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Play Sports for a Quieter Brain: Evidence From Division I Collegiate Athletes

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Background: Playing sports has many benefits, including boosting physical, cardiovascular, and mental fitness. We tested whether athletic benefits extend to sensory processing—specifically auditory processing—as measured by the frequency-following response (FFR), a scalp-recorded electrophysiological potential that captures neural activity predominately from the auditory midbrain to complex sounds.

Hypothesis: Given that FFR amplitude is sensitive to experience, with enrichment enhancing FFRs and injury reducing them, we hypothesized that playing sports is a form of enrichment that results in greater FFR amplitude.

Study Design: Cross-sectional study.

Level of Evidence: Level 3.

Methods: We measured FFRs to the speech syllable “da” in 495 student-athletes across 19 Division I teams and 493 age- and sex-matched controls and compared them on 3 measures of FFR amplitude: amplitude of the response, amplitude of the background noise, and the ratio of these 2 measures.

Results: Athletes have larger responses to sound than nonathletes, driven by a reduction in their level of background neural noise.

Conclusion: These findings suggest that playing sports increases the gain of an auditory signal by turning down the background noise. This mode of enhancement may be tied to the overall fitness level of athletes and/or the heightened need of an athlete to engage with and respond to auditory stimuli during competition.

Clinical Relevance: These results motivate athletics overall and engagement in athletic interventions for populations that struggle with sensory processing, such as individuals with language disorders. Also, because head injuries can disrupt these same auditory processes, it is important to consider how auditory processing enhancements may offset injury.

Keywords: frequency-following response; neural noise; auditory processing; neural plasticity

Playing sports promotes physical fitness, improves cardiovascular function, sharpens cognitive skills, and boosts neurological health.[4,20,40] However, it is unknown whether the benefits of sports participation extend to sensory processing, namely, sound processing. Given that athletes must rely on rapid and precise auditory processing in competition[6,32,36] and that many systems enhanced in athletes[16] integrate with the auditory system,[26] we tested the hypothesis that the benefits of playing sports extend to auditory processing. Specifically, we tested whether athletes have enhanced auditory-evoked responses to sound and, if so, how these differences manifest.

To measure auditory processing, we used the frequency-following response (FFR), an auditory-evoked potential with generators predominately in the auditory midbrain.[5,8,41,42] The FFR captures microsecond-fast neural activity that is a combination of the evoked response to sound and the auditory system’s ongoing background neural activity.[25,27,34] Thus, the

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FFR reflects both how well acoustic features are processed and the health of the infrastructure of the auditory system. These 2 aspects of auditory processing work in tandem to influence the strength of auditory encoding and are reflected in the FFR as the magnitude of the response relative to the background noise.[27,34]

The health of auditory infrastructure is affected by experience, and this can be seen in the FFR. For example, auditory enrichment through playing a musical instrument or speaking multiple languages enhances encoding of auditory features important for that experience, resulting in increased magnitude of the FFR.[22,25,28] The level of background neural activity is likewise experience dependent: Background noise levels are higher in adolescents of low socioeconomic standing (SES; as indexed by maternal education level[17]) compared with their higher SES peers.[35] This difference may be due to differences in auditory experience and/or a difference in overall health between children from low- and high-SES families, as children from lower SES backgrounds tend to be exposed to fewer words and higher ambient noise levels and eat food of lower nutritional value.[9,12,15]

Because collegiate athletes train to peak physical conditioning, maintain a healthy diet, and constantly hone their auditory system to communicate and react in noisy settings,[1,6,32,36] we hypothesized that they would have a healthier and more efficient auditory system than nonathletes. We predicted that their FFR will have less background noise and larger evoked responses than their peers. To test this hypothesis, we recorded FFRs from male and female student-athletes across 19 National Collegiate Athletic Association (NCAA) Division I teams and compared their responses with age- and sex-matched nonathletes.

