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Performance on auditory, vestibular, and visual tests is stable across two seasons of youth tackle football

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ABSTRACT

Objective: Few studies have tracked neurologic function in youth football players longitudinally. This study aimed to determine whether changes in tests of auditory, vestibular, and/or visual functions are evident after participation in one or two seasons of youth tackle football.
Study Design: Prospective cohort study.
Subjects and Methods: Before their 2017 and/or 2018 seasons, male tackle football players (ages 7–14 yrs) completed three tests that tend to exhibit acute disruptions following a concussion: (1) the FFR (frequency-following response), aphysiologic test of auditory function, (2) the BESS (Balance Error Scoring System), a test of vestibular function, and (3) the King-Devick, a test of oculomotor function. We planned to repeat these on all subjects at the end of each season.
Results: Performance on neurosensory tests was stable, with no changes observed in FFR or King-Devick and a slight improvement observed in BESS performance across each season. Performance was also stable over two years for the subjects who participated both years. Across-season test-retest reliability correlations were high.
Conclusions: In the absence of concussion, young athletes' performance on the FFR, King-Devick, and BESS is stable across one or two seasons of youth tackle football.

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Introduction

There is growing concern about potential negative neurologic effects from participation in American tackle football. Consequently, much effort and attention has been placed on rule changes, rule enforcement, education about concussion recognition/management, and teaching proper tackling technique to reduce concussion rates in football. However, many have theorized that, even in the absence of a concussion, the accumulation of repetitive head impacts potentially sustained during routine practice and games leads to long-term changes in neurologic function (1–3). While this neurologic dysfunction may take years or decades to emerge, especially in interaction with neurodevelopmental processes, one prediction that follows from this hypothesis is that short-term neurologic dysfunction might be evident after even one or two season's participation in youth football.

A small number of retrospective studies have associated exposure to tackle football at a young age with long-term neurologic deficits (1,2), but few studies have prospectively and longitudinally measured neurologic function and symptoms in football players. Those that have report conflicting results, with some demonstrating a positive correlation, and others showing no relationship, between repetitive head impacts and changes in brain function (4–11). A systematic review of 30 such studies found methodological flaws in the majority, which significantly limits the available evidence for concluding that repetitive head impacts negatively affect brain function (12). Notably, only four of these studies included youth football players (most examined high school and collegiate athletes) (4–7), even though the majority of tackle football in the United States is played by children. Moreover, none evaluated effects on auditory function, a domain recently implicated in concussion (13–16).

Neurosensory functions tend to exhibit acute disruptions in children with a concussion. For example, following a concussion, visual acuity is typically normal, but the ability of the eyes to work together (convergence, saccades and smooth pursuits) can be disrupted (17). Additionally, there is evidence that neurosensory abnormalities correlate with concussion severity (13,18).

Three neurosensory domains have received particular attention:

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- ***Auditory***. Auditory processing skills can be disrupted following a concussion (14,19,20). Thompson and colleagues reported that children with a sports-related concussion cannot understand speech in noisy environments as accurately as matched controls with musculoskeletal sports injuries, nor can they sustain performance on auditory tasks as effectively (15). Additionally, Kraus et al. reported that the frequency-following response (FFR), an objective electrophysiological test (21), indicates disruptions to auditory processing in adolescents recovering from a concussion (13). Importantly, in all of these studies, peripheral auditory function has been normal, indicating that the inner and middle ears remained healthy but that auditory processing centers of the brain did not.
- ***Vestibular***. Balance problems following a concussion are common and interact with other sensory and cognitive difficulties (22). Corwin and colleagues identified vestibular abnormalities in about 80% of patients with a concussion in a tertiary-care sports medicine clinic; these patients took substantially longer to be cleared to resume school (median 59 vs. 6 days) and sports (median 106 vs. 29 days). Postural stability, which relies on an intact balance system, can be measured quickly and easily with the Balance Error Scoring System (BESS), which has good reliability and validity (22). Khanna and colleagues studied BESS performance in 100 healthy young athletes aged 10–17 and showed that performance is normally distributed and not related to demographics such as age, sex, height/weight, or sports history, supporting its use as a clinical measure (23). Additionally, a study in 14 collegiate football athletes showed that postural control is stable across one football season (24).
- ***Visual***. Tasks that require fast, complex, and coordinated visual processing can reveal deficits in concussion patients. Master and colleagues showed that ≈70% of concussed adolescents in a convenience sample had one or more vision diagnoses (17). The King-Devick test, a quick test of visual processing, requires patients to rapidly recite a series of printed digits (25). Galetta and colleagues showed that boxers and mixed martial arts fighters who sustain head trauma during a fight take ≈25% longer to complete the task than at baseline (25). Studies in child and collegiate athletes also support the King-Devick's use as a rapid screening for potential concussions (26–28).

