Identifying the Effects of Microsaccades in Tripolar EEG Signals*

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***Abstract*— Microsaccades are tiny, involuntary eye movements that occur during fixation, and they are necessary to human sight to maintain a sharp image and correct the effects of other fixational movements. Researchers have theorized and studied the effects of microsaccades on electroencephalography (EEG) signals to understand and eliminate the unwanted artifacts from EEG. The tripolar concentric ring electrode (TCRE) sensors are used to acquire TCRE EEG (tEEG). The tEEG detects extremely focal signals from directly below the TCRE sensor. We have noticed a slow wave frequency found in some tEEG recordings. Therefore, we conducted the current work to determine if there was a correlation between the slow wave in the tEEG and the microsaccades. This was done by analyzing the coherence of the frequency spectrums of both tEEG and eye movement in recordings where microsaccades are present. Our preliminary findings show that there is a correlation between the two.**

I. Introduction

During fixation, the eyes produce small, involuntary movements, called microsaccades. The reasons for the existence of microsaccades are still under debate, although they are often thought to reduce visual fading, increase peripheral vision, or correct movements from drifts, another type of fixational eye movement [1]. However, the correlation to drifts is debated due to the randomness of microsaccade trajectory. There are three different types of fixational eye movements, which include drift, tremor, and microsaccades. Microsaccades are the largest of the three types [2]. Microsaccades are binocular movements and have an amplitude below 1 degree and occur at an average rate of 1-2 Hz during fixation [3]. They most often occur in the horizontal direction, rather than the vertical direction [4]. Through previous research, it has also become apparent that it is possible for a participant to repress their microsaccades, specifically if asked to do a task to produce the fixational eye movements. During most studies, the presented images and stimuli are chosen to prevent this phenomenon [1].

As technology advances, specifically for high-resolution cameras, the instruments needed to record eye movements have become more readily available, allowing more research to be done to study the mechanisms and purposes of these fixational movements. The effects of microsaccade eye movements in neural activity are becoming more recognized in electroencephalogram (EEG) research as more work is being done to identify these effects and to filter them from the EEG signal. Prior studies have shown that the muscle contractions at microsaccade onset produce spike potentials in the EEG signal [5]. There have also been studies which identify large potentials in actual cortical activity that accompany the muscle spikes caused by microsaccades [4].

Fig.1. (Left) disk electrode. (Right) TCRE.

Tripolar concentric ring electrode (TCRE) sensors (Fig. 1 right) have been shown to estimate the surface Laplacian directly through the nine-point method, an extension of the five-point method used for bipolar CREs, and significantly better than other electrode systems including bipolar and quasi-bipolar CRE configurations [6], [7]. Compared to EEG with conventional disc electrodes (Fig. 1 left) Laplacian EEG via TCREs (tEEG) have been shown to have significantly better spatial selectivity (approximately 2.5 times higher), signal-to-noise ratio (approximately 3.7 times higher), and mutual information (approximately 12 times lower) [8]. Because of such unique capabilities, TCREs have found numerous applications in a wide range of areas including brain–computer interface [9], [10], seizure onset detection [11], [12], detection of high-frequency oscillations and seizure onset zones [13], etc.

A slow wave frequency has been visually identified in some locations of tEEG signals, which is hypothesized to have resulted from the 1-2 Hz frequency of microsaccade eye movements. The goal of this work was to confirm whether these slow waves are the result of such fixational eye movements or not.

II. Methods

A. Experiment

The participants were seated approximately 65 centimeters away from a 33.5 by 27-centimeter external computer monitor. The monitor was connected to a laptop which controlled the visual stimulus and data acquisition. A Gazepoint GP3 eye tracker camera was positioned directly at the base of the monitor, 40 centimeters below eye level and angled upwards, and a chin rest was used to ensure these measurements (see Fig 2). There were

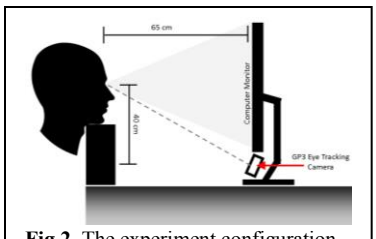

Fig 2. The experiment configuration.

