Auditory Processing After Sport-Related Concussions

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Objective: The aim of the study is to investigate whether sport-related concussions disrupt auditory processes.

Design: Sixteen university athletes participated in the study: eight had one or more sport-related concussions, and eight never experienced a concussion. The Frequency Pattern Sequence test, the Duration Pattern Sequence test, the Synthetic Sentence Identification test, and the Staggered Spondaic Word test were used to assess auditory processing.

Results: All nonconcussed athletes have normal auditory processing. In contrast, more than half of the concussed athletes had deficits for one or more of the auditory processing tests.

Conclusions: The pattern of results suggests that sport-related concussions can disrupt the neurological mechanisms implicated in several auditory processes, including monaural low-redundancy speech recognition, tone pattern recognition, and dichotic listening.

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INTRODUCTION

Focal and localized brain lesions to various structures of the auditory pathway can disrupt auditory processing while preserving peripheral auditory perception (Bellis 2003; Champoux et al. 2007). Some evidence also suggests that a more diffuse brain injury can lead to auditory processing deficits. In a retrospective study, 16% of the children admitted to a rehabilitation unit for a mild or a severe brain injury had an auditory processing deficit (Cockrell & Gregory 1992). However, only one auditory process was evaluated, namely recognition of low-redundancy speech presented monaurally. More recent findings suggest that a closed head injury causes deficits to other aspects of auditory processing. Measuring auditory brain stem responses, distorted speech discrimination, and sound localization, Bergemalm and Lyxell (2005) reported deficits 7 to 11 yrs after a head injury in 58% of their participants.

A concussion is defined as a complex pathophysiological process affecting the brain that can be caused by a direct blow to the head, face, neck, or elsewhere on the body with an "impulsive" force transmitted to the head (McCrory et al. 2005). The typical signs and symptoms are confusion, amnesia, headache, dizziness, nausea, loss of balance, and/or poor concentration (McCrory et al. 2005; Ellemberg et al. 2009). Traumatic brain injuries occurring in the athletic population is a major public health problem, with an estimated of 1.6 to 3.8 million injuries each year in the United States (Langlois et al. 2006). Considering the epidemic proportion of sport-related concussion, it is important to verify its impact on the neurological mechanisms implicated in auditory processing. This preliminary study presents data from a heterogeneous and small group of concussed athletes using a central auditory test battery and compared their results with nonconcussed teammates.

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PARTICIPANTS AND METHODS

Participants

Sixteen university athletes participated in the study: eight athletes who sustained one or more sport-related concussions and eight who never experienced a concussion, sport-related or otherwise. At the time of the study, all athletes were active members of a university football or soccer team. All athletes were recruited by consulting the teams' clinical records. Concussions were identified at the time of injury by a team physician using the criteria established by the American Academy of Neurology (Practice parameter 2000). Furthermore, at the time of testing, all athletes completed a Post-Concussive Symptom Checklist (Aubry et al. 2002) to confirm the content of their medical records. The checklist consisted of 27 commonly reported symptoms presented into three categories: sleep disturbance, cognitive problems, and somatosensory problems (e.g., somnolence, confusion, dizziness, headache, and noise/light sensibility). Participants were asked to indicate whether they ever experienced an impact to their head or body that resulted in any of these symptoms as well as the duration of each symptom (the number of symptoms per concussion for each concussed participant is reported in Table 1). None of the athletes from the nonconcussed group reported experiencing a concussion or any of these symptoms during the course of their sport.

Participants from both groups were comparable in terms of age and years of education. Specific group details are presented in Table 1. According to a health questionnaire completed by the participants from both groups, none had a history of learning disabilities, attention deficit disorder, or neurological or psychiatric disorders. Considering that outcome after a concussion may vary based on gender (Ellemberg et al. 2007), only men were included in the study. None of the participants reported having tinnitus; hearing loss; or difficulties recognizing speech, music, or sounds from the environment. All participants were consenting volunteers and were treated according to the Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans (Medical Research Council of Canada, MRC, 2003).

To ensure that all participants had normal auditory detection, classic audiometric tests were first conducted. Subsequently, a psychophysical hearing test battery was conducted to test the integrity of several auditory processes. The tests used are described in detail in previous work (see the article by Champoux et al. 2007).