The purpose of this study is to determine whether changes in performance on the FFR, BESS, and/or King-Devick (three tests of neurosensory function) are evident after one or two seasons of participation in youth tackle football. This allows us to test one aspect of an emerging hypothesis: that repetitive hits sustained in tackle football disrupt neurologic health in the short-term (3,29,30). In our study, we test the prediction that immediately following one season of football we would observe subtle, but significant, declines in neurosensory function. We tested this prediction by following participants in an urban youth tackle football league through their 2017 and 2018 seasons. In the subset of children that participated in both years of the study, we looked for potential changes in neurosensory function after two years.

Materials and methods

Study procedures were approved by the Institutional Review Board of Northwestern University. Parents or legal guardians provided written consent; children ages ≥12 provided written assent, while children ages <12 provided verbal assent.

Recruitment

In August 2017 and August 2018 all players in an urban youth tackle football program serving males aged 7–14 years of age were invited to participate (N ≈ 200). Exclusion criteria were a diagnosed hearing loss, epilepsy, or developmental disability. All subjects passed a hearing screening performed by a licensed audiologist (clear otoscopies and normal distortion product otoacoustic emissions, a screening of peripheral hearing function).

A few days before the start of the season, enrolled players completed tests of auditory, vestibular, and visual functions while their parents completed a survey to report history of concussion, other head/neck injury, neurologic disorder, learning disability, ADHD, hearing loss, speech-language therapy, or individualized education program. All subjects were invited to return one week after the season ended to repeat the auditory, visual and vestibular tests. Pre- and post-season testing sessions were conducted in a field house next to the football field in a multipurpose room, which was divided with check-in, visual, and vestibular testing on one side of the room and auditory testing on the other side.

The length and extent of the football season varies by age within the league. Details are provided in Table 1. The league uses the following modified version of USA Football's Youth Practice Guidelines[1]: there are 5 levels of contact. Not all practices involve contact. For 7-8-year-old players, full contact (levels 4 and 5) is allowed for a maximum of 30 minutes/practice and 60 minutes/week. For 9-14-year-old players, full contact is allowed for up to 30 minutes/practice and 120 minutes total/week during the preseason, and 90 minutes total/week during the regular season.

Table 1. Description of the league's season length and scope of activities for each age group.

Age (years)	Season Length (weeks)	Pre-season practice (weeks)	Regular-season practice (weeks)	Number of games	Practices/ week	Non-contact weeks (drills only)	Full contact onset
7	10	3	7	7	2	2	Start of Week 3
8							
9							End of Week 2
10							
11	12		9	10	5 for Weeks 1–3; 2 for Weeks 4-12	1	
12							
13							
14							

Auditory testing: auditory brainstem responses (ABRs)

ABRs reflect the health of early synapses between the ear and brain. ABRs were elicited to a 100 μs rarefacting click at 80 dB sound pressure level (SPL) and 31.1 Hz to the right ear via shielded insert earphones (ER-3). Three runs of 2,000 trials were presented. Responses were recorded by a Bio-Logic Navigator Pro (Natus Medical Inc., Mundelein, IL) and band-pass filtered from 100–1500 Hz.

Click ABRs have three stereotyped peaks (Waves I, III, and V). Peak latencies were identified manually; as is standard practice, once post-season data were available the pre- and post-season waveforms were viewed in tandem to resolve ambiguities in the peak locations. Also calculated were the amplitudes of each peak, determined as the root-mean squared (RMS) amplitude over three time bins (Wave I: 1.-28–1.82 ms; Wave III: 3.53–4.28 ms; Wave V: 5.07–5.91 ms).

ABRs were conducted by experienced electrophysiology researchers.

Auditory testing: frequency-following responses (FFRs)

We measured FFRs, which predominantly reflect synchronous neural firing in the auditory midbrain, to speech. We have previously shown that children with a concussion demonstrate disrupted auditory processing as measured by the FFR (13). FFRs were collected by experienced electrophysiology researchers.

