Applied Psychophysiology and Biofeedback (2018) 43:211–216
https://doi.org/10.1007/s10484-018-9400-x

Utilizing the Quantitative Electroencephalograph (qEEG) to Objectively Document the Nature and Severity of Concussions in Junior Hockey Players: A Pilot Investigation

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Published online: 28 June 2018

Abstract
Concussions represent a major concern for hockey teams. During one winter season, all players on two Junior Hockey Teams were assessed in order to establish an incidence baseline for concussions. The qEEG was utilized as it measures the probability of concussion and its severity. The SCL 90-R and CNS questionnaire were used to provide insight into various aspects of cognitive functioning. Results indicated that of the players assessed (N = 46) approximately two-thirds (N = 32) tested positive for concussions. A minority of the concussions were assessed as mild (N = 13), while 19 were assessed as moderately severe. The most common sites indicated as injured were F8 and T6 (right side of head) and O1 and O2 (back of head) and F7 (left front of head). A comparison of the questionnaire results to expected behavioural issues are discussed. This appears to be one of the first studies of junior hockey players using an objective measure of study (qEEG).

Keywords Concussions · Hockey · qEEG · Baseline · Incidence

Introduction

Much concern presently exists in the sports medicine field about concussions, including how best to evaluate and treat them. Wennberg and Tator (2003) recently reported that the National Hockey League (NHL) concussion rate in the past 5 years was three times that reported in the previous decade. However, increased awareness, reporting and recognition may be responsible in part for this increase.

The word "concussion" derives from the Latin word concussus, which means to shake violently. Several features are common to a concussive head injury (Brooks and Hunt 2006). These include: (a) may be caused by a direct blow that transmits an impulsive force to the head or elsewhere on the body; (b) may result in the rapid onset of short-lived impairment of neurological function; (c) may result in neuropathological changes; and (d) may result in a graded set of clinical syndromes, possibly involving loss of consciousness, being dazed or retrograde amnesia.

Concussions were initially thought to involve only transient disturbance of brain function, without gross structural change. Currently, concussions are viewed as a subset of mild traumatic brain injury (MTBI), which are generally self-limited, and at the less-severe end of the brain injury spectrum (Harmon et al. 2013). It is now recognized that some concussions do involve structural damage through neuron loss or death (Brooks and Hunt 2006). It is further recognized now that cognitive dysfunctions, such as memory, executive functioning, attention and emotional being are all associated with closed head injury (Levin et al. 1982; Ross et al. 1994). Despite this, questions remain about whether there is adequate understanding of appropriate concussion management (Goodman et al. 2001). To this day, there is no single gold standard for the diagnosis of a concussion, as it is based upon a constellation of symptoms and suspicions of medical personal. Further complicating matters, some signs and symptoms evolve or change over time and can last for years (Eckner and Kutcher 2010).

Junior hockey generally involves individuals in the age range of 16–20; although, this may vary slightly in different jurisdictions. The issue of concussions in this age range is even more of a concern than that of adults as the brain is still developing and maturing during the age range (Casey et al. 2014). To date, available research concerning junior

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hockey is limited, with most studies being descriptive in nature. Echlin et al. (2010) studied 67 junior hockey players (ages 16–19) for one season. Using the Sideline Concussion Assessment Test (SCAT2) and the Immediate Post-Concussion Assessment and Cognitive Test (ImPACT), along with concussion surveillance at each regular season game of the participating teams, these authors reported that 17 players (25%) received concussions with 5 out of the 17 receiving a second concussion. Kontos et al. (2016) studied 397 players (ages 12–18), utilizing trained observers and medical practitioners to diagnose concussions. They found that 37 players (9.3%) sustained concussions. More concussions occurred during games from illegal hits and to younger players. In a second investigation, Echlin et al. (2012) studied 45 male and female varsity hockey players. Using the Sport Concussion Assessment Tool-2 (SCAT2), Immediate Post-Concussion Assessment and Cognitive Test (ImPACT), and magnetic resonance imaging (MRI), 11 (20%) concussions were documented. Interestingly, the incident rate for females was almost twice that for males during regular season play. Neuropsychological testing suggested no statistically significant preseason/postseason differences for concussed players.

Unfortunately, another pressing issue is the chance of Second Impact Syndrome (SIS). Although not heavily researched, it can be defined as the attainment of a subsequent brain injury before fully recovering from a preliminary brain injury (Cantu 2014). Fatal reports have even been documented when the second impact occurs several weeks after the initial trauma (Quintana 2016). McCrory (2001), the leading sceptic of SIS, attributes these reports to diffused cerebral swelling, using virtually all his own research as evidence.