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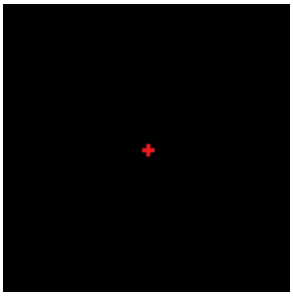


Fig. 3. The image displayed during the experiment. The single red cross serves as a fixation point to generate microsaccades.

no bright light sources facing the participant's face. Recordings were often taken with the lights turned off, to prevent any lighting interference that can often affect the eye tracking system's ability to lock onto the pupils.

During the experiment, an image was displayed on the monitor, consisting of a black screen with one red cross in the center (See Fig. 3). The participants were instructed to fixate on the red cross without blinking for the duration of the trial to produce fixational microsaccades. For each trial, eye tracking and tEEG were recorded for a period of 30 seconds. No more than 10 trials were completed in one session, and short breaks occurred between each trial.

B. Participants

Six participants completed the University of Rhode Island approved informed consent, and have had tEEG and eye tracking recorded. There were three male and three female participants, all between the ages of 18 and 24 years old.

C. Eye Tracking Recording

Eye movements were recorded with the Gazepoint GP3 eye tracker using a 9-point calibration for each participant. The system is binocular and has a 0.5 - 1 degree of visual angle accuracy. The sampling rate is approximately 60 Hz. The system runs through the Windows operating system and does not produce exact increments. To account for the uneven time intervals between samples, the data was interpolated in MATLAB after recording to provide an exact interval of 1/60 seconds between each data sample. All other filtering was implemented in MATLAB after the recording was completed and exported.

D. tEEG Recording

The tEEG was recorded with Tripolar Concentric Ring Electrodes (TCRE) and the t-Interface 20 pre-amplifier. The signal was then amplified with a Brain Vision V-Amp and sampled at 500 Hz. Sixteen electrodes were placed in the frontal, central, temporal, and parietal regions using the 10/20 System. In one exception, only six electrodes were used on one participant of this experiment. All filtering was implemented in MATLAB after the recording was completed and exported.

E. Data Alignment

The eye tracking recordings and tEEG recordings were taken using different systems and were time-aligned in MATLAB. A push button was used as a trigger marker through the Brain Vision V-Amp amplifier to indicate the start time of the eye tracking recording. All tEEG data before the sample where the trigger occurred was removed. Each data set was then windowed to the same length, measured in seconds.

F. Data Selection

The Gazepoint GP3 system includes a "valid" flag function which indicates invalid data samples that most often occur during blinks, head movements, or other disruptions to the recording. A valid flag is provided for each sample of both the left pupil and the right pupil tracking using a value of 1 for valid data and 0 for invalid data. Using the valid flags, all invalid data samples were removed in MATLAB. If only one eye exhibited an invalid data sample at a particular time, then the corresponding data sample in the other eye was also removed for consistency when the two data sets were later averaged.

Only eye tracking recordings, or segments of a recording, with less than 1% of invalid data were used for analysis, along with their corresponding tEEG recordings. In most cases, a single recording was either over 20% invalid or less than 1% invalid, depending on a number of issues, including the head position, movements, quality of the calibration, the number of blinks, shadows, and other lighting issues.

G. Eye Tracking Data

The eye tracking recordings were exported as four data sets: left pupil x-coordinate location, left pupil y-coordinate location, right pupil x-coordinate location, and right pupil y-coordinate location as a percentage of screen height or width. After the removal of invalid data samples, each data set was subtracted by its mean. Next, the data sets were interpolated and left and right eye data sets were averaged together for each time sample. High and low pass filters were implemented using a 5th order Butterworth filters, eliminating frequencies below 0.5 Hz and above 8 Hz.

H. tEEG Data

tEEG filtering was also accomplished in MATLAB. A 5th order Butterworth filter was used to filter out 60 Hz noise and harmonic 120 Hz noise from the signal. Next, each tEEG channel signal was subtracted by its mean. High and low pass filters were implemented using a 5th order Butterworth filters, eliminating frequencies below 0.5 Hz and above 8 Hz.

I. Frequency Domain

The aligned sections of the tEEG and eye tracking recordings were transformed using the fast Fourier transform (FFT) and Welch's power spectral density estimate (WPSD).