FFRs were elicited to the speech-like sound /d/, a five-formant, 40 ms sound (13) constructed in a Klatt-based synthesizer (SenSyn, Sensimetrics Corporation, Malden, MA). Responses were recorded by a Bio-Logic Navigator Pro System. FFRs were measured in a vertical montage with three Ag-AgCl electrodes (Cz active, Fpz ground, A2 reference). Stimuli were delivered to the right ear via insert earphones (ER-3) at 80 dB SPL in alternating polarities. Two runs of 3,000 trials were presented, with online artifact rejection at ± 23 μV. Responses were bandpass filtered from 100–2000 Hz (2nd-order Butterworth) epoched in a 75 ms time window with stimulus onset set to 0 ms and a 15.8 non-stimulus pre-period. Unless otherwise noted, responses to the two presentation polarities were averaged.

FFR dependent variables are:

- ***Neural timing***. FFRs to /d/ have stereotyped peaks reflecting the response to the onset (Peaks V and A), sustained phaselocking (Peaks D, E, and F), and the offset (Peak O). Latencies of each peak were identified and verified following post-season testing by viewing pre- and post-season responses in tandem.
- ***Response size***. RMS amplitude of the response was calculated from 22–40 ms.
- ***Stimulus-response correlation***. Each individual's FFR was cross-correlated the stimulus waveform. The maximum correlation within one period of the F0 was determined and converted to a Fisher's z correlation coefficient.
- ***Fundamental frequency (F0) response***. A fast Fourier transform (FFR) was applied to the envelope response from 19.5–44.2 ms (2 ms Hanning window). Total amplitude of the spectrum from 75–175 Hz was calculated.
- ***First formant (F1) response***. An FFT was applied to the fine structure response using the same parameters as for the envelope spectrum. To obtain the fine structure response, responses to alternating polarities were subtracted. Total amplitude of the fine structure spectrum from 175–750 Hz was calculated.

The Auditory dependent variables are: neural timing, response size, stimulus-response correlation, F0 spectral coding, and F1 spectral coding.

Vestibular testing: balance error scoring system (BESS)

BESS testing was performed by certified athletic trainers and an advanced practice nurse experienced in its administration, per previous studies (23,31,32). Three positions were tested: (1) feet touching side-by-side, (2) single leg stance on the non-dominant leg, and (3) heel-to-toe stance with the dominant foot in front. The dominant leg was determined by asking subjects which foot they would use to kick a ball. Subjects were instructed to close their eyes, place their hands on their hips, and hold each pose for 20 seconds each on a firm floor surface and a 6-cm thick foam pad (Airex Balance-Pad Elite; Airex AG, Sins, Switzerland). One error point was given when the subject moved hands off the hips, opened eyes, stepped, stumbled, abducted, or flexed the hip > 30º. For each trial the maximum (i.e., worst) score was 10 points. If a subject could not maintain a position for ≥ 5 sec that trial was assigned 10 points. The Vestibular dependent variable was the sum of the scores from all 6 trials.

Visual testing: the King-Devick (KD) test

KD tests were administered by certified athletic trainers and an advanced practice nurse experienced in its administration. Subjects read aloud single-digit numbers on a practice card and then on two (subjects ages ≤ 9) or three (subjects ages 10 +) test cards. Subjects were asked to read the numbers as quickly as possible without error. The Visual dependent variable was the average reading time per card.

Statistical analyses

The specific hypothesis we tested is that repetitive head impacts sustained during tackle football impair neurologic health in the short-term. Were this the case, we would predict that performance on these neurosensory tests declines across the football season. We tested this prediction with linear mixed-effects models, a variant of the general linear model that allows for a combination of independent factors. The advantage here is that we could include subjects who participated in either or both the 2017 and 2018 seasons in a single model, with two data points for subjects who participated in only one season (pre- and post-season) and four for subjects who participated in both (pre- and post-season in 2017 and 2018). Pre- vs. post-season and study year were the fixed factors and subject was a random factor. In cases where there are related measures, such as the

Table 2. Performance on neurosensory tests at pre-and post-season.

