sounds (segregated percept), or not able to decide, i.e., bistability (ambiguous percept). We coded an adaptive stimulus paradigm using a two-down one-up staircase procedure in Matlab (ver. R2017a). The testing started after giving five to seven practice trials and ensuring that the participants understood the instructions. The test was repeated five times (five blocks) to track the thresholds. Figure 1 demonstrates the block diagram of the stimulus processing paradigm and the spectrogram of the synthesized vowel /ɑ/.

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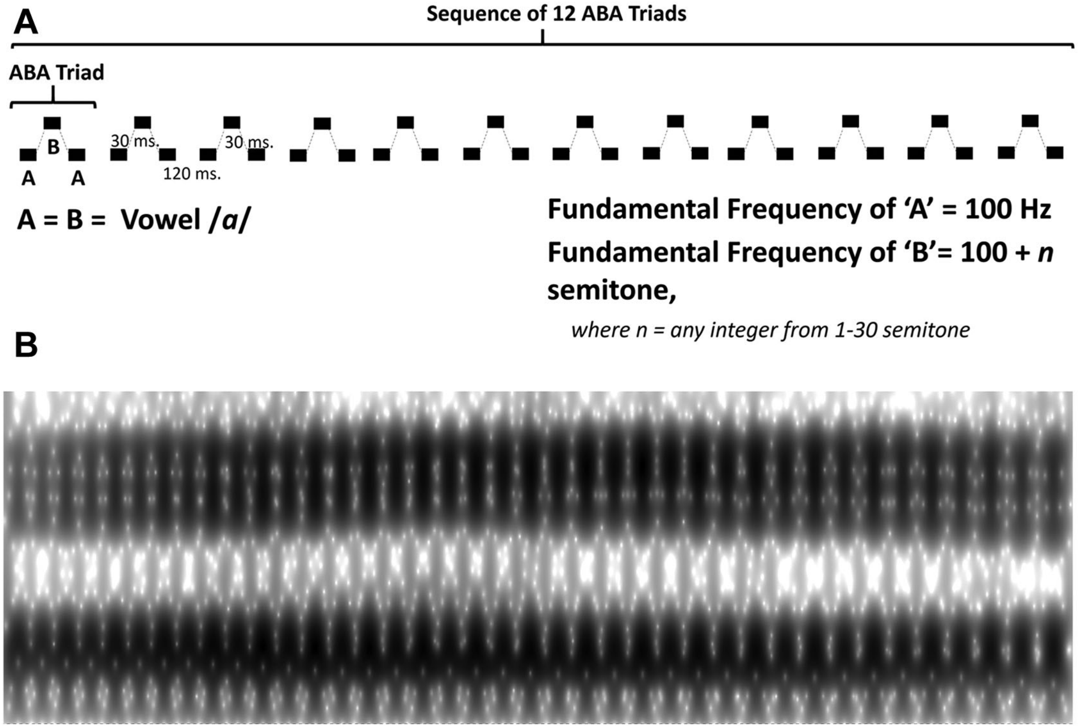

FIGURE 1. A) The block diagram indicating the auditory stream segregation paradigm; B) the spectrogram of the vowel /ɑ/.

TEST-RETEST RELIABILITY

The temporal release of masking and auditory stream segregation was measured three times within four months, with a minimum of a one-month interval between every consecutive measurement. Figure 2 displays the entire test protocol.

TEST ENVIRONMENT

We tested the participants in a sound-treated room (ANSI S3.1, 2013) using a computer-based audiometer (Piano Plus c/o Inventis, Italy). The stimulus presentation level was set to each participant's most comfortable level (~65–70 dB H.L.), binaurally.

Results

EFFECT OF MUSIC TRAINING AND REHEARSAL ON VAS SCORES

Initially, we compared our data with published norms for musicians and nonmusicians, given by Guo et al. (2015). A Student's *t*-test compared the obtained VAS scores with that of Guo et al.'s reported scores. Table 2 shows the *t*-test results. There was no statistically significant difference in our values and that of Guo et al. across all VAS categories. Hence, the obtained results were considered reliable and at par with the existing norms.