The above studies illustrate some of the major issues with diagnosis and injury. The use of observational techniques, neuropsychological testing and tests for concussions lead to incidence rates ranging from 9 to 25%. While some of the players noted that they had a previous history of concussion, there is no way to know if those who did not report one had forgot or were not being forthwith. As Amen (2008) notes, people who have had previous concussions tend to forget about them due to the nature of the beast.

Quantitative Electroencephalograph (qEEG)

The brain is the only organ in the human body that modern medicine cannot physically examine. Inferences about the brain's activity are made from observations, neuropsychological tests and self-report. Standard and conventional visually read electroencephalograms (EEGs) and conventional MRIs scans are not sensitive or reliable in their detection of mild brain trauma, nor are they helpful in predicting outcome and gradations of severity (Thatcher et al. 2001; Trudeau et al. 1998).

The qEEG was chosen as the instrument to measure concussions due to its extensive use in the field of brain functions, its reliability, and the availability of an extensive database for facilitating assessment and diagnosis of varied conditions. Presently, the qEEG has been used in over 140,000 publications and is widely utilized by sports teams, the US military and legal systems as an objective measure of brain injury and function. The MTBI index forms part of the qEEG. It is a subscale that was specifically designed to assess MTBI, rather than severe injuries, such as coma and/or skull fractures. Thatcher et al. (2001) report that the qEEG has a discriminative accuracy as high as 95.67% in detecting MTBI. In addition, the qEEG is 75.8% accurate or greater in predicting outcome 1 year after injury (Thatcher et al. 2001).

For purposes of this pilot study, the data analyses included: (a) MTBI probability: the probability as measured by percentage that an individual has a concussion; (b) severity of concussion index (measured on a 10-point scale); and (c) those sites in the brain (out of 19) that are most frequently injured.

Methods

Participants

Participants included 47 junior hockey players from two different hockey teams.

Procedure

Both teams followed the same protocol. Each player was given a qEEG information packet, project outline, consent form, CNS Functioning Assessment (CNS), and Symptom Checklist 90-Revised (SCL 90-R) questionnaire. An intake form with basic personal information was gathered by the qEEG administrator. The players then completed the CNS and SCL 90-R. These forms were labelled with a number generated from a table of random numbers in order to protect their privacy, yet keep them together for data analysis. The players were allowed as much time as necessary to complete the forms. They were assured that the coaches and team staff would not have access to their individual results of the self-reported questionnaires. If the player was under age 18, a consent form for participation was signed by the parent or guardian and assent was obtained from the player. After the qEEGs and other tests were scored, the participants met with the authors to discuss the results. A trainer was involved only at the request of the player or parent or guardian as age appropriate.

Questionnaires

The Symptom Checklist 90-R (Derogatis and Cleary 1977; Derogatis and Savitz 2000) is a widely used paper-and-pencil test, with strong psychometric support, designed to measure the severity of current psychological symptoms and distress. It assesses nine symptom dimensions: somatization, obsessive–compulsive, interpersonal sensitivity, depression, anxiety, hostility, phobic anxiety, paranoid ideation, and psychoticism, and three global indices of psychological distress: Global Severity Index (GSI), Positive Symptom Distress Index (PDSI) and Positive Symptoms Total (PST). The players rated each of 90 items on a five-point scale from 0 (Not at All) to 4 (Extremely) specifying how much each has bothered them during the past 7 days. The test was computer scored using the Pearson Q Local (2012) scoring system, with scores obtained for each of the different scales. The GSI and PDSI were used as an indicator of the generalized psychological status of the player.

The CNS Functioning Assessment, as developed by Ochs (2013), is a clinical tool to help evaluate the impact of cognitive, behavioural and emotional issues reflecting brain activity. Forty-nine items are divided into eight categories: sensory, emotions, clarity, energy, anxiety, memory, movement and pain. The players were asked to indicate on a 10-point scale how frequently were they bothered by each item. The scores for each item were totaled to give an estimate of how the players were being affected.

qEEG Administration

The qEEG was administered and scored following standard procedures (see Thatcher 2012, for details). Administration of the qEEG took 1 h on the average and all sites were under 5 kΩ for resistance.

Data Analysis

qEEG–MTBI

The MTBI is specifically designed to assess the probability of membership in the MTBI population. The MTBI utilizes 20 different measures, some involving specific brain sites (i.e., T6), and some involving interactions between sites (i.e., F4–O2). Research has shown that certain sites and/or the interactions between certain sites are predictive of a concussion and are used as the markers for diagnosis. Thatcher et al. (1989) demonstrated a discriminant classification accuracy of 94.8% which was replicated at two other facilities. In developing the MTBI scale Thatcher et al. indicated that three "classes of neuropsychological variables … attributable to mechanical head injury". These are: (a) increased coherence and decreased phase in frontal and frontal–temporal regions; (b) decreased power differences between anterior and posterior cortical regions; and (c) reduced Alpha power in posterior cortical regions.