	N	Pre-season mean (95% CI)	Post-season mean (95% CI)	Across-season reliability (*r* with 95% CI)
BESS (# Errors)	83	24.5 [22.8, 26.3]	20.8 [18.9, 22.6]	.589 [.446, .709]
King-Devick (s/card)	82	21.0 [20.0, 22.1]	20.7 [19.49, 21.97]	.700 [.537, .869]
Peak V Latency (ms)	84	6.63 [6.58, 6.68]	6.63 [6.58, 6.69]	.659 [.518, .778]
Peak A Latency (ms)	84	7.71 [7.63, 7.78]	7.71 [7.65, 7.79]	.671 [.516, .804]
Peak D Latency (ms)	84	22.59 [22.50, 22.69]	22.55 [22.43, 22.67]	.621 [.442, .763]
Peak E Latency (ms)	84	30.98 [30.89, 31.07]	30.98 [30.89, 31.09]	.594 [.427, .729]
Peak F Latency (ms)	84	39.50 [39.40, 39.61]	39.51 [39.41, 39.61]	.494 [.294, .699]
Peak O Latency (ms)	84	48.21 [48.11, 48.31]	48.11 [47.98, 48.25]	.236 [−.124, .607]
FFR Size (μV)	84	0.107 [0.101, 0.113]	0.106 [0.099, 0.112]	.744 [.517, .874]
FFR Stim-Resp Corr (z)	84	0.23 [0.22, 0.25]	0.22 [0.21, 0.24]	.566 [.352, .728]
F0 Amplitude (μV)	84	0.060 [0.056, 0.064]	0.058 [0.054, 0.061]	.641 [.422, .785]
F1 Amplitude (μV)	84	0.019 [0.017, 0.020]	0.019 [0.017, 0.019]	.700 [.547, .807]

For each test the mean value for the cohort is shown at pre-season and post-season tests, with the number of available data points reported. Also reported are 95% confidence intervals, estimated through 10,000 bootstrapped iterations. Finally, the across-season reliability is reported.

several peaks in the FFR, we included those as repeated-measures factors in a single model. All models covaried for age, a rough proxy for both how much contact the player is exposed to over the course of the season (see Table 1), and potential lifetime exposure to contact sports. Because correlation is a measure of test-retest reliability, we calculated Pearson's correlation coefficients between the pre- and post-season observations (reported with 95% confidence intervals, bootstrapped with 10,000 iterations).

Results

Subject characteristics

Approximately 200 players were invited to participate each season. In 2017, 57 enrolled and completed pre-season testing; 44 returned for post-season testing. In 2018, 85 enrolled and completed pre-season testing; 65 returned for post-season testing. There were 30 players who participated in both seasons. The 2017 cohort was slightly older than the 2018 cohort (2017: 11.9 ± 1.7 yr; 2018: 11.4 ± 1.6 yr; $t(127) = 2.03$, $p = .044$). The children who participated in post-season testing were similar in age to those lost at follow-up ($t(127) = 0.473$, $p = .637$). Additionally, a similar proportion of children were lost at follow-up in 2017 and 2018 ($\chi^2 = 0.647$, $p = .421$).

Approximately 8-9% of the cohort reported either a learning problem or positive neurologic history. Specifically, 12 reported a learning problem (diagnosed learning disability, ADHD diagnosis, presence of an IEP, or history of speech-language therapy). Additionally, 11 reported a positive neurologic history (history of one or more concussions, other head/neck injury, or neurologic disorder). The proportion reporting a learning problem or neurologic history were similar across both study years (learning problem: $\chi^2 = .926$, $p = .336$; neurologic history: $\chi^2 = .004$, $p = .952$). Additionally, the children who completed the study did not differ from those lost to follow-up re proportion who reported a learning problem ($\chi^2 = .516$, $p = .473$) or neurologic history ($\chi^2 = .039$, $p = .843$).

One subject sustained a concussion in the 2018 season. Because our focus here is on testing for changes in neurosensory function *absent* a concussion, his data are excluded.

Neurosensory test results

Pre- and post-season means for all neurosensory tests are reported in Table 2, along with cross-season reliability, collapsed across both the 2017 and 2018 seasons. Although we were underpowered to statistically test for effects of a learning problem or neurologic history, our visual inspection of the data suggested no interactions between pre-to-post season, a learning problem, and/or a positive neurologic history.

Auditory testing (ABR and FFR)

Post-season ABR and FFR data were available on 84 of the 88 (95%) subjects. ABR timing did not change (Peaks I, III, and V analyzed were analyzed in a single mixed-effects model; no main effect of pre-to-post season, $F(1,6.439) = 0.365$, $p = .566$, and no peak × pre-to-post season interaction, $F(2,66.634) = 1.756$, $p = .181$). There were no interactions between pre-to-post season and age.