We then measured the effect of music training and rehearsal on VAS scores using multivariate analysis of variance (MANOVA). Table 3 lists the mean VAS scores and MANOVA results. We found no significant effect of music training on all VAS categories except confidence and talkativeness. The effect size of the magnitude of difference for both confidence (ŋ$P^2 = .034$) and talkativeness (ŋ$P^2 = .047$) was less, indicating that these differences may be due to the chance factor. On the other hand, rehearsal significantly affected the VAS scores (as noted in Table 3). Except for nervousness, for all other VAS categories, we found significantly better pre-rehearsal scores. The effect size for nervousness was less (ŋ$P^2 = .024$), indicating that no difference in the scores might be due to the chance factor. Based on the VAS scores, we inferred that the rehearsal caused significant fatigue in both musicians and nonmusicians. Therefore, we renamed pre-rehearsal scores as pre-fatigue and post-rehearsal as post-fatigue scores.

EFFECT OF MUSIC TRAINING AND FATIGUE ON TEMPORAL RELEASE OF MASKING

We first measured the reliability of the test scores. Cronbach's alpha correlation test measured interjudge and test-retest reliability. The correlation coefficient for

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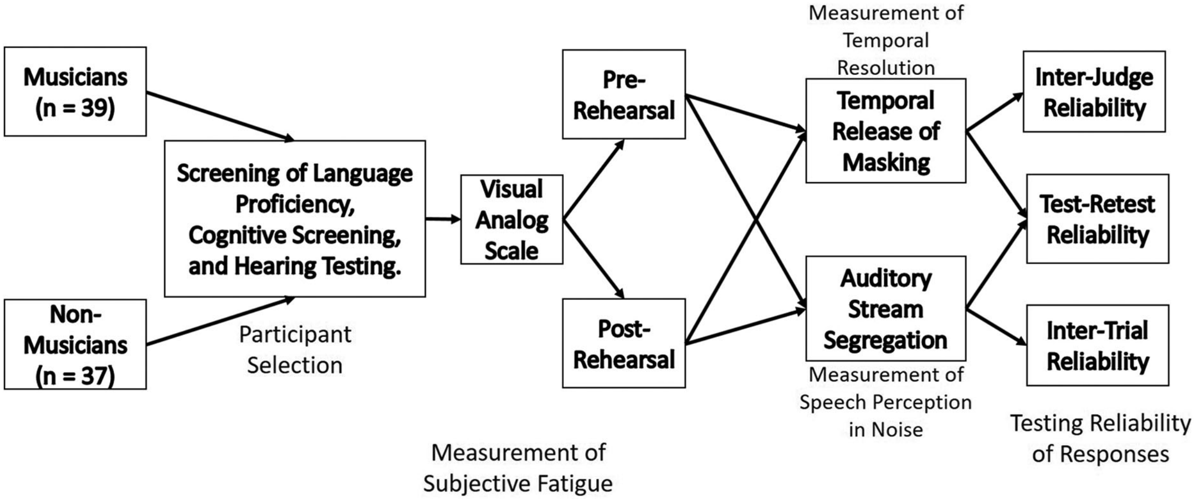

FIGURE 2. The block diagram showing the study protocol.

TABLE 2. *Comparison of Obtained Scores to Guo et al's. (2015) Reported Scores*

	Pre-Rehearsal				Post-Rehearsal			
	Musicians		Nonmusicians		Musicians		Nonmusicians	
VAS Categories	*t* value	*p*	*t* value	*p*	*t* value	*p*	*t* value	*p*
Concentration	1.241	.218	1.163	.248	1.464	.147	1.900	.061
Anxiety	0.728	.468	0.377	.706	1.893	.062	1.080	.283
Energy	1.112	.269	1.577	.119	1.962	.053	1.914	.059
Confidence	0.667	.506	0.342	.733	1.749	.084	1.948	.055
Irritation	1.770	.080	1.292	.200	1.820	.072	0.993	.324
Nervousness	0.799	.426	1.490	.140	1.821	.072	1.025	.308
Sleepiness	0.784	.435	1.141	.257	1.629	.107	1.618	.110
Talkativeness	1.812	.074	1.078	.284	1.699	.093	1.048	.298