If a probability score occurred in the range 65–99.5%, the player was assigned to the concussion group. If the data indicated a non-significant result, the player was assigned to the non-concussion group.

As seen in Table 1, approximately 66% tested positive for the probability of having a concussion. These results were discussed with the players and trainers to verify the categorization. Several players recalled off ice incidents (i.e., trailer falling on his head during the summer), and previous hockey hits which accounted for the majority of the findings.

Further analysis was conducted to determine which of the 19 sites contributed the most to the probability scores. This was determined by counting the number of times each site was noted to be approximately two standard deviations above or below the norm.

Figure 1 highlights these findings and shows that sites F8 and T6 were the ones most often injured (Jasper 1958).

Severity Index

Although the qEEG cannot determine how many concussions or when these concussions have occurred, it can determine the effect of damage and depict the current functioning of a player's brain. Thatcher et al. (2001) measured certain aspects of patients' data, comparing it to the Glasgow Coma Scale, producing results that differentiated between mild and severe head injury. These results showed a classification accuracy of 96.39%, a sensitivity score of 95.45% and a specificity of 97.44%.

The index ranges from 0 to 10.0, with 10 being severely injured. Table 2 shows the range and average scores for the concussed players.

The severity index score rates how severe an injury is on a 10-point scale separating the scores into mild (0–3.33), moderate (3.33–6.66) and severe (above 6.66). Table 3 shows the breakdown into mild, moderate and severe categories.

Table 3 displays that team #1 had more players testing positive for concussion, but team #2 had a higher severity rating. The Chi square value for severity scores (n = 32) is

Table 1 Summary of MTBI results

	Team #1	Team #2
Number of players	23	23
Non-concussed	6	8
Concussed	17	15
MTBI range (concussed)	65–99.5%	65–99.5%
MTBI average (concussed)	83.79%	83.43%

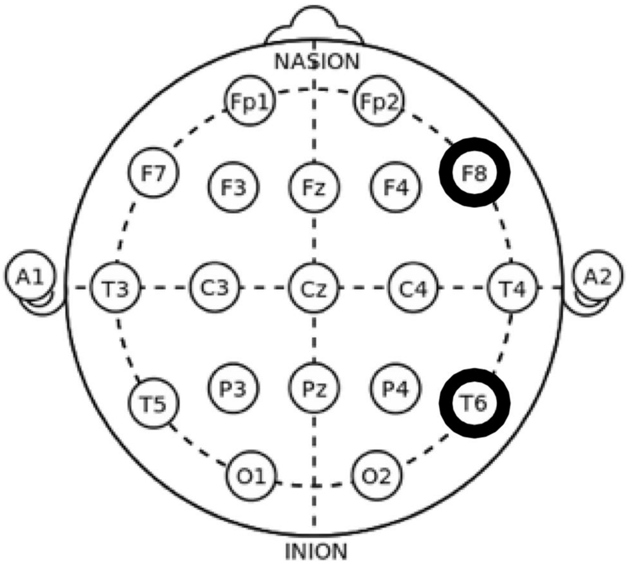

Fig. 1 Site F8 is responsible for spatial and visual working memory, gestalt, sustained attention, conscious facial emotional processing, and prosody. Site T6 is responsible for categorization, organization, visual memory and visualization, and is affected by loud noises (Thompson and Thompson 2015)

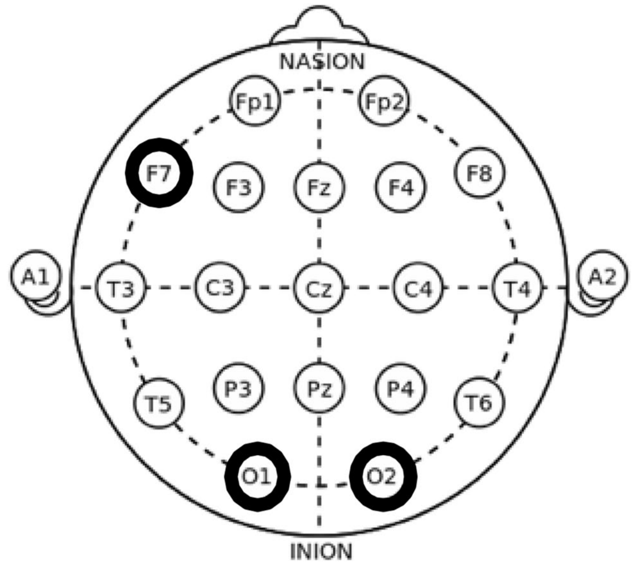

Fig. 2 The sites O1 and O2 are involved in vision and visual acuity. Site F7 is involved in visual and auditory working memory, selective attention, Broca's area, and word retrieval (Thatcher et al. 1989)

Table 2 Summary of severity results—concussed

	Team #1	Team #2
Severity range	1.24–4.48	2.21–4.94
Severity average	2.952	3.768

Table 3 Distribution of severity scores

Team #	Mild	Moderate	Severe
1	9	8	0
2	4	11	0

106.609 with degrees of freedom of 29 and asymmetry significance of .001.