FFR timing did not change (Peaks V, A, D, E, F, and O were analyzed in a single mixed-effects model; no main effect of pre-to-post season, $F(1,14.5) = 0.149$, $p = .705$ and no peak × pre-to-post season interaction, $F(5,105.68) = 0.418$, $p = .836$; Figure 1). There were no interactions with FFR timing, pre-to-post season, and age.

FFR amplitudes did not change ($F(1,2.08) = 4.197$, $p = .172$; Figure 1). There were no interactions between pre-to-post season FFR amplitudes and age.

FFR correlations did not change ($F(1,2.98) = 1.05$, $p = .381$; Figure 1). There were no interactions between pre-to-post season FFR correlations and age.

FFR spectral coding (F0/F1; Figure 2) did not change (F0 and F1 amplitudes were analyzed in a single mixed-effects model; no main effect of pre-to-post season, $F(1,3.698) = 2.151$, $p = .222$ and no F0/F1 × pre-to-post season interaction, $F(1,21.515 = 2.115$, $p = .160$). There were no interactions with F0/F1, pre-to-post season, and age.

Vestibular testing (BESS)

BESS scores improved, with subjects exhibit approximately four fewer errors at post-season than pre-season ($F(1,68.046) = 21.645$,

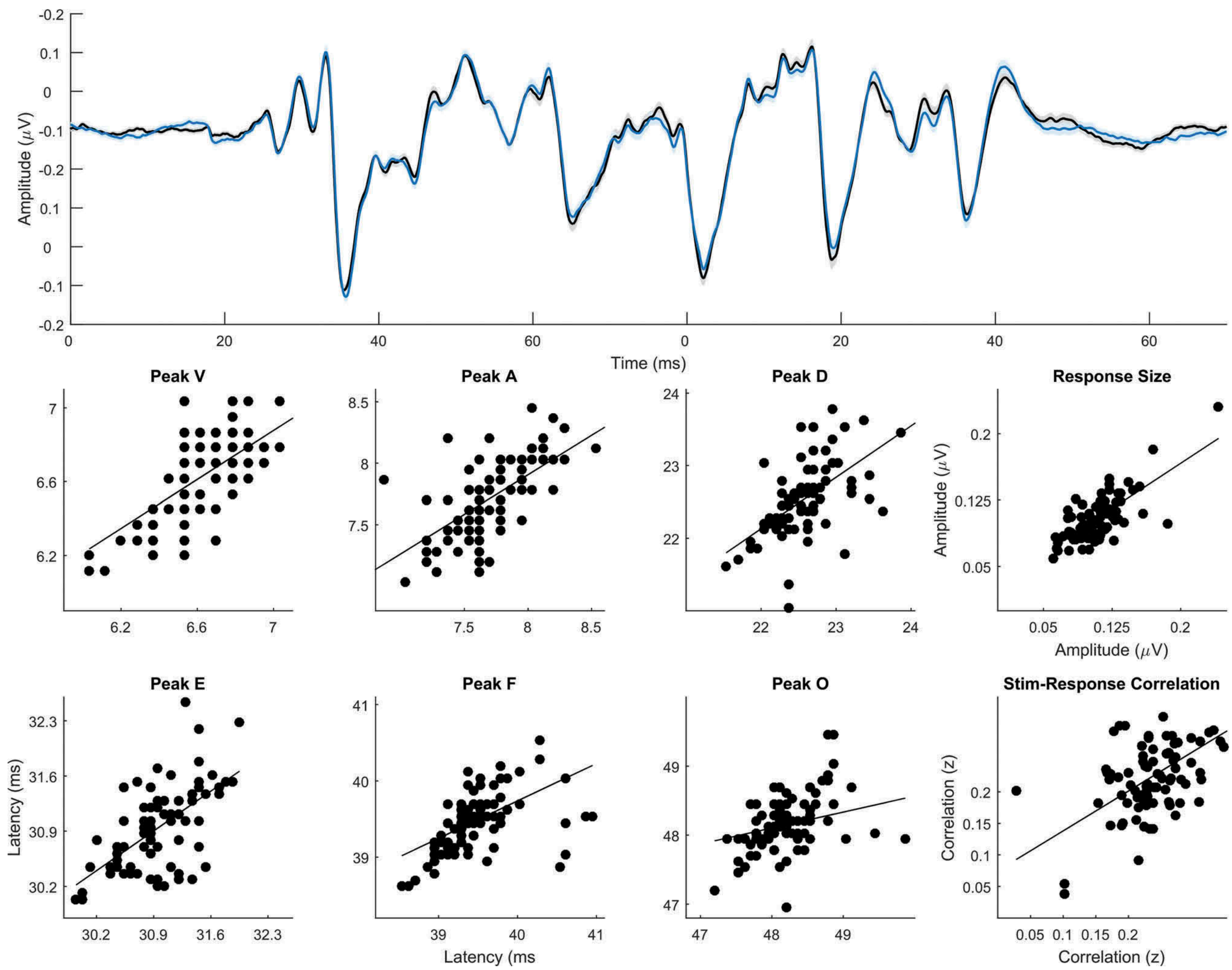

Figure 1. Frequency-following responses to speech: Time domain.