TABLE 3. *Mean (SD) Scores and MANOVA Results to Measure the Effect of Music Training and Rehearsal on Each VAS Category*

	Mean (SD)				MANOVA			
	Musicians		Nonmusicians		Effect of Music Training		Effect of Rehearsal	
VAS Categories	Pre-rehearsal	Post-rehearsal	Pre-rehearsal	Post-rehearsal	*F* value	*p*	*F* value	*p*
Concentration	75.69 (6.03)	53.07 (22.84)	76.45 (5.02)	45.21 (23.08)	1.711	.193	98.663	< **.001**
Anxiety	24.64 (18.37)	41.92 (20.96)	27.37 (12.42)	47.35 (14.48)	2.197	.140	45.375	< **.001**
Energy	64.35 (9.87)	42.20 (10.11)	68.02 (7.37)	37.27 (15.93)	.121	.729	210.370	< **.001**
Confidence	75.74 (15.52)	56.38 (12.57)	70.97 (15.98)	49.78 (16.66)	5.287	**.023**	67.220	< **.001**
Irritation	26.30 (13.33)	28.84 (16.54)	27.72 (9.81)	34.59 (9.00)	3.068	.082	5.276	**.023**
Nervousness	28.23 (16.11)	33.92 (17.69)	31.37 (20.89)	36.29 (13.78)	0.966	.327	3.569	.061
Sleepiness	39.79 (9.02)	63.05 (8.51)	36.62 (9.16)	66.32 (8.50)	0.001	.972	343.408	< **.001**
Talkativeness	30.79 (10.22)	17.97 (11.29)	38.08 (17.28)	22.67 (14.93)	7.314	**.008**	40.551	< **.001**

Note: Values in bold text are significantly different at 95% confidence interval.

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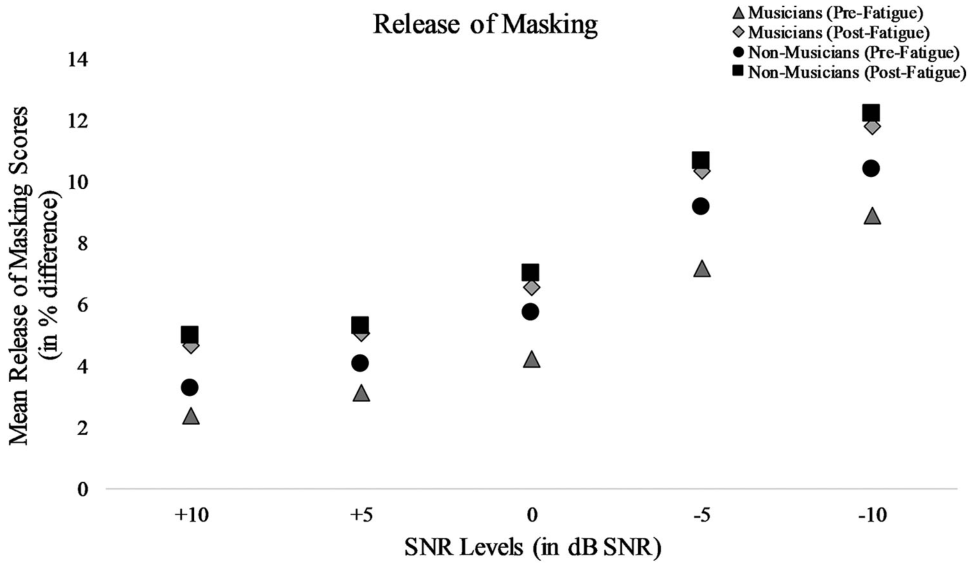

FIGURE 3. The mean release of masking scores at different SNR levels by musicians and nonmusicians in pre-fatigue and post-fatigue conditions.