METHODS

Participants

A total of 913 college-aged individuals were recruited from a midwestern US university (mean age, 20.03 ± 1.67 years; range, 17.7-23.7 years); 470 were NCAA Division I student-athletes (227 females; mean age, 20.06 ± 1.30 years) across 19 sport teams that ranged from noncontact (eg, golf) to collision (eg, football), tested prior to the start of each team's season. The student-athlete group was compared with a group of 443 nonathlete peers (246 females; mean age, 19.99 ± 1.99 years; range, 17.0-23.9 years). The groups were matched on sex distribution, age ($t_{(911)} = 0.678$; $P = 0.50$, *t* test), and auditory periphery function, as measured by wave V latency of their click-evoked auditory brainstem response (ABR; athletes, 5.73 ± 0.20 ms; controls, 5.73 ± 0.19 ms; $t_{(911)} = 0.145$; $P = 0.89$, *t* test). All procedures were approved by the university's institutional review board (STU00202670) in accordance with the Declaration of Helsinki. All participants consented to participate and were compensated monetarily for their time.

Stimulus and Recording Parameters

The FFR was elicited by a 40-ms, 5-formant synthesized speech sound,[21] "da," described previously in detail.[29,34] To collect the FFRs, silver/silver chloride electrodes were applied in an ipsilateral vertical montage, with active at Cz, reference on the right ear lobe, and ground on the forehead. The participant sat comfortably in a darkened, quiet room while the FFR was recorded passively. No behavioral response from the participant was required. The "da" was presented through a shielded insert earphone (ER-3A; Natus Medical Inc) monaurally to the right ear at 10.9 Hz and 80 dB sound pressure level in alternating polarity. FFRs were collected in Bio-logic Navigator Pro AEP (Natus Medical Inc) over an epoch window that began 15.8 ms prior to stimulus onset to capture background neural activity. FFRs were online filtered from 100 to 2000 Hz and artifact rejected at ±23,800 nV. Responses to 6000 artifact-free presentations, 3000 of each polarity, comprised the final average. FFRs were generated in 2 ways: one in which the averages of each polarity were added together ("add"), a method that accentuates the envelope and lower frequencies of the response, and one in which the responses were subtracted ("subtract"), a method that accentuates high-frequency FFR components.[2]

As part of the collection protocol, 2 ABRs were collected at the beginning and 1 ABR was collected at the end of the session. These ABRs were in response to a 100-μs broadband click presented in rarefaction at 31.25 Hz. ABRs were used to verify that the participant had a healthy auditory periphery and that ear insert placement was consistent over the course of the recording session, as determined by peak latency.

Experimental Design and Statistical Analyses

Because we were measuring amplitude of a time-varying signal, we determined amplitude by computing the average deflection, in nanovolts, from baseline (0 nV) over a specific time range. Deflections can occur in either the positive or negative direction. As we were only interested in the size of the deflection, not its direction, the deflection value at each point was squared before these values were averaged. Next, the square root of the squared average was taken to yield a final value of averaged amplitude, or root mean square (RMS) amplitude over a time region. We compared the groups on RMS amplitude of the response, RMS amplitude of the background noise, and the ratio of these 2 measures for both the added and subtracted responses. For the background RMS, the time region was −15.8 to 0 ms, and for the response RMS, the time region was 19.5 to 44.2 ms. Signal-to-noise ratio (SNR) was calculated as the response RMS amplitude divided by the background RMS amplitude. For each FFR measure, we ran a 2 (polarity: add vs subtract) × 2 (group: athlete vs control) repeated-measures analysis of variance controlling for artifact reject count to confirm that any group differences were not due to external factors. These were computed using SPSS statistical software (IBM Corp). Because the effects of adding or subtracting polarity on response magnitude are well documented[2,27] and we were only interested in group differences, only group main effects and group-by-polarity interactions are reported.