Pure-Tone Detection Thresholds • Detection was assessed using an adaptive method independently for each ear at 0.25, 0.5, 1, 2, 4, and 8 KHz.

Speech Perception in Quiet • The speech recognition task consisted of 25 phonetically balanced French words (PB

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TABLE 1. Athlete characteristics

	Age (yrs)	Education (yrs)	No. concussions sustained	Time since concussion (yrs)	No. checklist symptoms reported after each concussion
1	21	15	3	4; 3; 3	7; 12; 4
2	25	19	3	8; 5; 5	2; 12; 6
3	21	15	1	3	8
4	21	15	1	5	5
5	21	14	2	8; 6	6; 5
6	28	18	5	8; 8; 7; 6; 4	3; 6; 3; 3; 3
7	29	17	5	8; 2; 2; 2; 1	4; 5; 2; 2; 6
8	22	15	1	10	3
Concussed group	23.5 ± 3.38	16 ± 1.77	2.6 ± 1.68	—	—
Control group	22.1 ± 1.6	15.2 ± 1.3			

words) presented to each ear at a conversational level (50 dB HL) and without any competing signal.

Tone Pattern Recognition • Two tasks were administered monaurally at a comfortable level: the Frequency Pattern Sequence test (FPS: Pinheiro & Patcek 1971) and the Duration Pattern Sequence test (DPS: Pinheiro & Musiek 1995). For the FPS test, two pure tones were used to create tonal sequences consisting of three tones each. After each trial, subjects had to identify the tonal pattern using a verbal (30 trials) or a hummed (30 trials) response. The DPS test consisted of the presentation of three tonal pulses with a duration of 250 or 500 msecs. A total of 30 tonal patterns were presented to each ear. Subjects were asked to verbally identify the tonal pattern that was presented.

Monaural Separation/Closure • The French-Canadian version of the Synthetic Sentence Identification in Ipsilateral Competing Message (SSI-ICM: Jerger & Jerger 1974) was used to obtain monaural speech recognition scores in the presence of a competing speech signal channeled to the same ear. This test consists of presenting meaningful, continuous competing discourse at a comfortable level and 10 episodic nonsense target sentences. Subjects were asked to ignore the continuous discourse and to repeat the target sentence. The competing verbal message is presented at a signal-to-noise ratio of −10 dB.

Dichotic Listening Ability • The French-Canadian version of the Staggered Spondaic Word test (SSW: Katz 1968) evaluated the ability to process information presented simultaneously to both ears (i.e., binaural integration). In this test, two spondaic words are presented separately to each ear at a comfortable level in such a manner that the last half of the first spondee and the first half of the second spondee are received simultaneously. Word errors are scored for four different listening conditions, each comprising 40 trials: left (L) and right (R) ears in competing (C) and noncompeting (NC) modes.

RESULTS

For all subjects, pure-tone detection thresholds, at octave frequencies ranging from 250 to 8000 Hz, and speech reception thresholds were well within normal limits in both ears (≤20 dB HL). All participants scored 100% on the PB word recognition task presented at a conversational level (50 dB HL) without masking noise. Therefore, both the concussed and nonconcussed athletes have normal auditory detection.

Figures 1 and 2 present individual results for each concussed athlete compared with the mean results of the nonconcussed group, for the tests of central auditory processes. The results of the nonconcussed athletes all fall within the normative data for each of the tests. The data of the concussed athletes that fall 2 SD beyond those of the nonconcussed group are identified by an asterisk, indicating abnormal values according to clinical standards.

Five concussed athletes presented deficits for one or more tests of central auditory processes. The scores for the FPS test, DPS test, and SSI-ICM task are presented in Figure 1 as a percent error rate. Three concussed athletes obtained scores that were above normal values for the FPS test (Fig. 1A) (S3: RE = 30%; S5: LE = 54%; S6: RE = 33%; LE = 40%). For two athletes, the responses obtained on the DPS test (Fig. 1B) were also 2 SD above those of the nonconcussed group (S6: RE = 43%; S6: LE = 17%; S8: RE = 13%). Last, the performance of one concussed athlete was deficient for the SSI-ICM task (Fig. 1C) (S6: RE = 30%).