(Top) Average FFRs to "da" are shown for pre-season (black) and post-season (blue). Shaded regions represent ±1 SEM. No changes are observed across the season. (Middle/Bottom). Each individual's pre-season score (x-axis) is plotted against his post-season score (y-axis) for FFR measures. Across-season correlations are shown for the latencies of Peaks V, A, D, E, F, and O. Also shown are the measures of response size (amplitude of the total response) and the stimulus-response correlation.

$p < .001$; Figure 3). There were no interactions between BESS score and age.

Visual testing (KD test)

KD test scores did not change ($F(1,77.78) = 0.008$, $p = .930$; Figure 3). There were no interactions between pre-to-post season and age.

Discussion

This is the first study of youth tackle football players to measure short-term effects of play on multiple domains of neurosensory health, including auditory function, in the absence of concussion. We used three tests that tend to exhibit acute disruption following a concussion: the FFR (13), BESS (22), and King-Devick (25). Performance on the FFR and King-Devick was stable across the season. Performance on the BESS improved slightly across the season. These patterns held true regardless of the player's age. Also noteworthy is that test performance was stable (or improved) across *two seasons* in a subset of the subjects who participated in both years of the study. These results are similar to those found in previous studies of youth and high school football athletes measuring cognitive and neurologic functions, self-reported symptoms, and quality of life (4,8,33). However, our results differ from other studies that have found a correlation between the frequency of repetitive head impacts and deficits on balance, oculomotor, and/or neuropsychological tests in high school and collegiate football athletes (5,7,10,34).

It is possible that individual differences in brain metabolism or networking lead some athletes' brains to be more susceptible to the effects of repetitive head impacts than others, regardless of age or sport. This notion is supported by substantial individual differences reported in studies that showed correlations between repetitive head impacts and deficits in neuropsychological, oculomotor, or balance tests (5,7,9,10,34). Future studies should aim to identify baseline risk factors that predict who may be more susceptible to developing neuropsychological deficits with tackle football participation, in addition to directly quantifying the cumulative number and force of head impacts sustained over