We wanted to include a large number of student-athlete and control participants because we had no a priori hypothesis regarding the magnitude of potential group differences. A

Table 1. FFR amplitude in student-athletes and nonathlete controls[a]

	Student-Athletes		Controls	
	Mean ± SD	95% CI	Mean ± SD	95% CI
Background RMS				
Add	30.22 ± 10.96	29.22-31.21	33.19 ± 10.98	32.17-34.22
Subtract	29.51 ± 12.85	28.34-30.67	34.03 ± 16.65	32.47-35.58
Response RMS				
Add	101.57 ± 31.43	98.72-104.42	104.30 ± 27.00	101.78-106.82
Subtract	60.82 ± 19.61	59.04-62.60	60.54 ± 21.44	58.53-62.54
SNR				
Add	3.70 ± 1.49	3.57-3.83	3.45 ± 1.39	3.32-3.58
Subtract	2.29 ± 0.94	2.20-2.38	1.95 ± 7.72	1.88-2.02

FFR, frequency-following response; RMS, root mean square; SNR, signal-to-noise ratio.
[a]RMS values are in nanovolts, SNR measures are unitless.

power analysis showed that an alpha of 0.05, power of 0.95, sample sizes of 450 participants per group, and 2 different recording methods would provide 95% power to detect "small" effect sizes (as small as $\eta_p^2 = 0.011$).

RESULTS

SNR was larger for athletes than nonathletes ($F_{(1, 910)} = 31.357$; $P < 0.01$; $\eta_p^2 = 0.033$) (Table 1, Figure 1). This effect did not differ by averaging method ($F_{(1, 910)} = 0.668$; $P = 0.41$; $\eta_p^2 = 0.001$) and was driven by a reduction in the athlete's background neural activity ($F_{(1, 910)} = 44.087$; $P < 0.01$; $\eta_p^2 = 0.046$), which also did not differ across the 2 recording methods ($F_{(1, 910)} = 3.275$; $P = 0.07$; $\eta_p^2 = 0.004$). The 2 groups were matched on response magnitude ($F_{(1, 910)} = 1.310$; $P = 0.25$; $\eta_p^2 = 0.001$) across both recording methods ($F_{(1, 910)} = 2.581$; $P = 0.11$; $\eta_p^2 = 0.003$).

DISCUSSION

We found that SNR of auditory processing in Division I collegiate athletes was larger than that of age- and sex-matched nonathletes. This difference in SNR was driven by a reduction in ongoing background neural activity in the athlete brain. Athletes and nonathletes were matched on encoding of acoustic features, as evidenced by the similar amplitude of their responses to the stimulus. These SNR and background activity differences were present in averaging methods.

Interestingly, plasticity of subcortical auditory processing from other forms of enrichment manifests as *increased* encoding of the acoustic features important for that experience. For example, musicians show greater encoding of a sound's harmonics,[25] an important feature for conveying an instrument's timbre, while bilinguals increase their response to the fundamental frequency,[28] a cue that aids in language identification and talker identity. In contrast, athletes appear to boost their neural response to sound by lowering their background noise. While beyond the scope of the current study, follow-up studies can determine whether differences in how enhancements manifest result from differences in the demands of athletes versus musicians or bilinguals.

Auditory processing differences between athletes and nonathletes may be caused by holistic differences in their overall health and fitness and/or an athlete's heightened reliance on sensory processing to quickly and reliably respond to environmental cues. In support of this difference being driven by increased whole-body health, children from lower SES, who tend to be exposed to greater ambient noise and poorer nutrition,[9,12,15,17] have noisier brains relative to higher-SES children of the same age.[35] However, there is also evidence that, across sports, athletes rely on auditory cues to monitor their own and others' movements or to respond to cues during competition[1,6,32,36,43] and that neural efficiency, or a reduction in neural activity, has been observed for elite athletes during motor and cognitive tasks.[10,11] Thus, the high auditory processing demands of sports activity may underlie these enhancements. While it may be reasonable to assume that the fitness level of the student-athlete group is greater than the nonathlete group, future studies should be designed to investigate whether fitness level or sport demands underlie the reduction in background noise levels. That these effects were observed across a range of teams suggests it is a general benefit of playing sports and does not preclude the possibility that there are also sport-specific gains in auditory processing of acoustic features relevant to that sport.