Figure 2 shows the four conditions included in the dichotic speech test (SSW). The percent error rate is plotted as a function of the four test conditions. Four of the eight concussed athletes presented deficits on this task, and deficits were found for both the competing and noncompeting conditions. A similar pattern of response was found for the four participants who each had more errors for the left ear conditions (S2, S3, S6, and S8), attesting a left ear disadvantage in dichotic listening (S2: LC = 17%, S3: LC = 17%, LNC = 10%; S6: LC = 30%, LNC = 10%). It should be noted that S8 had a deficit for all conditions (RC = 30%, LC = 27%; RNC = 17%, LNC = 10%).

DISCUSSION

The results from this study are consistent with previous reports on head injury unrelated to the sport context (Bergemalm & Lyxell 2005; Cockrell & Gregory 1992; Musiek et al. 2004) as it shows that concussions can lead to an auditory processing deficit while preserving auditory detection.

Each of the five concussed participants with auditory processing difficulties presents a different pattern of deficit. Two of the five participants have deficits on only one task (S2 and S5), two have deficits on two tasks (S3 and S8), and one has deficits on the four tasks (S6). The varying profile of

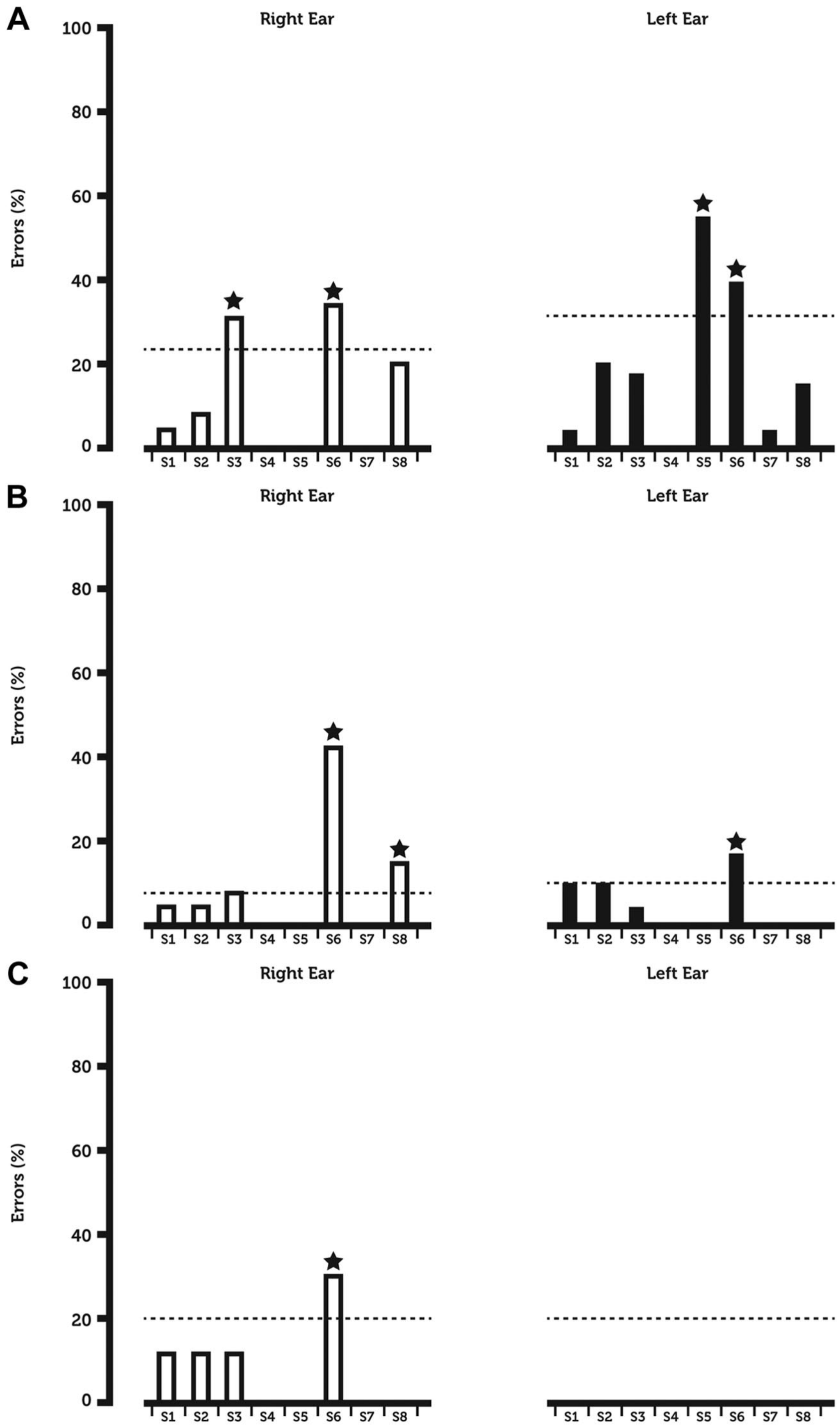

Fig. 1. Mean performance (% errors) for each concussed (S1–S8) athletes on the Frequency Sequence Test (A), the Duration Pattern Sequence Tests (B), and the Synthetic-Sentence Identification in Ipsilateral Competing Message task (C). The dashed line represents 2 SD above the mean of the control group. Asterisk (*) represents scores 2 SD above the control group and identify participants with abnormal results. The white bars represent data from the right ear and the black bars represent data from the left ear.

