Neuroscience Letters 646 (2017) 21–23

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Research article

The neural legacy of a single concussion

Nina Kraus[a,b,c,*], Tory Lindley[d], Danielle Colegrove[d], Jennifer Krizman[a], Sebastian Otto-Meyer[a], Elaine C. Thompson[a], Travis White-Schwoch[a]

[a] Auditory Neuroscience Laboratory, Department of Communication Sciences, Northwestern University, Evanston, IL, USA[1]
[b] Department of Neurobiology, Northwestern University, Evanston, IL, USA
[c] Department of Otolaryngology, Northwestern University, Chicago, IL, USA
[d] Sports Medicine Unit, Department of Athletics, Northwestern University, Evanston, IL, USA[2]

HIGHLIGHTS

- Concussion history shapes neural function.
- History is evident despite no symptoms.
- Detectable through neural responses to speech.

ARTICLE INFO

Article history:
Received 6 February 2017
Received in revised form 3 March 2017
Accepted 5 March 2017
Available online 6 March 2017

Keywords:
Concussion
Mild traumatic brain injury
Sports medicine
Auditory processing
Neurophysiology
FFR

ABSTRACT

It has been hypothesized that concussions impart lasting brain damage, even after a patient has ostensibly recovered. This hypothesis is based largely upon neuropathological studies in deceased athletes, however, leaving open the question of whether it can be detected *in vivo*. We measured neural responses to speech in collegiate student-athletes with a history of a single concussion from which they had recovered. These student-athletes had weaker responses to speech than age- and position-matched peers. This group difference suggests that concussions engender small, but detectable, changes in brain function prior to the emergence of frank behavioral indications.

1. Introduction

Lasting neurological damage is attributed to repeated head traumas, such as concussive or subconcussive injuries [1], even in young athletes. This raises the possibility that neural damage persists even after an athlete appears to have recovered from a concussion [2]. This idea has been supported by electrophysiological [3] and neuroimaging [4] studies that suggest blows to the head impart neural damage in the absence of behavioral signs. The extent of this neural legacy remains undetermined, however.

We previously showed that the frequency-following response (FFR) is disrupted in children diagnosed with a concussion [5]. The FFR depends on synchronous neural firing and reflects auditory pathway health with microsecond precision. The FFR is a sensitive measure of the integrity of auditory processing, especially when elicited by speech [6]. Auditory processing is contingent upon the fast integration of multiple neural systems and is easily disrupted by disease [6,7], including brain trauma [8]; it stands to reason, then, that tests of auditory function could serve as proxies to detect subtle neural damage.

This idea is supported by evidence that children with a concussion have smaller FFRs to the fundamental frequency (F0); in contrast, responses to higher-frequency harmonics remain robust. The F0 is a chief cue for identifying sounds and therefore supports listening in the complex environments that challenge individuals with a previous head injury [8].

* Corresponding author at: 2240 Campus Dr., Evanston, IL, 60208, USA.
E-mail address: nkraus@northwestern.edu (N. Kraus).
[1] www.brainvolts.northwestern.edu.
[2] www.nusports.com.

http://dx.doi.org/10.1016/j.neulet.2017.03.008
0304-3940/

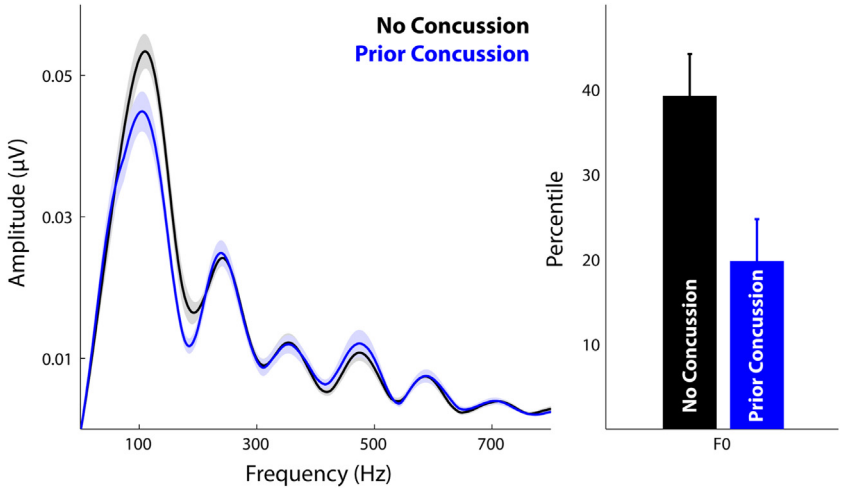

Fig. 1. Student-athletes with a single prior concussion have poorer neural processing than their teammates. (Left) Neural responses are shown in the frequency domain. Student-athletes with one prior concussion (blue) have smaller F0 responses (at 100 Hz) than their teammates who have never had a concussion (black). The two groups have similar responses to the higher-frequency harmonics, however. (Right) Percentiles are shown for F0 responses referenced to published norms. Student-athletes, on average, perform around the 40th percentile. Those with a previous concussion, however, perform around the 20th percentile. Shaded regions and error bars indicate 1 SEM. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2. Methods

We used the FFR to test the hypothesis that concussions impart lasting neurological damage. Twenty-five male student-athletes with a history of one concussion (11–82 months before participation; mean = 36.1, SD = 20.0) were recruited from a college football team. All were healthy and active at the time of testing. Controls were twenty-five age- and position-matched teammates who reported no previous concussions. Sports medicine staff reviewed subjects' medical records to corroborate reported concussion histories. Subjects were paid $20 and provided written consent. Procedures were approved by the Northwestern Institutional Review Board.