TABLE 4. *MANOVA Results to Measure the Effect of Music Training and Fatigue on Auditory Processing*

	Effect of Music Training		Effect of Fatigue		Effect of Music Training			
	Overall Effect		*Overall Effect*		*Pre-Fatigue*		*Post-Fatigue*	
Auditory Processing Tests	*F* value	*p*	*F* value	*p*	*F* value	*p*	*F* value	*p*
RoM[a] (+10)[b]	21.203	< **.001**	235.868	< **.001**	22.491	< **.001**	3.233	.076
RoM (+5)[b]	17.018	< **.001**	133.248	< **.001**	31.104	< **.001**	0.970	.328
RoM (0)[b]	6.051	**.015**	20.388	< **.001**	8.852	**.004**	0.515	.475
RoM (-5)[b]	4.855	**.029**	20.695	< **.001**	6.264	**.015**	0.209	.649
RoM (-10)[b]	2.889	.091	18.297	< **.001**	3.001	.087	0.326	.570
ASS[c]	57.435	< **.001**	453.023	< **.001**	128.707	< **.001**	0.204	.653

Note: Values in bold text are significantly different at 95% confidence interval. [a]RoM = Release of Masking. [b]Measured in dB SNR. [c]ASS = Auditory Stream Segregation.

interjudge reliability was .81, and test-retest reliability was .71. Cronbach's alpha correlation of greater than .70 indicates “;good” reliability (Bland & Altman, 1997). Hence, we averaged the scores. We did parametric statistics as Shapiro Wilk's test results indicated normally distributed data ($p > .05$).

We plotted the mean release of masking scores (as percentage difference) across different SNR in Figure 3. MANOVA measured the effect of music training and fatigue on the temporal release of masking. Table 4 shows the MANOVA results. As noted from the table, musicians had a significantly better release of masking scores from +10 dB to -5 dB SNR. At -10 dB SNR, the effect size was.019, indicating that such a result may be due to the chance factor. We later split the data and measured the effect of music training independently in pre-fatigue and post-fatigue conditions. Musicians had a significantly better release of masking abilities than nonmusicians in the pre-fatigue conditions, except at -10 dB SNR. The effect size at -10 dB SNR was .012, showing that the results may be due to the chance factor. However, in post-fatigue conditions, no significant difference in the release of masking scores was noted between musicians and nonmusicians at all SNR levels. Hence, we inferred that fatigue neutralized the music training-related advantage in the release of masking scores.

EFFECT OF MUSIC TRAINING AND FATIGUE ON AUDITORY STREAM SEGREGATION

We measured auditory stream segregation scores as Δf (in semitones) for segregated percept. The intertrial (between blocks) and test-retest reliability, calculated using Cronbach alpha correlation, were .74 and .79. We thus averaged the scores. In the pre-fatigue

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condition, the mean Δf for musicians was 4.022 (*SD* = 0.493) semitones, and for nonmusicians was 5.264 (*SD* = 0.459) semitones. The mean Δf in post-fatigue condition for musicians was 6.442 (*SD* = 0.621) semitones, and that for nonmusicians was 6.502 (*SD* = 0.526) semitones. We used MANOVA to estimate the effect of music training and fatigue on auditory stream segregation and tabulated the results in Table 4. We found no significant effect of music training and fatigue on auditory stream segregation. Music training's independent effect revealed a significant difference in musicians and nonmusicians in pre-fatigue conditions, but no significant difference in the post-fatigue scores. Thus, we inferred that the fatigue nullified the music training-related advantage in auditory stream segregation.

Discussion

In the present study, we measured the auditory processing abilities of trained musicians while considering fatigue as an intervening variable. We measured fatigue using a visual analog scale. We found that 5–6 hours of rigorously playing musical instruments (for musicians) and stage practice (for nonmusicians) induced fatigue in musicians and nonmusicians. We found that fatigue significantly increased after rehearsal/practice.

We measured temporal resolution abilities using the temporal release of masking test, and speech perception in noise abilities, using the auditory stream segregation test, in both musicians and nonmusicians in the pre-fatigue and the post-fatigue conditions. We found that the musicians had a higher release of masking scores and lower stream segregation scores than nonmusicians, only when fatigue was not an intervening variable. These scores indicated superior performances of musicians when fatigue was controlled. At low SNR levels (i.e., -10 dB SNR), the musicians performed similarly to no-musicians even in the pre-fatigue condition, probably due to a floor effect. In the post-fatigue condition, when the scores were compared, no significant difference was found between musicians and nonmusicians. Even at low SNR levels, the musicians performed similarly to nonmusicians. These results were consistent with that of Elangovan, Payne, Smurzynski, and Fagelson (2016), who also found no effect of music training on temporal masking release from interrupted noise, irrespective of the SNR levels. They found no difference in the trend of masking release between musicians and nonmusicians across SNR levels. Fatigue compromised these abilities in both musicians and nonmusicians, and the effect was more for musicians than for nonmusicians.