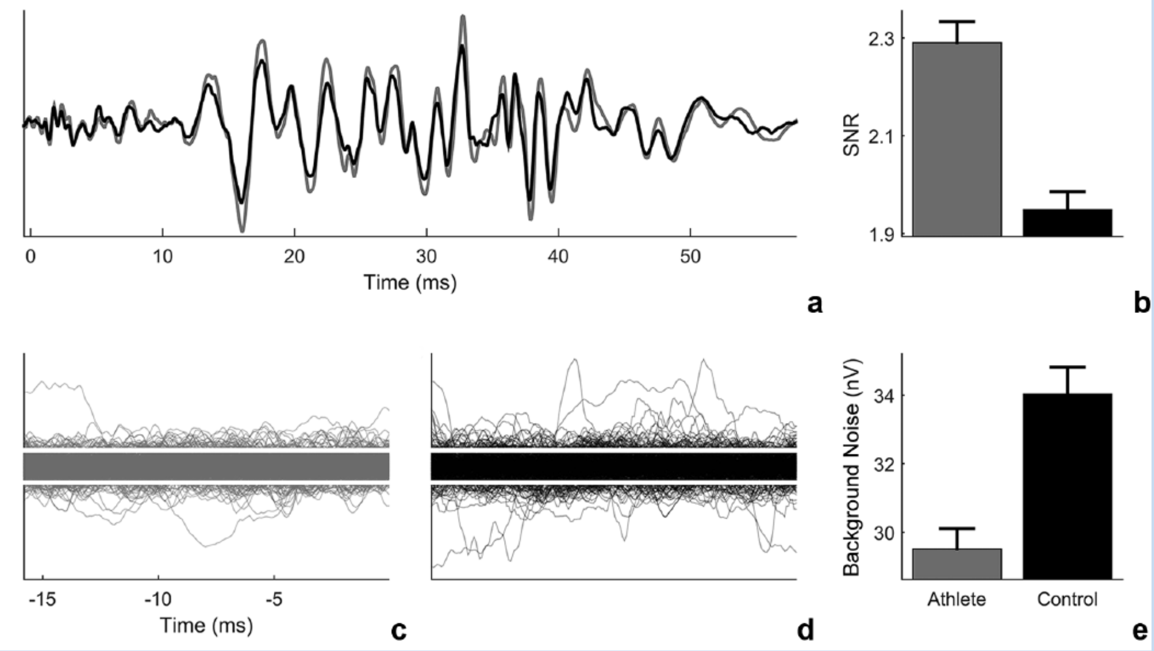

Figure 1. Signal-to-noise ratio (SNR) and background root mean square (RMS) differences between athletes and controls. (a) The SNR of the grand average waveforms of the subtracted response, computed by dividing the response RMS by background RMS, demonstrates the larger SNR of the response for athletes (gray) relative to controls (black). (b) Bar graph of average SNR plus 1 SE for athletes and controls. (c) Individual athlete and (d) control background activity, with white fiducials at ±50 nV, demonstrates the greater background neural noise for controls relative to athletes. (e) Bar graph of mean background activity plus 1 SE shows that athletes have less background activity than age-matched controls.

Given that background activity reflects brain health, as evidenced by differences in background activity across socioeconomic strata[35] and increases in neural noise after acoustic trauma in animal models,[30,31] the reduction in ongoing neural activity in athletes suggests a healthier and less noisy neural infrastructure for them relative to nonathletes. Additional research is needed to better understand how these differences manifest and how they influence daily function, because this reduction in background activity could have important consequences for perception. A quieter system can work more efficiently to translate an external stimulus into a meaningful signal, and noise levels in sensory systems can affect higher-level functions that depend on that signal.[13] The auditory system shares reciprocal connections with executive, language, sensorimotor, and reward systems[7,14,19,26,37]; and thus, the observed auditory processing enhancements may support athlete enhancements previously reported in these systems.[16]

CONCLUSION

The finding that playing a sport is associated with enhanced subcortical auditory processing provides insight into the athlete brain and opens up a new avenue of research. These results motivate studies of short-term athletic interventions in populations that struggle with sensory processing, such as older adults[3] or individuals with language disorders.[18] Such strategies might mitigate sensory processing difficulties in addition to engendering broad benefits for health. Furthermore, because brain injury, such as concussion, can adversely affect auditory processing,[23,24,33,38,39] an important area of research to pursue is to determine whether these enhancements offer a neuroprotective effect against injury. Future studies should investigate the origin of these differences, their generalizability or specificity across other sports or levels of athletic competition, and how these enhancements may intersect with brain injuries that disrupt auditory processing.[24]

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