3. Results

Student-athletes with and without a previous concussion responded distinctly to the F0 and harmonics (Fig. 1; group × frequency interaction: $F(1,48) = 6.012$, $p = .018$, $\eta^2 = 0.111$).

Student-athletes with one previous concussion had smaller F0 responses than those without ($t(48) = 2.251$, $p = .029$, Cohen's $d = .918$; Concussion mean (SD) = .0467 μV (.0014), 95% CI = [.0407, .0527]; No Concussion mean (SD) = .0557 μV (.0138), 95% CI = [.0500, .0613]). These groups had similar responses to harmonics ($t(48) = .066$, $p = .947$, Cohen's $d = .021$; Concussion mean (SD) = .0155 μV (.0060), 95% CI = [.013, .018]; No concussion mean (SD) = .0154 μV (.0031), 95% CI = [.013, .017]).

As a whole, the student-athletes had F0 responses below the 50th percentile for this age group [9] (Fig. 1; one-sample *t*-test: $t(49) = 4.507$, $p < .001$, mean percentile = 28.4, 95% CI = [20.6, 37.8]). On average, the group without a previous concussion had F0s at the 38.5th percentile ($t(24) = 1.837$, $p = .079$, 95% CI = [25.6, 51.4]) whereas the group with a previous concussion had F0s at the 19.8th percentile ($t(24) = 4.628$, $p < .001$, 95% CI = [11.0, 31.9]).

4. Discussion

Student-athletes with a prior concussion had smaller responses to the F0 of speech than their teammates who never experienced a concussion. The putative legacy of this injury was evident despite indications that student-athletes had recovered. This neural hallmark of a previous concussion manifests similarly—albeit more mildly—as that observed in younger, symptomatic concussed student-athletes [5].

We cannot rule out that these group differences are due to pre-existing group differences. Additional limitations include that only males participated in this study and we relied on reported medical history. A longitudinal study in male and female athletes is warranted to address these issues and determine if deviations from neural baselines following a concussion impart lasting damage.

This report nevertheless suggests that a single concussion imparts a small, but reliable, lasting mark on neural function, consistent with emerging ideas in the field [1,3]. Subtle damage from the repetitive, subconcussive hits incumbent in football may account for the student-athlete cohort's F0s falling below the 50th percentile—including those without a previous concussion. This idea can be tested more thoroughly in a longitudinal study that follows student-athletes through their collegiate careers. Together, these results support the hypothesis that mild head injuries impart lasting neural damage prior to the emergence of frank behavioral sequelae.

Funding

This work was supported by the Knowles Hearing Center.

Author contributions

Study design: NK, TL, DC, JK, ECT, TW-S; Data collection: JK, SO-M, ECT, TW-S; Analysis: NK, TL, DC, JK, SO-M, ECT, TW-S; Manuscript preparation: NK, TL, DC, JK, SO-M, ECT, TW-S. All authors have approved the final manuscript.

Acknowledgments

We thank Alexa Kryglowski Bannerman, Liam Gibbs, Christine Liu, and Trent Nicol for their support in this project.

References

[1] A.C. McKee, T.D. Stein, C.J. Nowinski, R.A. Stern, D.H. Daneshvar, V.E. Alvarez, H.-S. Lee, G. Hall, S.M. Wojtowicz, C.M. Baugh, et al., The spectrum of disease in chronic traumatic encephalopathy, Brain 136 (2013) 43–64.
[2] A.J. Carman, R. Ferguson, R. Cantu, R.D. Comstock, P.A. Dacks, S.T. DeKosky, S. Gandy, J. Gilbert, C. Gilliland, G. Gioia, et al., Expert consensus document: mind

the gaps—advancing research into short-term and long-term neuropsychological outcomes of youth sports-related concussions, Nat. Rev. Neurol. 11 (2015) 230–244.
[3] M.J. Wilson, A.W. Harkrider, K.A. King, The effects of visual distracter complexity on auditory evoked p3b in contact sports athletes, Dev. Neuropsychol. 39 (2014) 113–130.
[4] T.M. Talavage, E.A. Nauman, E.L. Breedlove, U. Yoruk, A.E. Dye, K.E. Morigaki, H. Feuer, L.J. Leverenz, Functionally-detected cognitive impairment in high school football players without clinically-diagnosed concussion, J. Neurotrauma 31 (2014) 327–338.
[5] N. Kraus, E.C. Thompson, J. Krizman, K. Cook, T. White-Schwoch, C.R. LaBella, Auditory biological marker of concussion in children, Nat. Sci. Rep. 6 (2016).
[6] N. Kraus, T. White-Schwoch, Unraveling the biology of auditory learning: a cognitive-sensorimotor-reward framework, Trends Cognit. Sci. 19 (2015) 642–654.
[7] I.I. Maro, N. Moshi, O.H. Clavier, T.A. MacKenzie, R.J. Kline-Schoder, J.C. Wilbur, R.D. Chambers, A.M. Fellows, B.G. Jastrzembski, J.E. Mascari, et al., Auditory impairments in HIV-infected individuals in Tanzania, Ear Hear. 35 (2014) 306.
[8] F.J. Gallun, A.C. Diedesch, L.R. Kubli, T.C. Walden, R.L. Folmer, M.S. Lewis, D.J. McDermott, S.A. Fausti, M.R. Leek, Performance on tests of central auditory processing by individuals exposed to high-intensity blasts, J. Rehabil. Res. Dev. 49 (2012) 1005.
[9] E. Skoe, J. Krizman, S. Anderson, N. Kraus, Stability and plasticity of auditory brainstem function across the lifespan, Cereb. Cortex 25 (2015) 1415–1426.