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USING EVESTG ASSESMENTS FOR THE DETECTION OF SYMPTOMOLOGY CONSEQUENT TO A LATERAL-IMPACT CONCUSSION

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INTRODUCTION

The term concussion has been used interchangeably with mild traumatic brain injury (mTBI), which is the most common form of brain injury. The individuals affected by mTBI are commonly young adults [1], and often sustain some neuropathological, neurophysiological, and/or neurocognitive changes that can last for months, years or permanently [2], [3]. When physical, emotional and/or cognitive symptoms persist long after the concussion it is referred to as Post-Concussion Syndrome (PCS).

Concussion symptoms can vary, and depend on the site of the head impact. Many studies on humans have demonstrated lower head impact tolerance for lateral- (i.e. side impact) than anterior-posterior (i.e. forward-backward impact) or axial (top of the head impact) [4]-[6]. According to a study on football, hockey and soccer players who received a concussion, impact to the side/temporal region is more probable to result in a concussion [7].

In this study, we used a novel technology called Electrovestibulography (EVestG) [8] that holds the potential to objectively and cost-effectively for diagnosing PCS. Using EVestG, we investigate the plausible differences between left and right vestibular responses for individuals with PCS who sustained a side/lateral-impact.

Methodology

A. Electrovestibulography (EVestG)

EVestG is a technique, developed to record vestibulo-acoustic (predominantly vestibular) electrical signals modulated by a vestibular stimulus. The signals are recorded from the external ear in response to a vestibular stimulus. The EVestG provide a quantitative indirect measure of activity in the brain regions and neural pathway and more particularly the vestibular nucleus and vestibular peripheral apparatus. During the recording the participants sit in a hydraulic chair with their eyes closed and head supported, whilst they receive several passive whole body tilts including a side tilt to both right and left (Fig. 1A).

The recordings are made in an acoustically attenuated (>30 dB) and electromagnetically shielded chamber. Two active gelled recording electrodes are placed in both ear canals proximal to the ear drum with another two reference electrodes on each ipsilateral ear lobe close to the ear canal (Fig.1B) as well as a common ground on the forehead. The electrodes are silastic wrapped wire with the tip covered in cotton wool soaked in a mixture of saline and conductive gel to reduce interface impedance.

The movement of the chair is designed to be smooth and the duration of each movement/tilt was 3s: 1.5s acceleration, and 1.5s deceleration. The chair movements and the signals collected by the electrodes in the ear are recorded simultaneously with a sampling rate of 41667 Hz. Different segments of interest are: 1.5s immediately prior to the movement (BGi), 1.5s acceleration (onAA) and 1.5s deceleration (onBB). These segments are extracted from the ears' recorded signals using the chair's movement profile as shown for side tilt in Fig.1C.