auditory processing deficit found in this study could be explained by the relatively heterogeneous profile of injury caused by a sport-related concussion (Ellemberg et al. 2009) and is also consistent with the literature indicating that auditory processing deficit is itself quite heterogeneous (Bellis 2003). This comes as further support for the need of an exhaustive battery when assessing auditory processing in concussed athletes.

In this study, concussed participants presented a heterogeneous clinical profile with the number of concussions sustained per athlete ranging from 1 to 5 and time since the last injury ranging from 1 to 10 yrs. Symptoms manifested at time of injury also varied greatly from one individual to the other (ranging from 1 to 12). Although the small number of participants does not allow us study the relationship between these variables and the results on the auditory processing tests, these preliminary data nonetheless support the conclusion that sport-related concussions can cause auditory processing deficits. Therefore, the present findings justify the additional investigation of auditory processing after a sport-related concussion. Future studies need to investigate the effect of accumulating concussions, time since injury (i.e., recovery and long-term consequences),

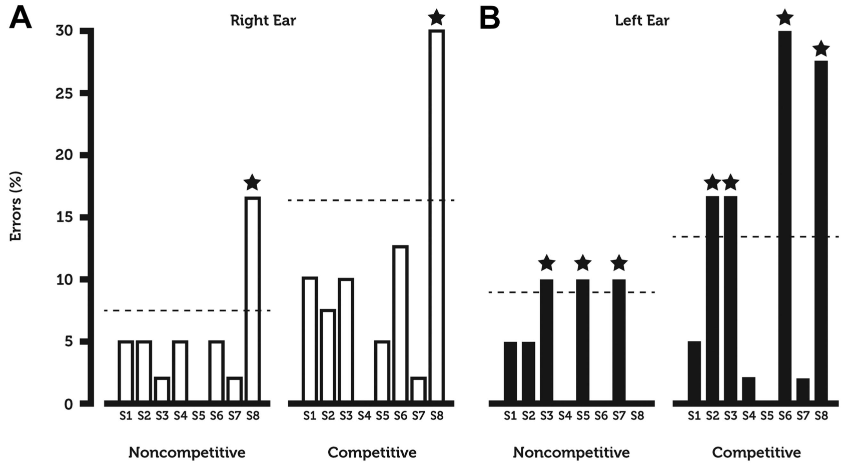

Fig. 2. Performances of concussed (S1–S8) athletes (% errors) on the four test conditions (right noncompeting; right competing; left competing; left noncompeting) of the Staggered Spondaic Word test. The dashed line represents 2 SD above the mean of the control group. Asterisk (*) represents scores 2 SD above the control group and identify participants with abnormal results. The arrows identify participants with abnormal results on at least one condition. The white bars represent data from the right ear and the black bars represent data from the left ear.

severity of the concussions, and potential interactions with psychological factors such as anxiety and depression. Moreover, the possible relationship with cognitive factors, such as memory and attention, should also be investigated in future studies.

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