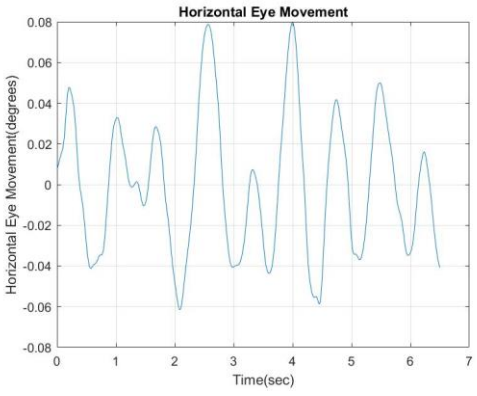
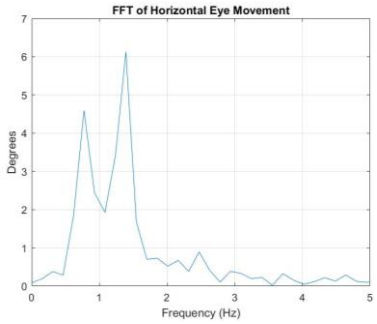


Fig. 4. The horizontal eye movement of the left and right pupils averaged per sample.



a.

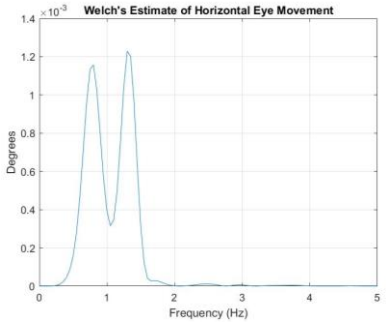


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Fig. 5. (a) The FFT of the averaged horizontal eye movement. (b) The WPSD of the averaged horizontal eye movement using a 5 second Hamming window and 2.5 second overlap.

The WPSD provides a more averaged version of the frequency spectrum for a cleaner view of the tEEG signal in the frequency domain.

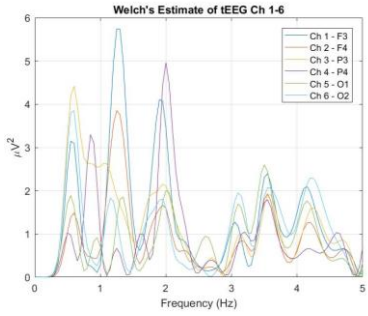
The aligned sections of the tEEG and eye tracking recordings were also compared with magnitude-squared coherence, using the MATLAB mscohere function. The tEEG recordings were resampled to 60 Hz for this purpose.

II. Results

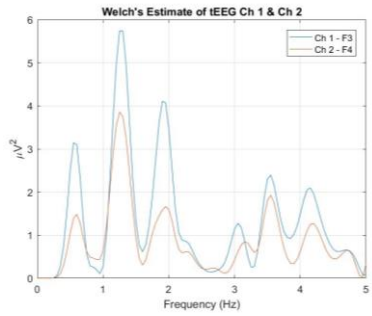
A. Microsaccade Detection

The eye tracking recordings displayed visually apparent microsaccades, determined by the 1-2 Hz oscillation of amplitude peaks seen in a plot of horizontal eye movements (see Fig. 4). The vertical eye movement displayed some oscillations; however, they were less consistent and more erratic than those seen in the horizontal direction. Due to this occurrence and prior knowledge that microsaccades are most often found in the horizontal direction, the analysis was concentrated on the data set for horizontal eye movement.

The horizontal eye movement data were converted to the frequency domain to quantitatively confirm the frequency of the microsaccade oscillations seen in the time domain plot. Fig. 5a displays the FFT of the horizontal eye movement and shows a strong peak in frequency magnitude at 1.392 Hz. This frequency is consistent with the frequency of 1-2 Hz visually estimated in the time domain. Fig. 5b displays the WPSD of horizontal eye movement with a 5 second Hamming window and a 2.5 second overlap. This method of frequency domain transform shows an elevation in frequency magnitude at 1.3 Hz. This slight inconsistency is due to the averaging done by the WPSD. The purpose of this averaged frequency spectrum is mainly for comparison with the tEEG frequency spectrum, rather than for identification of microsaccade frequencies.



a.



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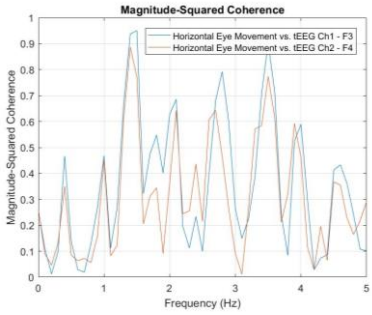

c.