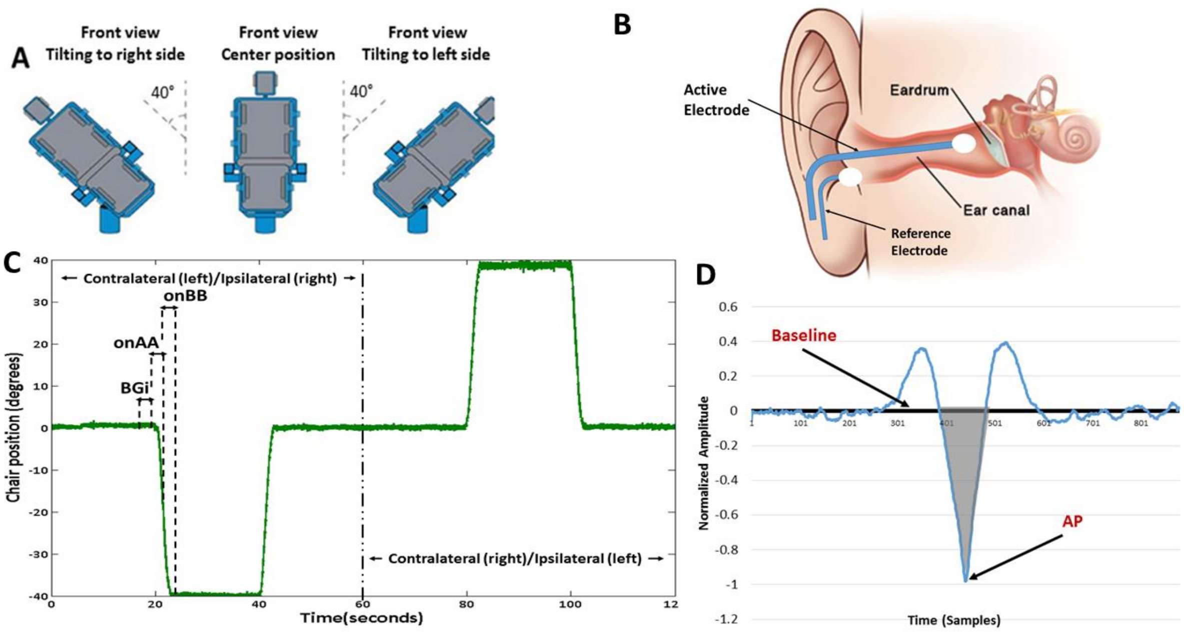

Figure 1: (A) chair position during side tilt. (B) Electrodes placement. (C) Pattern of chair movement during side tilt and the segments of interest. (D) A typical normalized FP. The grey area represent the bounded area between baseline and AP point and was used as a characteristic feature (Horizontal scale 41.6 samples= 1ms)

In this study, we used the left and right ear signals in response to the side tilt.

B. Participants

Twelves individuals with PCS after a lateral head impact (44.5±10.5 yrs, 5 with right lateral-impact and 7 with left lateral-impact) participated in this study. The duration between head trauma and the recording date varied from 5 months to 3 yrs with ongoing PCS. The PCS participants were diagnosed and referred by the 3rd coauthors, who is a neurologist/neuro-ophthalmologist (B.M.). Twelve age and gender-matched healthy controls were also recruited as the control group; their EVestG signals were recorded with the same protocol as that for the PCS group. All participants (PCS and controls) had normal hearing. The study was approved by the University of Manitoba Biomedical Research Ethics Board, and all study participants signed an informed consent prior to the experiment.

C. Signal analysis and classification

The vestibulo-acoustic Field Potentials (FPs) were extracted using the Neural Event Extraction Routine (NEER) [8]. The extracted FPs (Fig.1D) were normalized with the absolute value of the action potential (AP) to be -1. After normalization, we extracted features from the bounded part of the FP between the baseline and the AP point (Fig.1D) that showed differences between FPs extracted from the left and right ears of lateral impact PCS participants compared to those of the healthy controls. We subtracted the area measured from the left ear from that of the right ear, and considered the absolute value of the subtraction as a characteristic feature; this was done for each of the acceleration and deceleration segments, resulting in two characteristic features. Using these two features, we applied linear discriminant analysis (LDA) to classify the two groups of participants.

A leave-one-out routine was used for training and testing the classifier, in which all participant's data except one were used for training and the left-out subject's data was used for testing; this routine was repeated till each participant's data was used as the test data once.

Results

Figures 2A and 2B show the mean ± standard error (SE) of the AP area of the extracted FP of the left and right ears for PCS patients who had left and right lateral-impact, respectively. As shown in Fig. 2A, in the case of left lateral-impact, the left side of the AP area was found to be narrower than that of the right side. Likewise, for the participants who received a right lateral-impact, the AP area of the right side was narrower than that of the left side (Fig. 2B). Both left and right lateral-impact PCS participants showed a significant asymmetry between the left and right vestibular signals.

Figure 2C shows the mean ±SE of the AP area of the extracted FP from the left and right ears of healthy controls. Unlike the case observed in the lateral-impact PCS participants, the left and right