Sites Most Severely Injured

The severity index consists of 20 items that have been demonstrated as related to injury severity (Thatcher et al. 2001). These items were totaled to determine which of the 19 specific sites in the brain were most severely injured. Figure 2 highlights these findings and shows that sites F7, O1, and O2 were the ones most severely injured. This was also determined by counting the number of times each site was noted to be approximately two standard deviations above or below the norm.

SCL 90-R

t Tests for independent samples for the results from the SCL 90-R, each using the 0.05 level for significance given the exploratory nature of this investigation, showed the concussion group to be significantly elevated compared to the non-concussed group on only the Phobic Anxiety scale ($p < .04$). The concussion group had a mean of 48.97, and a standard deviation of 6.6. The nonconcussed group hada mean of 46.29 and a standard deviation of 1.8. The *t* value was 2.127 with 40 degrees of freedom. Equal variances was not assumed. No significant differences between the concussed and non-concussed groups were found in the remaining seven individual or three global scales.

CNS Functioning Assessment

No scales were found to be significantly different.

Conclusion

This appears to be one of the first documented studies to establish a baseline on the incidence and severity of concussions of all players on a team in junior hockey. As such, it must be considered a pilot project that needs to be replicated with a larger database.

The information presented in this paper indicates a high rate of concussions amongst the junior hockey players, with varying degrees of severity, and injury before the season even starts. It is noteworthy that some of the players reported receiving their concussions outside of hockey, while some reported concussions from a previous year. This addresses the importance of establishing a baseline profile for junior hockey players.

This paper also raises the issue of possible SIS. Cantu (2014) states "SIS is simply an individual that has sustained an initial brain injury, who while still symptomatic, sustains another brain injury." The definition of symptomatic becomes important as symptoms of concussion (i.e., post-concussion syndrome) can last for weeks, or even years (Cifu et al. 2017; Yeates 2014).

In developing the MTBI scale Thatcher (2012) indicated that three "classes of neuropsychological variables … are attributable to mechanical head injury". This includes: (a) increased coherence and decreased phase in frontal and frontal–temporal regions; (b) decreased power differences between anterior and posterior cortical regions; and (c) reduced Alpha power in posterior cortical regions. The present data indicates that the right side of the brain, the left frontal site in the forehead and the back of the brain are most commonly affected, consistent with Thatcher's (2012) data.

The most frequently injured sites (F8 and T6) are located around the right ear suggesting sideways impacts (i.e., hitting the side of the head on the glass) occur the most frequently. In particular, T6 is associated with the integration of social, behavioural and verbal cues. Loud noises disrupt this processing. NHL players previously in treatment with the authors anecdotally reported their "read and react skills" improved when T6 was treated. It is speculated that the improvement in T6 allowed the brain to become more efficient in silencing out the noise, allowing them to focus better. The more severely injured sites (O1 and O2) suggest that crosschecks to the back or neck are the probable cause. The F7 site in all probability is a result of a coup and contrecoup reaction to the crosschecks to the back of the head or neck.

Data from the psychological testing revealed few significant findings but the 2 that emerged confirm some observations and also point to potential new areas of research. Findings from the SCL 90-R and the CNS analyses suggest the heightened presence of symptoms of anxiety. Many athletes are superstitious and engage in ritualistic behaviours, perhaps as a method of coping. Brain site F8 is suspected of being one of the sources of rumination, and it was one of the most commonly injured sites. Further investigation is needed, but it is possible that this combination of increased anxiety and diminished function at F8 will lead to diminished performance.

A major concern is the impact of these concussions later on in life. Former hockey players, who now are at ages 35 and 40, are reportedly experiencing diminished performance at home and in the workplace. It is hoped that this study will continue to provide informative assessments to more players offering them a chance to have effects of their concussions minimized, if not eliminated, giving them a brighter future.

Acknowledgements The authors would like to thank Kelsey Moss for her assistance in editing this manuscript.

Funding Funding was provided by Tarus Consultants LTD.

Compliance with Ethical Standards

Conflict of interest The authors have no conflict of interest.

Ethical Approval All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed Consent Informed consent was obtained from all individual participants included in the study.

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