Fig. 6. (a) The WPSD of all 6 tEEG channels using a 5 second Hamming window and 2.5 second overlap. (b) The isolated WPSD for tEEG channels 1 and 2 in electrode locations F3 and F4, respectively. (c) The magnitude-squared coherence of horizontal eye movement verses tEEG channels 1 and 2.

B. Frequency Comparisons of tEEG and Eye Movements

To compare the frequencies of the tEEG signal and microsaccade eye movements, both data sets were converted to the frequency domain. The tEEG has a much busier frequency spectrum and generally requires averaging with the WPSD to provide visible spikes in frequency magnitude to compare to the eye tracking frequency spectrum. Fig. 6a includes a WPSD with a 5 second Hamming window and a 2.5 second overlap for six tEEG channels during a time interval aligned with the previously discussed eye tracking

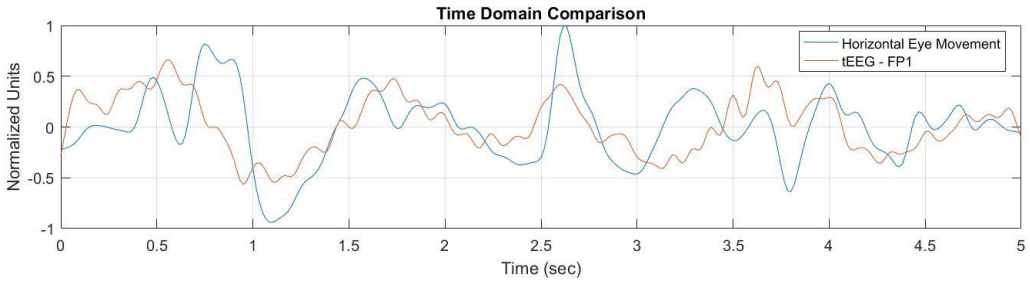

Fig. 7. A comparison of normalized eye movement and normalized frontal tEEG signal in the time domain.

data. Of the six channels, only channels 1 and 2, electrode locations F3 and F4, respectively, display prominent high magnitudes of frequency in a range near the frequency of the microsaccades (Fig. 6b). The peak in the WPSD for tEEG channels 1 and 2 occurs at 1.25 Hz. The difference in the peak from the WPSD is again the result of the averaging and smoothing effect. In the comparison of each channel verses horizontal eye movement, magnitude-squared coherence also confirmed a peak in frequency at 1.4 Hz for channels 1 and 2 (Fig. 6c).

C. Time Domain Comparison of tEEG and Eye Movements

Similarities in frequency can be seen in the time domain as well as the frequency domain. Fig. 7 shows a time domain plot of horizontal eye movement and the corresponding tEEG signal in the FP1 electrode location. Both signals display an in-phase frequency of approximately 1-2 Hz.

III. Discussion

The results have shown that similarities can be found between the tEEG and eye movement frequency spectrums in the frequency range of microsaccades. A frequency of approximately 1.4 Hz is found in high magnitude in both tEEG and horizontal eye movement. The slight inconsistency of the 1.25 Hz frequency spike in the tEEG WPSD is likely due to the averaging effect of the WPSD or the different sampling rates of the tEEG and eye movement data sets, which cause differences in the frequency spectrum resolutions. Even more promising, is the fact that the matching frequencies occurred in electrode locations F3 and F4, matching the location where a larger amplitude low frequency wave was originally detected, prompting this experiment. The results will allow for a better understanding of the effects of eye movements in EEG signals and will allow the frequencies and artifacts caused by microsaccades to be more easily identified.

The lower frequency peak, at approximately 0.75 Hz, (Fig. 5) is likely biological. However, the slightly inconsistent frequency location in the EEG FFT and the low magnitude-squared coherence indicate that it is not strongly correlated in the EEG and eye tracking signals. This peak will be investigated in future work.

IV. Conclusion

At this time, it appears likely that the microsaccades may be producing the slow wave frequency in tEEG signals. The current results encourage further research in the current path and exploring other methods. The future objective will be to include more participants and quantitatively analyze the data to determine the strength of the similarities statistically.

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