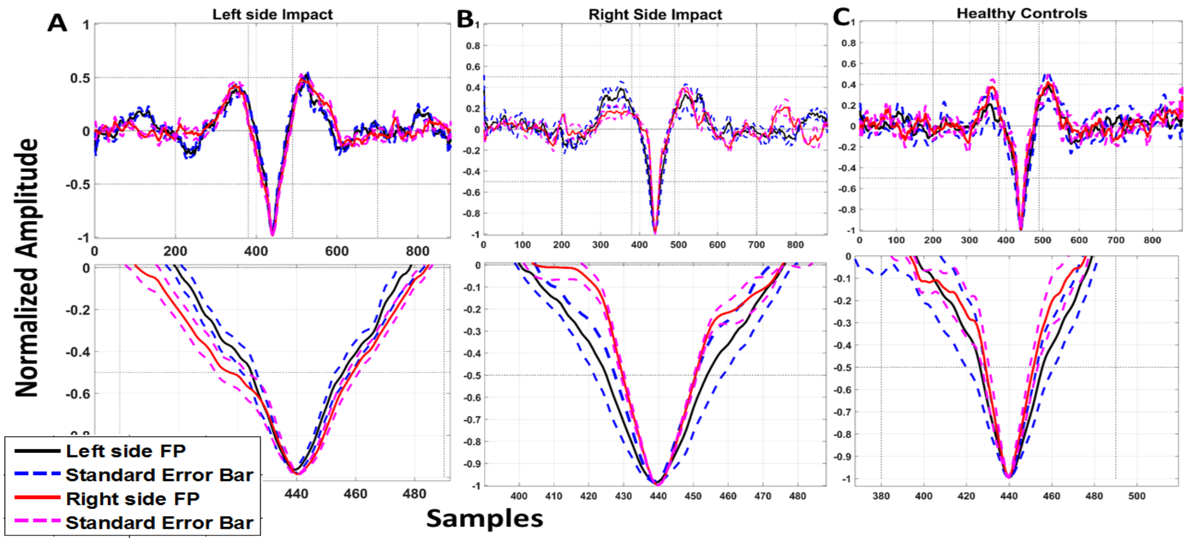

Figure 2: Average FP response extracted from left and right ear ± SE of (A) Left lateral-impact (n=7) (B) Right lateral-impact (n=5) (C) Healthy control (n=12).

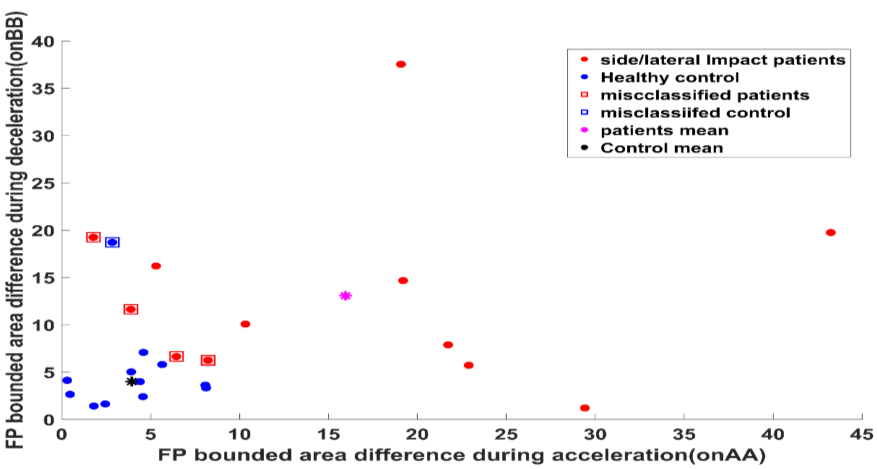

Figure 3: Absolute difference area between right and left sides during acceleration and deceleration during side tilt.

extracted AP area of controls were almost symmetric; hence no significant asymmetry.

Figure 3 shows the scatter plot of the two characteristic features (left-right difference in the normalized FPs extracted from acceleration and deceleration phases of the EVestG signals during the side tilt) calculated for all study participants. As it can be seen, the two features show a significant ($p<0.05$) separation between the two groups. The LDA classifier resulted in 67% sensitivity and 92% specificity for separating PCS participants from controls; the overall accuracy was calculated as 79%.

Discussion and conclusion

Our results show a clear and statistically significant ($p<0.05$) asymmetry between the left and right vestibular responses in the lateral-impact group but not in the control group. The observed asymmetry in the left and right EVestG signals was expected due to the nature of the lateral-impact of the concussion. Our findings are consistent with the results of previous studies [5], [6], where a 3D finite element model of the brain was used to characterize most of the components of the head, including the scalp, dura, cerebellum and brain stem [5], [6]. The results of those studies suggested that applying a large enough lateral-impact to the head model could result in a deformation of the skull and development of intracranial pressure in the brain for both the coup (impact side) and contrecoup (opposite side of the impact) sites. The intracranial pressure distribution pattern showed that after a lateral-impact a maximum compressive (positive) pressure was observed at the coup site, while maximum tensile (negative) pressure was observed at the contrecoup site. Thus, damage is likely to affect both sides of the brain.