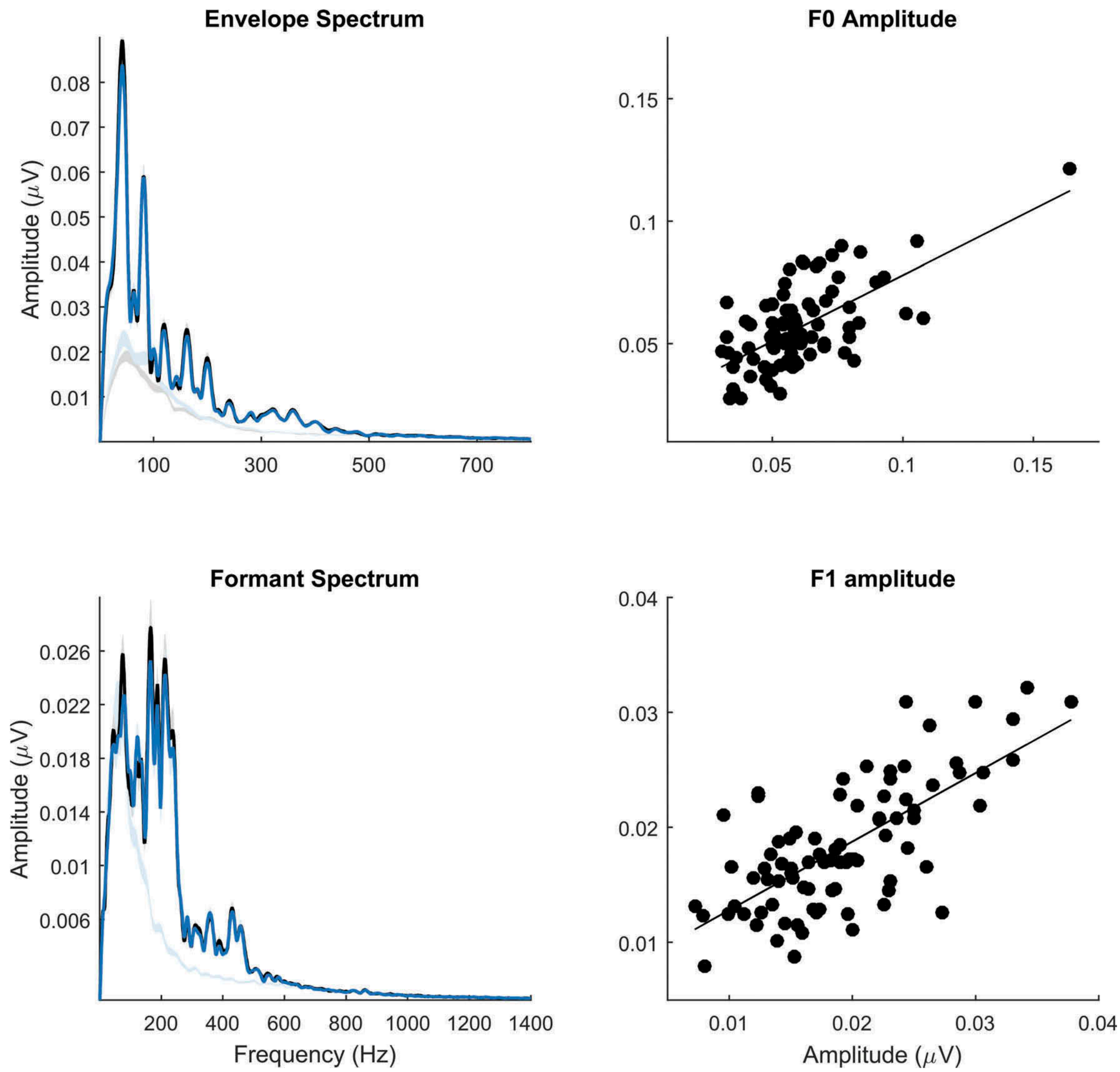

Figure 2. Frequency-following responses to speech: Frequency domain.

(Left) Grand average spectra of the FFR to the envelope (top) and formant structure (bottom) of the stimulus are shown for pre-season (black) and post-season (blue). The shaded regions flanking the thick lines represent ±1 SEM. The shaded regions underneath represent the baseline noise level in the signal ±1 SEM. (Right) Each individual's pre-season score (x-axis) is plotted against his post-season score (y-axis).

a season of tackle football. This is of particular interest in this age group, when the brain – including sensory systems – remains under development (35). In the subset of athletes who participated in both years of the study, we found no evidence for cumulative negative effects of participation in multiple seasons. Likewise, their performance was in line with age-matched peers who only participated in a single season, suggesting no interactions between tackle football participation and neurosensory development.

Neurosensory tests used in concussion evaluations are reliable

We show that neurosensory tests typically used in concussion evaluations (KD and BESS) are reliable in young athletes. This is important because most of these tests have been developed and are used more widely in teenage and adult athletes. This lends support to their use as clinical measures in younger athletes.

Some authors report that the King-Devick shows moderate learning effects (25,28,36). One might argue that lack of a learning effect in our data belies subtle neurosensory dysfunction. In other words, we might interpret the lack of change as a worsening relative to expected improvement. Our population was younger than the collegiate and adult populations that show learning effects, and there is evidence that rapid oral naming is still under development in this age range, blunting potential learning effects (37). Therefore, we are cautious about making this interpretation.

A systematic review of the BESS shows a range of test-retest reliabilities, averaging ≈0.75 (22). Our reliability was slightly lower; we think this was because our study included young males <10 years, a population that tends to perform more poorly than females and older males, and who have wider range of normal scores than older athletes (38,39). In our study, performance improved across the season. This could be due to learning effects on the test, improvement in balance due to neuromuscular maturation, sports participation, and/or subtle differences