We tried to minimize other factors that might have influenced temporal resolution and speech perception in noise test findings. All the selected participants belonged to similar socioeconomic and cultural backgrounds. They had no family history of auditory or cognitive processing disorder, and hence, ruled out the effect of family background on auditory processing. The pre-rehearsal and post-rehearsal testing time varied for each participant. For 60% of the participants, pre-rehearsal testing time was morning, but it was afternoon or evening for the remaining 40%. We found no marked difference in the scores due to the testing time difference on visual inspection of data. We minimized the linguistic variation in the test results by selecting speakers with native-like proficiency in the Kannada language.

Most importantly, we screened the participants' cognitive abilities and found that no participant was at risk of Dementia or other related cognitive problems. The selected tests for temporal resolution and speech perception in noise required participants' active involvement and immediate response, limiting the possible role of inattention influencing the results. Finally, our exclusion criteria at every step ensured that the participants belonged to the homogenous group, and musicians and nonmusicians were similar in all aspects except for music training. Thus, we attempted to safeguard that the changes in temporal resolution and speech perception in noise scores may be attributed only to music training and fatigue and preclude the role of other possible interfering factors.

We also searched for causes outside of fatigue that may have led to reduced temporal resolution and speech perception in noise in trained instrumental musicians. A survey on British musicians (Gross & Musgrave, 2016) found that professional musicians are three times more likely to report mental health problems. Professional music performances are demanding and require extensive training, commitment, interest, motivation, patience, and passion. Long working hours induce fatigue in musicians (Park et al., 2001; Salve, 2017), which might affect their performances in nonmusical auditory tasks. Wesseldijk et al. (2019) have reported that instrumental musicians are at a significantly higher risk of developing anxiety disorders, schizotypal, depressive, and burnout symptoms than those who never played instruments. Such symptoms were associated with fatigue and auditory processing disorders (Iliadou & Iakovides, 2003; Kähkönen et al., 2007; Obuchi et al., 2017). These may be underlying factors based on which the association between fatigue and temporal resolution and speech perception in noise in trained instrumental musicians can be explained.

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Fatigue may cause anxiety, depression, schizotypal disorders, and burnouts, which may cause cognitive processing deficits. Continuous practice during training sessions requires extensive self-monitoring. The monitored auditory input for a long duration may induce fatigue and reduce temporal resolution and speech perception in noise abilities. Moore and colleagues (2017) measured the pattern of brain activation while listening for a long duration. They found a reduction in the N1 component of EEG (related to arousal activity), which represents reduced attention. Dobrucki et al. (2017) reviewed various auditory fatigue aspects caused by listening to music. They stated that listening to music over a longer duration leads to fatigue, making sustained attention difficult. Attention is crucial for the temporal release of masking (Günel et al., 2018) and auditory stream segregation (Paredes-Gallardo et al., 2018). Fatigue likely modulated attention, which in turn modulated the auditory processing abilities.

Conclusion

The present study was the first to assess fatigue's effect on the temporal release of masking and auditory stream segregation in trained instrumental musicians. The scores were compared with that of nonmusicians. The fatigue was measured using a visual analog scale at two-time points: before and after training/practice. We found that post-training/practice scores of both musicians and nonmusicians were lesser than the pre-rehearsal scores, indicated the training/practice caused significant fatigue in them. The pre-fatigue scores for temporal release of masking and auditory stream segregation were significantly better for musicians than nonmusicians, but the post-fatigue scores were not significantly different. We thus concluded that fatigue caused a reduction in these abilities in trained instrumental musicians. In the end, we recommend that musicians consider fatigue a significant factor, as it might affect their performance in auditory processing tasks.

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