Since our results showed a significant left/right

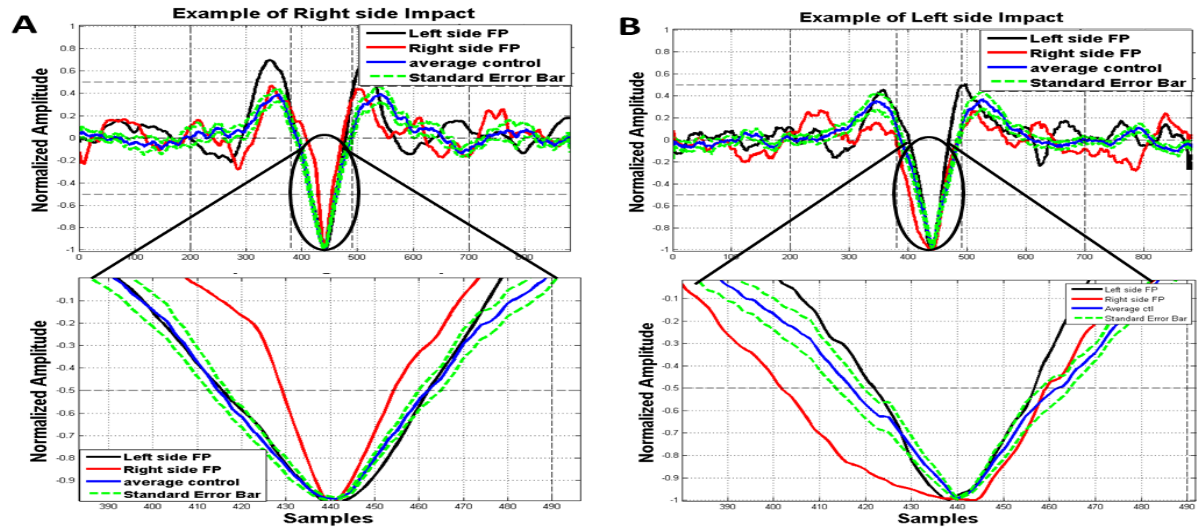

Figure 4: An examples of (A) coup Impact and (B) coup and Contre-coup Impact.

EVestG signal asymmetry in lateral-impact concussed participants, we investigated whether each concussed participant had merely a coup impact or if the impact was large enough so that it could be transmitted to the contrecoup site as well. Two out of the eight correctly classified individuals with lateral-impact had signal abnormality only in the coup site. Figure 4A shows an example of an individual who received a right lateral-impact. As can be seen, the right side vestibular signal was narrower than the left vestibular signal as expected. Compared to the healthy controls, the left vestibular signal was within the SE interval of the left average FP of the healthy controls. Thus, from the signal analysis results we may conclude that this individual had vestibular abnormality only in the right side and not in the left side (coup impact).

The remaining six correctly classified lateral-impact PCS participants had vestibular abnormality in both coup and contrecoup sites. Figure 4B shows the signal of an individual who received a left lateral-impact. As expected, AP area of the left vestibular signal was narrower than that of the right; also, comparing to the healthy controls, the right vestibular signal was wider than the SE interval of the right average FP of healthy controls. Thus, in this case, from the signal analysis, we may conclude that this individual had bilateral deformations; the right signal was wider, while left signal was narrower compared to those in normal (i.e. coup and contrecoup impact).

There were four misclassified concussed individuals in our results. It worth mentioning that those four individuals had the longest post-concussion duration, and also were the youngest in their group. This result begs the questions as to how important post-concussion duration, age and brain plasticity are. Thus, one may speculate that those individuals had more time to recover and their youth was correlated with effective brain plasticity that enhanced the recovery, and the degree of plasticity might have been related to age. However, the sample size of this study is small. More PCS patients with lateral-impact should be recruited and recorded by EVestG to confirm this speculation.

Overall, the results of this study are encouraging on the use of EVestG analysis for screening and monitoring post-concussion syndrome and its recovery as well.

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