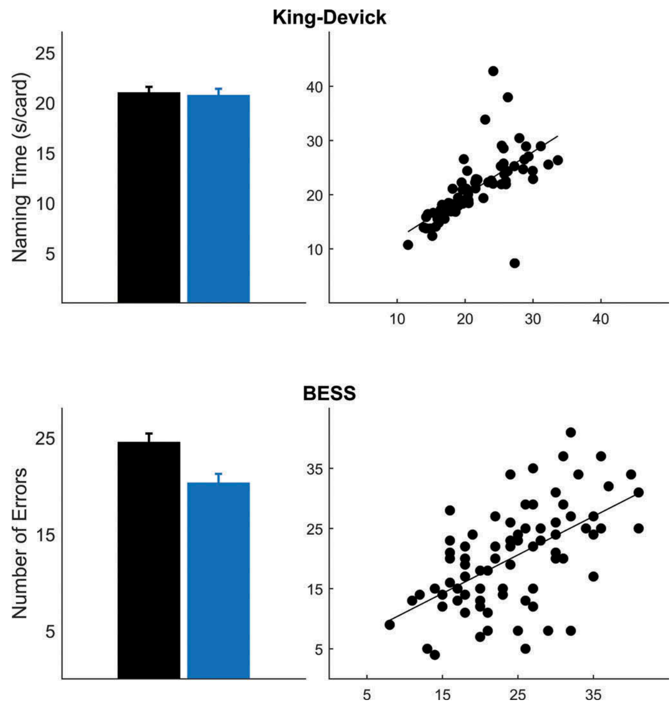

Figure 3. King-Devick and BESS scores.
(Left) Pre-season (black) and post-season (blue) scores are shown for the King-Devick and BESS. Illustrated are mean scores; error bars are 1 SEM. (Right) Each individual's pre-season score (x-axis) is plotted against his post-season score (y-axis) for the King-Devick (top) and BESS (bottom).

in test administration. These factors should be considered in longitudinal evaluations of balance performance.

FFR measures showed moderate-to-high reliabilities. While some individuals were outliers, such as on FFR amplitude, it is noteworthy that they were outliers at both test sessions (Figure 2). Our reliability estimates were slightly higher than those reported by previous studies (40,41). This may be due to the short timespan between tests and the highly controlled study design. Unlike the KD, there are no learning effects on the FFR, suggesting it may be a better test for evaluating head injuries in young athletes over the course of one or more seasons.

Limitations

Our sample size was small, and we followed only a subset of players for both seasons. Because we recruited from a tackle football league, we had only male subjects and lacked a control group of non-contact-sport athletes. A clear next step is to repeat this study in a larger sample of male and female athletes from contact and non-contact sports, as well as non-athletes. Our sample size provided only sufficient statistical power to detect "medium" effect size; one or two seasons of tackle football may affect neurosensory test performance, but the magnitude of these effects may only be detectable in a larger sample.

Our sample also represents a subset of the youth league, meaning sampling and selection biases may have unintentionally selected for certain children. For example, no participants in this study were diagnosed with a concussion, whereas a recent study suggested an incidence of 5% concussions in a similar cohort (42). We also used age as a proxy for the extent of contact exposure, which is less precise than head accelerometer data or exposure hours. Finally, while some of the players had a history of a neurologic condition or learning problem, we were underpowered to formally test whether these factors interacted with pre-to-post season changes in neurosensory functions. Our qualitative analyses showed that they fell in line with their peers, but it is important to test for these and related potential risk factors in future studies.

Lastly, our study relies on a critical assumption: that neurosensory tests that indicate dysfunction in a concussion are also sensitive enough to identify neural dysfunction in the setting of repetitive head impacts. These hits may initiate a disease process in non-sensory regions of the brain (43), or require more sensitive tests of neurosensory function for identification. It is also possible that neurosensory changes associated with repetitive head impacts may not become evident until after more than two seasons of participation in tackle football. The concept of a repetitive head impact remains somewhat ambiguous, especially because there is a wide range of force velocities involved in the hits sustained in tackle football and other sports (44). These open questions reinforce the importance of large, multisport, longitudinal studies to delineate and quantify both the health risks and benefits of contact sports, especially in young athletes.

Conclusion

Young athletes' performance on tests of auditory and visual functions were stable across up to two seasons of tackle football participation. Performance on a test of vestibular function improved slightly. This does not support the hypothesis that repetitive head impacts potentially sustained in tackle football disrupt these domains of neurosensory function. Despite its limitations, particularly the lack of non-contact athlete and non-athlete control groups, our study provides objective data regarding the short-term effects of youth tackle football on neurosensory function. This information should be valuable to clinicians, parents, and researchers who aim to better understand the short-term effects of youth tackle football on brain health.

Note

1. https://usafootball.com/resources-tools/coach/practice-guidelines/. Last accessed online 12-20-2018.

Disclosure of interest

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